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Part II

Department of Labor

Occupational Safety and Health Administration

29 CFR Part 1910

Occupational Exposure to Benzene; Final Rule

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DEPARTMENT OF LABOR

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29 CFR Part 1910

Occupational Exposure to Benzene

AGENCY: Occupational Safety and Health Administration (OSHA), Labor.

ACTION: Final Rule.

SUMMARY: By this action, the Occupational Safety and Health Administration (OSHA) amends its existing standard for occupational exposure to benzene. The revised standard reduces the permissible exposure limit (PEL) from 10 parts benzene per million parts of air (10 ppm) to an eight (8)-hour time-weighted average (TWA) of 1 ppm and a short-term exposure limit (STEL) of 5 ppm. An action level of 0.5 ppm is established to encourage lower exposures for employees and to reduce administrative burdens on employers. This standard applies to all industries covered by the Occupational Safety and Health Act, including the construction and maritime industries and general industry subject to certain partial exemptions where exposures are very low.

The basis for promulgation of this regulation is a determination by the Assistant Secretary that employees exposed to benzene face a significant health risk and that this standard will substantially reduce that risk. The record in this rulemaking demonstrates that employees occupationally exposed to benzene are at risk of developing pancytopenia, aplastic anemia, multiple myeloma, leukemia and other blood dyscrasias.

This standard also provides for methods of compliance, personal protective equipment, employee monitoring, medical surveillance, medical removal protection, communication of hazards to employees, regulated areas, and recordkeeping. When the action level is exceeded, employers must initiate certain compliance activities, such as monitoring and medical surveillance. Where the employer can demonstrate, by means of exposure monitoring results or historical data, that the exposures of his or her employees do not exceed the action level, the employer is not obligated to comply with many of the requirements of this standard. The 1 ppm 8-hour TWA substantially reduces significant risk from exposure and is considered by OSHA, based upon substantial evidence in the record, to be the lowest level feasible.

EFFECTIVE DATE: The amended standard published today takes effect on December 10, 1987.

ADDRESS: For additional copies of this final standard, contact: OSHA Office of Publications, U.S. Department of Labor, Room N-3101, 200 Constitution Avenue NW., Washington, DC 20210. Telephone (202) 523-9667.

FOR FURTHER INFORMATION CONTACT: Mr. James F. Foster, Director, Office of Information and Consumer Affairs, OSHA, U.S. Department of Labor, Room N-3649, 200 Constitution Avenue NW., Washington, DC 20210. Telephone (202) 523-8151.

SUPPLEMENTARY INFORMATION: This notice of final action is divided into 13 parts, numbered I through XIII. Numbers I through XI is the preamble of the standard.

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References to the rulemaking record are cited in the text. The following abbreviations have been used:

1. *Ex. No.:* Exhibit number in the benzene dockets. The dockets are located in the OSHA Docket Office, Room N-3670, Department of Labor. The benzene record includes Dockets H-059, H-059A, H-059B and H-059C. H-059 includes exhibits entered into the record prior to the publication of February 10, 1978, standard for benzene. H-059A includes the information and comments on benzene in liquid mixtures. H-059B includes documents submitted in reference to the Advance Notice of Proposed Rulemaking of July 8, 1983. H-059C includes documents submitted in response to the Proposal of December 10, 1985.

2. *Tr.:* Transcript date and page number.

I. Executive Summary

The 1987 final benzene standard lowers the 8-hour time-weighted average (TWA) for occupational exposures to benzene from 10 parts per million (ppm) to 1 ppm and the short-term exposure limit (STEL) from 25 ppm to 5 ppm. Various important industrial hygiene provisions including monitoring, engineering controls, respiratory protection, medical surveillance and hazard communication are incorporated.

The standard will result in a substantial reduction in the workers' risk of developing leukemia and other diseases of the blood and blood-forming organs. According to OSHA's best estimates, a working lifetime of exposure to benzene at 10 ppm would cause an excess leukemia risk of 95 leukemia deaths per 1000 exposed workers. Other reasonable estimates of risk range from 8 to 160 deaths per 1000 workers. These are clearly significant risks, greatly exceeding the excess risks of occupationally related accident deaths in high and average risk industries which are 30 and 3 per 1000 workers, respectively.

The new standard will create a minimum reduction in excess risk of 90 percent, a very substantial reduction based on comparing exposures at 10 ppm to 1 ppm. On the basis of the

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current distribution of exposures, OSHA estimates that the new standard will prevent a minimum of 328 deaths from leukemia and diseases of the blood and blood-forming organs over a working lifetime of 45 years.

In reality, the reduction in risk will be much greater. The standard incorporates an action level of 0.5 ppm. below which many industrial hygiene and medical surveillance provisions are not required. Many employers having workplaces in which such reductions are feasible will reduce employee exposures to below 0.5 ppm in order to have a high degree of confidence that they are protecting their employees, to avoid the costs of the industrial hygiene and medical surveillance provisions, and to have an adquate margin for exposure variability when there is an inspection.

Employers with exposures above the action level are required to implement a variety of industrial hygiene provisions which will increase employee protection. The monitoring provisions increase the probability that overexposures will be detected and reduced. The medical surveillance provisions will aid in the early detection of employees with abnormal blood counts.

The combination of these provisions, when carried out, assures OSHA that workers will be substantially better protected than the numbers estimated by the risk assessments indicate. Indeed, OSHA believes employers who fully comply with the standard's provisions as intended will provide substantial protection to their benzene-exposure workers.

OSHA wishes to commend industry, labor and public interest groups whose combined efforts have already led to substantial lowering of benzene exposures. These groups have also assisted OSHA in analyzing the data and coming to better decisions through the rulemaking process. OSHA sincerely hopes that the remaining, relatively narrow differences of opinion regarding practical issues of workers protection will not prevent the rapid implementation of the standard.

OSHA also believes that the standard, in addition to being protective, is cost-effective. A carefully developed series of practial exclusions for industry sectors where technology assures that exposures will be under the action level, concentrates industrial hygiene resources in areas of need. Similarly, a series of provisions reflective of industrial hygiene experience permits employers the choice of compliance strategies in maintenance and repair activities, when exposures are intermittent or are for a short term, where respirators are sometimes the control of choice. However, engineering and work practice controls are given preference in production activities and more continual exposures where they are generally the most effective control strategy.

OSHA is confident that the standard is technically feasible and that engineering controls, where required, can generally achieve the 1 ppm 8-hour TWA and 5 ppm STEL, consistently, with a high degree of confidence in most production operations in the covered industries. This conclusion is based on an extensive contractor survey, evidence submitted to the record and detailed analyses. Types of controls available include leak detection and repair, vapor recovery, automated sampling, dual seal valves, enclosures and many others. Exposures are already quite low as benzene and mixtures containing substantial amounts of benzene are handled in closed systems. Where one control may not be successful, others are available.

OSHA has concluded that the 1 ppm TWA is the lowest feasible level for industry in general. The action level will strongly encourage those employers who can do so to achieve exposures below 0.5 ppm

The standards will cost approximately $24 million in annualized costs (annual costs plus annualized costs of capital). This is clearly economically feasible, representing less than 0.2 percent of the annual revenues in the various industry sectors. See Tables A, C and D in Section VIII below for exposure and cost data.

A number of changes have been made from the proposal. Several additional sectors (natural gas and coke production) have been generally exempted from the standard. Data indicate that exposures in these sectors are consistently below the action level.

OSHA has decided to reduce the current short term exposure limit of a 25 ppm ceiling and a 50 ppm peak to a 5 ppm limit averaged over a 15-minute period. This decision is based on human and animal data indicating that intermittent or peak exposures appear to cause greater effects than continual exposures of the same or lower levels. Animal studies indicate that intermittent exposures (a good model for dose rate effects) caused greater decreases in certain blood counts than continual exposures at the same level. Several case control studies of refinery workers show excess leukemia risk among pipefitters, maintenance workers and employees in other jobs which probably involved intermittent peak exposures to benzene. This limit is feasible and adds little to costs because the 1 ppm PEL, in general, will be achieved through controlling peaks. It will also reduce cumulative dose in some circumstances.

The frequency of medical examinations has been reduced based on the advice of medical experts. The examinations are important to protect health and there is evidence of employee reluctance to take an examination if there is a possibility of job loss, Therefore, provisions are included to provide jobs in areas where benzene exposure is lower than the action level or if none are available, wage rate retention for a limited time, for employees who are removed from benzene exposure based on abnormal blood counts and physician recommendations.

The final standard retains a percentage exclusion. Where the only benzene exposure is from a mixture or solvent with less than a fraction of a percent of benzene, the work operation is excluded from the standard. This is both protective and cost-effective. Suppliers will be encouraged to refine solvents to keep benzene contamination low. This protects the many workers exposed to solvents from substantial benzene exposure, and employers using solvents with low benzene contamination will not have compliance expenses. The final standard reduced the period to achieve a 0.1 percent level of contamination from 5 years to 2 years. Initially the exclusion is at 0.5 percent. Record evidence indicates that liquid mixtures with less than 0.1 percent benzene are unlikely to cause exposures through dermal absorption and inhalation equivalent to the amount inhaled at the action level. Mixtures with less than 0.1 percent benzene are currently feasible.

In 1980, the Supreme Court in *Industrial Union Dept., AFL–CIO* v. *American Petroleum Institute* (*IUD* v. *API*). 448 U.S. 607 (1980), held that before OSHA issued a new health standard it must attempt to quantify risk, if possible, and determine whether the risk is significant. It must also determine that the new standard would achieve a substantial reduction in significant risk. OSHA had not performed a quantitative risk assessment on benzene prior to issuing the 1978 standard. In addition, the Supreme Court's analysis indicated that it desires a more careful economic analysis. The Fifth Circuit also had vacated the skin protection parts of the standard based on the belief that a study to definitively determine whether

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there was skin absorption could be quickly and easily performed.

Since the issuance of the 1978 standard and 1980 Supreme Court decision, there have been a number of major scientific developments. The two major epidemiologic studies available at the time have been upgraded and extended. (Infante/Rinsky and Ott/Bond). Several additional major epidemiologic studies have been completed (Wong, Decoufle et al.). These continue to demonstrate that benzene exposure causes increased risk of leukemia and other blood disorders. Several recent studies have demonstrated that benzene causes multiple-site specific cancers in animals. Other studies, which took substantially longer and proved to be more complex than predicted, have definitively demonstrated that benzene is absorbed through the skin. In addition, a number of risk assessments have been performed.

A series of studies (Infante 1977, Rinsky 1981, Rinsky 1986), analyzing the mortality of workers exposed to benzene at two rubber hydrochloride manufacturing locations, demonstrated excess risk of leukemia. The most recent demonstrated a Standardized Mortality Ratio (SMR) of 337 leukemia and 409 for multiple myeloma (An SMR of 100 is the normal value if an excess is not observed. An SMR of 200 represents a 100% excess risk over normal). The Rinsky 1986 study has excellent follow-up, 98.6% of the employees were traced to determine whether they were dead or alive and if dead, the cause of death. The study also carefully analyzed extensive past exposure data and was able to assign doses to individuals exposed 10 to 40 years in the past.

The Rinsky 1986 study also demonstrates a dose-response relationship. Workers who had lower exposure to benzene had a smaller excess risk (SMR=105). Medium exposure workers experienced medium excess risks (SMR=322 & 1186) and high exposure workers, very high excess risk (SMR=6637). The dose-response relationship increases the confidence in the results, provides a stronger basis for risk assessment and provides measured as opposed to extrapolated evidence that lowering exposure substantially reduces risk.

The Ott 1978 study and the Bond 1986 follow-up study demonstrate myelogenous leukemia risks about 4 times greater for benzene-exposed workers than for the general population. Because these studies were of small numbers of employees, the confidence intervals of the relative risks are large. However, the workers were exposed to low levels of benzene with average exposure being about 5 ppm of benzene.

The Chemical Manufacturers Association sponsored a study, Wong, 1983, of workers in chemical plants. The mortalities of the benzene-exposed workers at the plant were compared to the mortalities or workers at the plants who were not exposed to benzene and to the general population. A statistically demonstrable dose response relationship between benzene exposure and leukemia was observed. The workers exposed to benzene had an excess risk of leukemia and all lymphatic and hematopoietic cancer (which includes leukemia) as compared to the workers who were not exposed to benzene. The low exposure group (180 ppm months, or 15 ppm-years of exposure; the equivalent of 5 ppm exposure for 3 years) demonstrated a relative risk of 2.10; the medium exposure group (15-60 ppm-years), a relative risk of 2.95; and the higher exposure workers (more than 60 ppm-years), a relative risk of 3.93. (Relative risk (RR) is a concept similar to SMR; 3.93 RR can be considered equivalent to a 393 SMR).

OSHA believes these studies clearly demonstrate an association between benzene exposure and increased risk of leukemia. The Agency does not believe this conclusion is now seriously challenged.

Since the 1978 standard, three animal studies have demonstrated that benzene is carcinogenic in animals. For example, the National Toxicology Program study demonstrated excess risk of several types of cancers in both sexes of rats and mice. There was clear dose response for many sites of cancer. For example, among the male rats for oral squamous cell carcinoma (cancer of the oral cavity), there were no cancers in the controls, 6 percent in the low exposure group, 10 percent in the medium exposure group and 14 percent in the high exposure group. There was excess cancer incidence down to an equivalent of 20 ppm inhalation, the lowest exposure level tested.

Benzene has also been associated with several other diseases and various toxic effects in both human beings and animals. This includes multiple myeloma, aplastic anemia, an often fatal blood disease and various other sometimes reversible blood disorders, such as leukopenia and thrombocytopenia. Benzene also has been shown to cause damage to the genetic material in both human and animal cells resulting in chromosomal aberrations.

Both the human and animal studies furnish excellent bases for risk assessment, providing far more high quality data than would be necessary for a reasonable assessment. In addition to providing better human exposure data than is normally available, the studies show clear, measured dose-response and demonstrate increased leukemia risk as a result of exposures not much above the existing levels. Morever, the estimates of excess cancer risk from different studies are similar.

Risk assessment on benzene have been performed by a number of authoritative organizations and distinguished scientists. For example, the Environmental Protection Agency-Carcinogen Assessment Group (EPA-CAG) estimate, adjusted to occupational exposures, shows that benzene presents a risk of 34 excess leukemia deaths per 1000 workers exposed at 10 ppm and 3.4 per 1000 at 1 ppm. The International Agency for Research on Cancer's assessment, based on the Rinsky 1981 study, converted to an occupational setting, shows an excess risk of 14–140 at 10 ppm and 1.4–14 at 1 ppm. The White et al. risk assessment estimated excess leukemia risks of 44–156 at 10 ppm and 5–16 at 1 ppm.

Crump and Allen performed risk assessments using data from the three major epidemiologic studies that evaluated benzene and leukemia. Among various analyses, they use data from the Rinsky and Ott studies and a weighted cumulative dose and relative risk model. They also combined data from the Ott, Wong and Rinsky studies, and used a cumulative dose and relative risk model. This analysis utilized the most detailed exposure data available for the Rinsky study. That assessment indicated an excess risk per 1000 exposed workers of 95 leukemia deaths at 10 ppm and 10 at 1 ppm. The confidence intervals were also computed and are quite narrow. There is 95% confidence that for 1000 benzene-employees the risk is between 37 and 186 at 10 ppm and between 4 and 22 at 1 ppm.

NIOSH (Rinsky 1986) and the American Petroleum Institute (API) presented assessments utilizing a conditional logistic regression analysis. This type of analysis is more commonly used for differentiating between influencing variables than for risk assessment. It has an exponential term resulting in very large changes in risk over small changes in exposure. The NIOSH estimate of risk converted to the method of presentation used here is 634 per 1000 at 10 ppm and 5 at 1 ppm.

The API presented an assessment by Chinchilli as analyzed by Rodricks and Brett. Their preferred estimate, based on

the Rinsky study, utilizing a conditional logistic regression analysis, the initial Crump exposure assessment and various adjustments, is 8 excess leukemia deaths per 1000 at 10 ppm and 0.6 at 1 ppm. However, they argued the risk will probably be lower because they believe past exposures might have been higher.

Several risk assessments based on animal data have been performed. EPA-CAG estimated 30 excess human deaths per 1000 exposed workers at 10 ppm and 3 at 1 ppm based on Zymbal gland carcinoma in female rats. This estimate is virtually identical to the risk CAG projected based upon epidemiologic data. Crump, estimated 20 and 2 excess deaths based on all squamous cell carcinomas in male mice.

OSHA concludes that it is more appropriate to utilize the human data for significant risk analysis since it avoids the need to convert animal results into human terms. Most participants in the proceeding recommended this approach. However, the animal data are strong and are better able to control variables than the human studies. The animal estimates are also consistent with the human estimates and would be a strong basis for risk assessment if good human data were not available.

OSHA concludes that the Crump and Allen estimate based on the three epidemiologic studies with use of the cumulative dose and relative risk model is its preferred estimate. That estimate is based on the most data of any available risk assessment. Because of possible unique factors at one location or mistakes in estimation of exposure or relative risk, consistent results from several good studies add to the confidence in the estimate of risk. Crump and Allen made use of the most extensive exposure data with an approach preferred by API. They also used a model for epidemiologic data which is widely accepted for risk assessment purposes and the data fit the model acceptably. The model is also supported by biological data, as discussed below. Moreover, the Crump and Allen projection of 95 excess leukemia death per 1000 exposed employees for a working lifetime of exposure to 10 ppm benzene and 10 excess deaths per 1000 at 1 ppm is in the middle of the range of other reasonable estimates presented. The other reasonable estimates projected risks ranging from 8–634 at 10 ppm and from 0.6 to 16 at 1 ppm. These are maximum likelihood estimates not upper confidence bounds.

OSHA has followed a consistent approach for determining the significance of risk since 1982 when it first put into practice the directions of the Supreme Court in *IUD v. API*, the benzene decision. The approach has been used for the arsenic and ETO final standards which have been upheld by 2 Courts of Appeal. The approach was also used in the asbestos final standard and in the ethylene dibromide and formaldehyde proposals.

OSHA pointed out in the benzene proposal that the risk per 1000 workers associated with 10 ppm benzene of 95, was similar to the risk OSHA found significant at the old exposure limits in arsenic (148–425), ETO (69–109) and EDB (70–110). The lifetime occupational risk of death from accident or acute illness is 20 to 30 per 1000 in high risk occupations like mining and fire fighting, and 2 to 3 in occupations of average risk (all service and all manufacturing). OSHA stated in the preamble to those standards and in the benzene proposal.

> Congress passed the Occupational Safety and Health Act of 1970 because of a determination that occupational safety and health risks were too high. Based on this it is clear that Congress gave OSHA authority to reduce risks of average or above average magnitude when feasible. Further the Supreme Court stated that "if the odds are one in a thousand that regular inhalation of gasoline vapors that are 2% benzene will be fatal a reasonable person might well take the appropriate steps to decrease or eliminate it". (50 FR 50539).

Within this context OSHA concludes as it preliminarily concluded in the proposal that significant risk exists at the 10 ppm level. Based on the best supported estimates of 95 excess deaths per 1000, the risk from exposure to benzene at 10 ppm is clearly greater than that in the riskiest occupations and greater than the risk of one in 1000 which the Supreme Court found a reasonable person might find significant. Even the lowest estimate of risk, 8 per 1000 at 10 ppm, is greater than both the risks of average occupations and the one in 1000 risk example given by the Supreme Court. Therefore, based on any of these estimates, OSHA would determine that the risk is significant. No major party challenged OSHA's decision to reduce exposures from 10 ppm.

OSHA also concludes that the new benzene standard will result in a substantial reduction in significant risk. All the risk assessments indicate that the reduction in risk will be at least 90 percent, a clearly substantial reduction. In addition, several of the human and animal studies conclusively demonstrate that lowering exposures substantially lowers risk. The large majority of commenters agreed to the appropriateness of not having average exposure over 1 ppm. (Several stated the exposure limit should be set at 2 ppm, but that this would result in average exposures under 1 ppm). In addition, the standard at a minimum, will save *326* lives over a working lifetime, a substantial number.

OSHA believes that the actual reduction in risk will be substantially greater than the 90 percent predicted by its preferred risk assessment. The action level, industrial hygiene and medical provisions further reduce risk.

OSHA also finally concludes after reviewing all the evidence and comments and as it preliminarily concluded in its proposal, that the final

> standard is carrying out Congressional intent within the limits of feasibility and does not attempt to reduce insignificant risks * * * [and that its final] benzene standard will protect employees and that employers who fulfill the provisions of the standard will be taking reasonable steps to protect their employees from the hazards of benzene. Indeed many employers have already reduced exposures of employees to below those of the proposed standard (50 FR 50539).

Several oil and petrochemical companies raised the issue of exposure variability. Typically, exposures randomly fluctuate somewhat around the average in industry. They contended it fluctuates more than is usual in their segment because of the outdoor location of their facilities. They argued that because of the large random variation, employers might be cited based on a single measurement taken by a compliance officer (CO) that would be above the 8 hour TWA exposure limit, when in fact average exposures were consistently under the limit.

One recommendation they made was that OSHA might utilize an averaging scheme. If the CO measured an exposure above the PEL, the CO would review the employer's previous measurements and if they were under the limit, the CO would not cite but would remeasure.

OSHA has carefully reviewed the voluminous evidence introduced on the issue and concluded that its present approach to enforcement is correct. This permits the issuance of citations based on one measurement if the exposure is over the limit. However, CO's are to review employer data and if the data indicate the CO's measurement was not typical, the CO may take additional samples.

A number of industrial hygienists, including several employed by industry, testified that causes of variability can be identified by an industrial hygienist and that much variability is controllable. In addition, analysis indicates that

variability is not as great as has been suggested for those sectors.

Secondly, Dr. Harris, an expert on monitoring, pointed out that the implications of a high degree of random variability are different than some assume. If there is a high degree of variability it is unlikely that the CO will measure on a day that exposures are above the arithmetic average for that establishement. The most likely statistical implication of a high measurement is that exposures are high.

In addition, OSHA's present approach encourages employers to measure on high days and keep average exposures low by reducing peak exposures, a protective approach. An averaging approach encourages employers to measure on low days, to balance a possible high exposure that may be identified by the CO rather than identifying and controlling the sources and causes of high exposures.

As discussed in the feasibility section, OSHA has concluded that employers can consistently meet a 1 ppm level, taking into account uncontrollable random variation. Indeed one of the reasons for OSHA's confidence that risk will be reduced substantially below those predicted at 1 ppm is that employers will reduce controllable variability (eliminating many high fluctuations) and will keep exposures somewhat under a 1 ppm average to take into account normal random variation.

This final benzene standard applies to all occupational exposures to benzene except some subsegments of industry where exposures are consistently under the action level and are therefore exempt or partially exempt. These include distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing and the percentage exclusion for liquid mixtures. Exemption from methods of compliance and some monitoring provisions are included for barge cleaning and repair. Further consideration will be given to this sector.

The action level elliminates various industrial hygiene provisions such as routine monitoring and medical surveillance when exposures are under 0.5 ppm as an 8-hour TWA. The purpose is to concentrate industrial hygiene provisions where there is greatest need and encourage employers to reduce exposure below the 8 hour permissible exposure limit when feasible to do so. OSHA has incorporated action levels in its prior health standards, and they have worked well.

The standard requires employers to set up regulated areas where exposures are over 1 ppm or the STEL. This is to warn employees of the need to wear respirators and discourage employees who have no need to do so, from entering those areas.

The standard requires initial monitoring, semi-annual monitoring if exposures are over 1 ppm and annual monitoring if exposures are between 0.5 and 1 ppm. Periodic monitoring is not required when exposures are under 0.5 ppm, but remonitoring is required if products or processes change which might lead to increased exposures. This frequency of monitoring is consistent with OSHA's experience and is appropriate.

The standard places a preference on engineering and work practice controls for production activities or where exposures to benzene over 1 ppm are more frequent than intermittent. However, the employer may choose a compliance strategy including use of respirators in maintenance and repair activities, when exposures are intermittent in nature and limited in duration, during the time before engineering controls can be installed or where they are not feasible, and when benezene will be present in the area less than 30 days a year. This approach was supported almost without exception in the record and reflects industrial hygiene expertise as the best approach to protecting employees.

The standard requires employers with 8-hour TWA exposure over 1 ppm or 15 minute short-term exposures over 5 ppm to have a compliance program to indicate a schedule for and the methods to be used to reduce exposure below the limits. No program is required if exposures are under the limits.

The standard sets forth requirements for selection of proper respirators, their use, proper fit-testing, and other elements of a good respirator program. The provision reflects expert recommendations and field experience and record comments. Several appendices set forth protocols for fit-testing.

Protective clothing and equipment must be worn to prevent eye exposure and limit skin exposure to benzene. Benzene is absorbed through the skin. However, as the preamble indicates, it is not feasible for tire builders to wear gloves. Their explosure to benzene will be controlled by the industry utilizing solvents with less than 0.1 percent benzene contamination.

A medical surveillance program is required for employees exposed over the action level. This requires an initial medical examination to establish a baseline, subsequent yearly examinations and also examinations after exposures resulting from emergency situations. A complete blood count is required to determine if the blood elements remain normal. Since abnormal blood levels are a possible indicator of the development of a benzene-related blood disease, an additional examination by a hematologist or internist is required if an abnormal blood count persists.

If the physician believes it medically justified, employees will be removed from benzene exposure in order to improve the chance that blood disease will not progress. To encourage employees to participate in medical surveillance, employers are to provide alternate jobs in areas where the benzene exposure does not exceed the action level, if available. Certain medical removal protection provisions are included for a short period of time or until it is determined whether the condition is permanent.

The emergency medical examination includes a urinary phenol test to establish whether an employee has been exposed to high levels of benzene. If so, a further medical examination is required to determine if blood counts have become abnormal.

A medical evaluation also is required to determine if an employee who must, can safely wear a respirator. However, requirements for a chest x-ray have been eliminated based on medical advice.

The standard makes appropriate provisions for signs and labels, training, communication of benzene hazards to employees and observation of monitoring. They are necessary so that employees will be aware of the risks of benzene, will be better able to take precautions to protect themselves, and will understand the need for the standard's provisions. The provisions are designed to be consistent with OSHA's hazard communication standard.

There are requirements to keep and make available medical and exposure monitoring records. These are necessary to better diagnose possible disease and to review the success of the standard.

The standard is to become effective 90 days after issuance pursuant to statute and to permit interested parties time to learn about it and commence compliance activities. All provisions except for engineering controls must be completed 60 days after the effective date. This is adequate time, 5 months after the publication of the standard, to complete initial monitoring and medical surveillance, purchase respirators, etc.

Employers may use monitoring data taken within a year of the effective date to satisfy initial monitoring requirements.

Engineering controls require a longer period to design and install. Consequently, the completion of their installation is not required until 2 years after the effective date of the standard. In view of the already relatively low exposures, this is clearly a feasible time period for their installation.

The steel industry is currently having financial difficulties. Based on the recommendation of the United Steelworkers of America and the American Iron & Steel Institute, and extended compliance period of 5 years is provided for the installation of engineering controls in by-product plants and BTX units at coke facilities.

State Plan Revisions

The 23 States and 2 territories with their own OSHA-approved occupational safety and health plans must revise their existing standards within 6 months of this publication date or show OSHA why there is no need for action, such as in the case that an existing State standard covering occupational exposure to benzene is already "at least as effective" as the revised Federal standard. These states or territories are: Alaska, Arizona, California, Connecticut, Hawaii, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Mexico, New York, North Carolina, Oregon, Puerto Rico, South Carolina, Tennessee, Utah, Vermont, Virginia, the Virgin Islands, Washington, and Wyoming. (In Connecticut and New York, the plan covers only State and local government employees.)

II. Pertinent Legal Authority

The publication of a final standard is authorized by sections 6(b), 8(c), and 8(g)(2) of the Occupational Safety and Health Act of 1970 (the Act), 29 U.S.C. 655 (b), 657(c) and 657(g)(2). Section 6(b)(5) governs the issuance of occupational safety and health standards dealing with toxic materials or harmful physical agents.

It states:

> The Secretary, in promulgating standards dealing with toxic materials or harmful physical agents under this subsection, shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life. Development of standards under this subsection shall be based upon research, demonstrations, experiments, and such other information as may be appropriate. In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of standards, and experience gained under this and other health and safety laws. Whenever practicable, the standard promulgated shall be expressed in terms of objective criteria and of the performance desired.

Section 3(8) defines an occupational safety and health standard as "a standard which requires conditions, or the adoption or use of one or more practices, means, methods, operations, or processes, reasonably necessary or appropriate to provide safe or healthful employment and places of employment."

The Supreme Court has held under the Act that the Secretary, before issuing any new standard, must determine that it is reasonably necessary and appropriate to remedy a significant risk of material health impairment. *Industrial Union Department v. American Petroleum Institute*, 448 U.S. 607 (1980). The court stated that "* * * before he can promulgate *any* permanent health or safety standard, the Secretary is required to make a threshold finding that a place of employment is unsafe—in the sense that significant risks are present and can be eliminated or lessened by a change in practices" (448 U.S. at 642). The Court also stated "that the Act does limit the Secretary's power to requiring the elimination of significant risks" (448 U.S. 644, n. 49).

The Court indicated, however, that the significant risk determination is "not a mathematical straitjacket," and the "OSHA is not required to support its finding that a significant risk exists with anything approaching scientific certainty." The Court ruled that "a reviewing court [is] to give OSHA some leeway where its findings must be made on the frontiers of scientific knowledge (and that) . . . the Agency is free to use conservative assumptions in interpreting the data with respect to carcinogens, risking error on the side of overprotection rather than underprotection" (448 U.S. at 655, 656). The Court also stated that "while the Agency must support its finding that a certain level of risk exists with substantial evidence, we recognize that its determination that a particular level of risk is 'significant' will be based largely on policy considerations." (448 U.S. at 655, 656, n. 62).

After OSHA determined that a significant risk exists and that such risk can be reduced or eliminated by the proposed standard, it must set a standard "which most adequately assures, to the extent feasible on the basis of the best available evidence, that no employees will suffer material impairment of health * * *." Section 6(b)(5) of the Act. The Supreme Court has interpreted this section to mean that OSHA must enact the most protective standard possible to eliminate a significant risk of material health impairment, subject to the constraints of technological and economic feasibility. *American Textile Manufacturers Institute, Inc. v. Donovan*, 452 U.S. 490 (1981). The Court held that "cost-benefit analysis is not required by the statute because feasibility analysis is" (452 U.S. at 509). The Court further stated that the Agency could use cost-effectiveness analysis and choose the least costly of two equally effective standards. (452 U.S. 511, n. 32).

Two Courts of Appeals recently have upheld OSHA standards regulating carcinogens which, following the Supreme Court's guidance in *Industrial Union Department v. American Petroleum Institute* (Supra), were based on risk assessments and significant risk analysis. The standards were for inorganic arsenic (48 FR 1864, January 14, 1983) upheld in *ASARCO v. OSHA*, 746 F. 2d 483 (9th Cir., 1984) and ethylene oxide (49 FR 25734, June 22, 1984) upheld in *Public Citizen Health Research Group v. Tyson*, 796 F. 2d 1479 (D.C. Cir., 1986). The D.C. Circuit, however, remanded to OSHA for reconsideration OSHA's decision not to include a short term exposure limit (STEL) for ethylene oxide.

Section 8(c)(3) gives the Secretary authority to require employers to "maintain accurate records of employee exposures to potentially toxic materials or harmful physical agents which are required to be monitored or measured under section 6." Section 8(g)(2) gives the Secretary authority to "prescribe such rules and regulations as he may deem necessary to carry out [his]—responsibilities under this Act." Section 4(b)(2) gives the Secretary power to apply this standard through the contract powers of the government and to make it applicable under other statutes.

OSHA concludes that the new benzene standard substantially reduces a significant risk of leukemia and other adverse health effects, is feasible, is necessary and appropriate to carry out OSHA's responsibilities under the Act, and meets all statutory requirements.

III. History of Regulation

Benzene has been recognized as a toxic substance capable of causing acute or chronic effects since 1900. An initial exposure limit of 100 ppm was recommended in 1927 by Winslow. In

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the 1940s, as a result of blood abnormalities and one death among rubber coating workers exposed to benzene concentrations ranging from 40 to 80 ppm, the state of Massachusetts lowered its permissible limit for benzene exposure to 35 ppm.

The American Conference of Governmental Industrial Hygienists (ACGIH) recommended a threshold limit value (TLV) for benzene exposure of 100 ppm in 1946. This TLV was reduced in 1947 to 50 ppm. In 1948, following Massachusetts' lead, ACGIH adopted a TLV of 35 ppm. In 1963, a TLV of 25 ppm was proposed by the ACGIH. At this time, reports of benzene induced blood changes, aplastic anemia, and other blood dyscrasias served as a basis for this action. No mention was made of any association of leukemia with benzene exposure. In 1974, the ACGIH adopted the TLV of 10 ppm which had sometime earlier been recommended by the American National Standards Institute.

The present OSHA standard for benzene (29 CFR Part 1910.1000, Table Z–2) was adopted in 1971 from the then current ANSI standard without rulemaking under the authority of section 6(a) of the Act. Neither the ANSI standard nor the resultant OSHA standard was based on the possible leukemogenic effects of exposure to benzene.

On May 3, 1977, the Assistant Secretary for OSHA issued an Emergency Temporary Standard (ETS) for Occupational Exposure to Benzene (42 FR 22516), pursuant to sections 6(c) and 6(c) of the Act. A temporary stay of that standard before it took effect was issued May 20, 1977 in the case *American Petroleum Institute et al. v. Occupational Safety and Health Administration et al.* (Fifth Circuit, No. 77–1973). No decision on the merits of the Emergency Temporary Standard was ever issued but the ETS never took effect because of various stays. A decision on jurisdiction was issued December 7, 1977 by the D.C. Circuit in *Industrial Union Dept. AFL–CIO v. Bingham*, 570 F. 2d 965 (D.C. Cir. 1977).

On May 27, 1977, OSHA published a proposed permanent standard to control occupational exposure to benzene (42 FR 27452). Public hearings on the benzene proposal were held July 19 through August 10, 1977.

On February 10, 1978 (43 FR 59181), OSHA promulgated a permanent standard for occupational exposure to benzene, 29 CFR 1910.1028. This standard was based on a determination by OSHA that the available scientific evidence qualitatively established that employee exposure to benzene presented the cancer hazard of main[illegible] leukemia. In accordance with OSHA's regulatory approach to the control of employee exposure to carcinogens at that time, OSHA had set the PEL at the lowest feasible level once qualitative evidence of carcinogencity was demonstrated. The standard, therefore, limited employee exposure to benzene to 1 ppm as an 8-hour time-weighted average concentration, with a ceiling level of 5 ppm for any 15 minute period during an 8-hour workday. The standard also prescribed limits on eye and skin contact with benzene and included monitoring, medical surveillance, training and other provisions.

The standard was challenged in the case of *American Petroleum Institute et al. v. Occupational Safety and Health Administration et al.*, 581 F.2d 493 (Fifth Cir. 1978). The Fifth Circuit vacated the standard on the basis that the Act required OSHA to perform a cost benefit analysis which it had not performed to demonstrate substantial benefits. The Court vacated the skin absorption provisions on the basis that the agency should have waited for a further study which the Court believed would be definitive and would only take a few months to complete.

On July 2, 1980, the U.S. Supreme Court upheld the decision of the Fifth Circuit, vacating the new benzene standard in *Industrial Union Dept. v. American Petroleum Institute*, 448 U.S. 607 (1980). The Supreme Court did not reach the issue of cost-benefit analysis. (It was later decided in *American Textile Manufacturing Institute, v. Donovan*, 452 U.S. 490 (1981), that OSHA standards were not to be based on cost benefit analysis.) However, the Supreme Court held that before OSHA issued a new standard under section 6(b), it must determine that a significant risk existed (based on quantitative estimates, if possible) and that a new standard would substantially reduce or eliminate that risk. It held that OSHA's qualitative determination for benzene did not meet that requirement. (See the discussion under Legal Authority above.) After vacating the new standard, the old benzene 10 ppm standard remained in effect.

On April 14, 1983, OSHA received a petition from the Oil Chemical and Atomic Workers Union; the Industrial Union Dept, AFL–CIO; the International Union of Allied Industrial Workers; the International Chemical Workers Union; the United Rubber, Cork, Linoleum and Plastics Workers of America; the United Steel Workers of America; the Public Citizen Health Research Group and the American Public Health Association requesting an Emergency Temporary Standard reducing benzene exposures to 1 ppm (Ex. No. 126). In support of their position, the petitioners presented quantitative risk assessments which they argued demonstrated significant risk at 1 ppm.

In a letter on July 1, 1983, Assistant Secretary Auchter denied the petition for several reasons (Ex. No. 150). First, the risk assessments presented needed additional review prior to a decision. Second, exposure data indicated that more than 90 percent of benzene exposed workers were working in industries where exposures were below 1 ppm and most of the rest were experiencing exposures between 1 and 3 ppm. Consequently, the additional risk remaining in the interval before a thorough review could be completed was much less than if exposures were higher. Third, as the Supreme Court has noted, Congress has "narrowly circumscribed the Secretary's power to issue temporary emergency standards." (For example, OSHA issued an ETS for asbestos on November 4, 1983 (48 FR 51086). The Fifth Circuit U.S. Court of Appeals stayed the ETS on November 23, 1983 and ruled on March 7, 1984, that the ETS on asbestos was invalid. *Asbestos Information Ass'n. v. OSHA*, 727 F2d 415.) Finally, the Supreme Court's benzene decision indicated that a more thorough analysis was needed on feasibility issues. However, the Assistant Secretary stated that OSHA would review on an expedited basis the quantitative risk assessments performed on benzene and the new scientific evidence, and that the Agency intended to proceed with an expedited rulemaking. A feasibility analysis commenced immediately.

On July 8, 1983, OSHA published in the Federal Register a Request for Information and Regulatory Schedule (48 FR 31412). The Agency requested information about benzene generally and answers to twenty-three questions regarding a variety of relevant issues concerning current occupational exposures to benzene. Among the areas covered was information developed since 1977 concerning the health effects of benzene, its toxicologic properties, estimates of the risk presented, current occupational exposure levels, approaches and costs for reducing exposures and their cost-effectiveness. Comments were due by August 22, 1983. On August 26, 1983, OSHA extended the comment period to September 6, 1983 (48 FR 38858) at the request of several interested parties, so that they would have sufficient time to respond. OSHA received thirty-five comments in response to the Request for Information.

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OSHA contracted with the Institute for Environmental Mediation in September, 1983, to encourage interested trade unions, trade associations and other interested non-governmental parties to enter into discussions among themselves to see if they could narrow issues on benzene regulation. On February 13, 1984, OSHA was notified that the trade unions, trade associations and other non-governmental parties had not agreed on a joint document, though they agreed that informal discussions by the interested non-governmental parties were useful.

Later information indicated that there might be a possibility of agreement. Meetings commenced in June. However, OSHA was notified on July 16, 1984 that agreement had not been reached.

On December 10, 1984, several trade unions and a public health organization filed a petition for a writ of mandamus in the United States Court of Appeals for the District of Columbia Circuit under the name *United Steelworkers of America, AFL–CIO–CIC, et al. v. Raymond J. Donovan, Secretary of Labor, et al.* (Ex. No. 163). The petition requested the Court to direct OSHA to proceed with benzene rulemaking on an expedited basis.

OSHA, on December 10, 1985, published a proposed rule for a revised standard covering occupational exposure to benzene (50 FR 50512). The proposal, based on the entire benzene record, presented OSHA's preliminary determination that the risks of leukemia and other benzene-related health effects needed to be reduced, lowered the permissible exposure limit (PEL) and including other provisions designed to reduce the risk. Several public hearings were scheduled.

Following oral argument on the petition for a writ of mandamus, the Court ordered OSHA to submit a rulemaking schedule for issuance of a standard. In the schedule OSHA presented to the Court, the Agency stated that it expected to issue a final determination on the rulemaking record by approximately February, 1987.

On February 25, 1986, the Court rejected the petition for mandamus holding that the writ was not appropriate to compel OSHA to undertake more expedited rulemaking than the proposed 14-month timetable and that the past delay in issuing a permanent standard, even if the delay was unreasonable, was not grounds to impose a mandatory timetable. However, the Court stated that the petitioners could refile the law suit if the Agency subsequently delayed excessively.

In light of federal budget reductions two of the public hearings were cancelled and a new schedule set (51 FR 3474). Subsequently, OSHA received a number of requests to extend the comment period. Consequently, the Agency extended the date to receive public comments, notices of intention to appear and prehearing documentary evidence to March 6, 1986 (51 FR 5090). The commencement date for the Washington hearing was also changed to March 18, 1986 (50 FR 5090).

The benzene hearings, were held March 18–27, 1986 in Washington, DC and April 2 and 3, 1986 in Los Angeles, California, providing interested parties the opportunity to comment on the proposed revisions, pursuant to section 6(b)(3) of the Act (29 U.S.C. 655(b)(3)). Administrative Law Judge Stuart A. Levin presided over the hearings. The deadline for filing post-hearing submissions of data and comments was May 9, 1986. Post-hearing briefs were received through June 10, 1986.

The record, of H–059 C alone includes over 280 exhibits many of which contain multiple attachments and more than 36,000 pages of material. It was certified by Judge Levin on June 16, 1986, in accordance with 29 CFR 1911.17. Copies of materials contained in the record may be obtained from the OSHA Docket Office, Room N–3670, U.S. Department of Labor, 200 Constitution Avenue NW., Washington, DC 20210.

This final benzene standard is based on a thorough consideration of the entire record of this proceeding, including materials relied upon in all previous notices, the record of the informal hearings, and all written comments and exhibits received.

IV. Chemical Identification, Production and Use

Benzene (C_6H_6) is a clear, colorless, non-corrosive, highly flammable liquid with a strong, rather pleasant odor. The low boiling point and high vapor pressure of benzene cause rapid evaporation under ordinary atmospheric conditions, giving off vapors nearly three times heavier than air.

Benzene is produced primarily by the petrochemical and petroleum refining industries by a process called catalytic reformation, which converts certain lower octane hydrocarbon into higher octane aromatics. These two industries are responsible for 98 percent of the total U.S. production of benzene. Recovery through catalytic reformation and thermal cracking of petroleum hydrocarbons, including the benzene formed from the dealkylation of toluene, accounts for approximately 75 percent of the total quantity produced. Recovery of coal-derived benzene, primarily as a by-product of the coking process in steel mills, was once the major source of benzene. Today, however, this process accounts for only 2 percent of the total United States production.

The first major industrial use of benzene was as a solvent in the rubber industry just preceding World War I. During World War I, benzene production was stimulated greatly by the demand for and resulting production of toluene in the manufacture of explosives. Large quantities of benzene are used to manufacture other organic compounds such as ethylbenzene, styrene, cumene, and cyclohexanol. This situation led to greatly increased uses of benzene as a solvent in the artificial leather, rubber goods, and rotogravure industries.

Many products contain benzene exclusively as the result of contamination. Benzene is a naturally occurring compound in crude oil and natural gas (e.g., the benzene content of these streams varies by geographical location and is ususally between 0.1 and 3.0 percent by volume), and some degree of benzene contamination occurs in products refined from crude oil and natural gas (e.g., solvents, fuels, and oils) because of the nature of the fractional distillation process by which these substances are produced. Benzene generally does not improve the performance of these materials.

Unreacted benzene may also be present in major benzene derivatives (e.g., methylbenzene) or in other specialty chemicals that use benzene as feedstock (e.g., dicyclopentadiene). The presence of unreacted benzene in major derivatives or other specialty chemicals is undesirable from the producer's point of view and is not generally useful to product users.

Industries and processes currently using benzene or liquids containing benzene include the chemical, printing, lithograph, rubber cement, rubber fabricating, paint, varnish, stain remover, adhesive, and petroleum industries. Benzene is also used extensively in chemical laboratories as a solvent and as a reactant in numerous chemical applications. Where benzene is produced, used or stored in large amounts, it is generally contained in enclosed systems, although exposures can occur during liquid transfer operations, from equipment leakage and carryover losses, and in maintenance operations.

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V. Health Effects

A. Introduction

Benzene has been known to be a bone marrow poison since the report of aplastic anemia by Santesson (1897, Ex. No. 159-70) and the report of a blood abnormality that is thought to have been a case of leukemia by LeNoir and Claude (1897, Ex. No. 159-50). The first case associating leukemia with benzene exposure was reported by Delore and Borgomano in 1928 (Ex. No. 159-23).

Over the years, reports in the literature have linked hundreds of cases of aplastic anemia, leukemia and other diseases of the blood to benzene exposure. It has been established that benzene exposure is causally linked to leukemia, to aplastic anemia (an often fatal disease of the bone marrow) and to suppression of various cellular elements of the peripheral blood, i.e., decreases in white cells or leukocytes (leukopenia), red cells (anemia), platelets or thrombocytes (thrombocytopenia) and all three of these cellular elements (pancytopenia). In the early stages of leukopenia, anemia, thrombocytopenia or pancytopenia, the effects may be reversible.

Since the 1970's, formal epidemiologic studies have evaluated the relative risk of leukemia among benzene exposed individuals. One study demonstrates a significant excess of myelogenous leukemia among a cohort of workers exposed to average benzene concentrations of about 5 ppm. Additional studies, along with numerous case reports, have shown that benzene alone or in combination with other chemicals is associated with several hematological disorders including myelogenous leukemia and its variants, lymphatic leukemia, multiple myeloma, paroxysmal nocturnal hemoglobinuria, various forms of lymphoma, aplastic anemia and various cytopenias. The basic mechanism by which benzene affects bone marrow precursor cells is still unclear. Evidence in the record indicates that cytogenetic changes are likely to be involved (Ex. Nos. 128-46, 128-47, 252-A-17-95, Tr. 4/2/86, pp. 12-54).

The scientific literature includes many case reports, case series, and epidemiologic studies which qualitatively link benzene exposure with chromosomal damage in humans. This literature has been reviewed and summarized in several places (NAS, 1976; Goldstein, 1977; OSHA, 1978; IARC, 1982; and others; Ex. Nos. 128-5,7,8,59). Information also indicates that chromosomal damage in workers is associated with benzene exposures below 10 ppm. Recent experimental studies have demonstrated chromosomal damage in experimental animals exposed by inhalation for six hours to 1 ppm benzene.

Although suspicion of types of cancers other than of the lymphohematopoietic system has been raised, these have not been adequately evaluated from epidemiologic cohort or case-control studies of workers exposed to benzene. However, since 1978, experimental studies have demonstrated that benzene experimental studies have demonstrated that benzene administered either by oral gavage or by inhalation induces cancers of multiple sites in experimental animals. The major reports of these findings are presented in more detail below.

Several consensus groups have confirmed the carcinogenic potential of benzene, including the American Conference of Governmental Industrial Hygienists (ACGIH-TLV, 1983, Ex. No. 159-5), the International Agency for Research on Cancer (IARC) (1982, Ex. No. 128-8), and the National Toxicology Program (NTP) (Ex. No. 148).

B. Hematotoxic and Carcinogenic Effects in Humans

1. Non-malignant Blood Disorders

The toxic effects of benzene on the human hematopoietic system are well documented in the literature. A common clinical finding in benzene hematotoxicity is a decrease in various cellular elements of the circulating blood, called cytopenia. This decrease may manifest itself as pancytopenia and aplastic anemia or as unicellular cytopenias such as leukopenia or thrombocytopenia (Goldstein, 1977, Ex. No. 59).

Aplastic anemia or hypoplastic anemia is a rare disorder, characterized by a reduction of all cellular elements in the peripheral blood and in the bone marrow. Aplastic anemia has a poor prognosis. It has a high case-fatality rate of about 30-50% within one year of diagnosis. Aplastic anemia caused by benzene exposure is also associated with an increased risk of developing acute nonlymphocytic leukemia (ANLL) for those individuals who do not die from the anemia. Vigliani and co-workers in Italy and Aksoy and co-workers in Turkey have described several series of cases of leukemia and aplastic anemia attributed to occupational benzene exposure. Aksoy (1980, Ex. No. 144-039) reported on 44 cases of pancytopenia among 28,500 benzene exposed workers in Istanbul, Turkey during the years 1967 to 1979. Twenty-three of the 44 cases (52%) experienced remission of the aplastic anemia. Fourteen of the 44 cases (32%) died from complications of aplastic anemia or pancytopenia. Six of the 44 cases (14%) of pancytopenia later died from leukemia. Aksoy also reported that in twenty-six percent of 42 leukemia cases, the leukemia was preceded by a period of pancytopenia. The interval between the pancytopenic period and the onset of leukemia varied between 6 months and 6 years.

Vigliani (1976, Ex. No. 128-15) summarized cases of benzene hemopathy seen at the Institutes of Occupational Health of Pavia and Milano. At the Institute in Milano from 1942 to 1976, 66 cases of chronic benzene poisoning were seen. Of 18 deaths in this group, 7 were from aplastic anemia and 11 were from leukemia. All cases were employed at rotogravure plants, shoe factories, and other industries using benzene as a solvent. At the Institute at Pavia from 1959 to 1974, 135 cases of benzene hemopathy among workers in shoe manufacturing were enumerated. Of 16 deaths, 3 were from aplastic anemia and 13 were from leukemia. With data from both clinics combined, there were 24 deaths from leukemia and 10 deaths from aplastic anemia. In other words, there were 0.42 aplastic anemia deaths for each leukemia death. OSHA used this fraction for purposes of estimating the number of aplastic anemia deaths the new standard would prevent.

Some commenters have argued that this ratio may be too high for use in OSHA estimates because the cases of aplastic anemia observed may have resulted from higher exposures to benzene than have been seen in other cohorts of workers. For example, the Chemical Manufacturers Association (Ex. No. 258) considered the estimated benzene exposures in the Vigliani study to range between 200 and 500 ppm and not relevant to current low level occupational exposures in the United States.

Ott et al. (1978. Ex. No. 128-33) reported two deaths from leukemia and one from aplastic anemia among benzene exposed employees of a chemical manufacturing facility. Workers had relatively low average exposures in this study, about 5 ppm. Bond et al. (Ex. No. 256) reported in the update of the cohort study by Ott et al. that in addition to the death from aplastic anemia, one death was observed from myelofibrosis and one from pernicious anemia. The diagnosis of death from pernicious anemia (Ex. No. 170) may, in fact, have been due to megaloblastic anemia. If this is the case, then the ratio of leukemias to other

diseases of the blood and blood-forming organs for this cohort would be four to three (two additional leukemia deaths were observed in the update by Bond et al.). Consequently, there would be 0.75 cases of diseases of the blood and blood-forming organs, such as aplastic anemia, for each leukemia case.

In testimony at the OSHA hearing, API's (the American Petroleum Institute) witness, Dr. John Bennett commented that OSHA's estimate of 0.42 for the ratio of aplastic anemia to acute myelogenous leukemia (AML) seemed, in his view, inappropriate and that an appropriate ratio would be one aplastic anemia for every five or six AMLs (Tr., 3/26/86, 126–127) (0.17 aplastic anemia for each leukemia), and could be as low as 1 to 15 or 1 to 20 at current benzene exposures. Dr. Bennett did not indicate the number of cases upon which his estimate is based, nor did he indicate whether his estimate of this ratio is based on measured benzene exposures of patients he has seen.

OSHA concludes that its original estimate of 0.42 aplastic anemia (or the somewhat broader category of diseases of the blood and blood-forming organs) for each leukemia is reasonable. It is supported by one relatively large study. The Ott/Bond study with low worker exposure had a ratio of 0.75. Dr. Bennett's estimate is about 0.17. OSHA's estimate is also approximately the average of the two studies and Dr. Bennett's estimate. (It should be noted that OSHA's risk assessment and significant risk analysis is based on leukemia deaths alone.)

The Chemical Manufacturers Association has commented (Ex. No. 258, p. 9) "signs of hematotoxicity (including bone marrow depression, pancytopenia, aplastic anemia and less severe blood abnormalities) have not been associated with short-or-long-term exposure to benzene at levels below the range of 25 ppm–40 ppm." However, as discussed in the study of DOW employees by Ott et al. (1976), updated by Bond et al. (1986), three deaths due to diseases other than leukemia of the blood and blood-forming organs were observed as compared to 0.7 expected among a cohort of employees exposed to an average benzene concentration of 5 ppm. For the specific individuals who died from other diseases of the blood, their average exposures were 30 ppm (megaloblastic anemia), 19.3 ppm (myelofibrosis) and 4.6 ppm (aplastic anemia). Furthermore, Shell (Ex. No. 160–12) recently reported one person with thrombocytopenia as a result of average exposures between 1.3–2.2 ppm who was removed from benzene exposure on the advice of an hematologist.

This information strongly suggests that there are hematologic effects of benzene exposures well below 25 ppm and is indicative of effects below 10 ppm. Adding support to this suggestion, Shell, in its studies of refinery workers, has observed excesses of both total leukemias and myelogenous leukemias. It has been estimated (Runion and Scott, 1983), Ex. No. 159–67) that refinery workers have low average exposures to benzene.

2. Cancer

The classification of neoplastic diseases of the hematropoietic system has developed out of their gradual historical recognition. The major disease categories differ with respect to morphologic and clinical manifestations and often in their response to therapy. Leukemia may be divided into granulocytic leukemias (which include myelocytic, monocytic and erythroblastic cell types) and lymphocytic leukemias. Both granulocytic and lymphocytic leukemia may in turn be separated into acute and chronic forms. The designations "acute" and "chronic" are related to the rapidity of development of symptoms, signs and complications in these forms of leukemia (Wintrobe, 1974, Ex. No. 159–103). Lymphoma may be divided into Hodgkin's disease and non-Hodgkin's lymphomas. Other cancers of the hematopoietic system include multiple myeloma, a neoplasm affecting plasma cells in the bone marrow, and myelofibrosis.

A substantial amount of evidence on morbidity and mortality associated with benzene exposure has accumulated in the epidemiologic literature during the past decade. The epidemiologic literature during the past decade. The epidemiologic studies employ standard methods, which are briefly explained here to assist the general reader who is not familiar with epidemiologic terms. A proportionate mortality ratio (PMR) compares the proportion of observed deaths from a specific cause, such as leukemia, in the group under study to the proportion of deaths expected from this cause in a standard or comparison population. A PMR of 2.0 indicates a 2-fold increase in the proportion of individuals that died from a specific disease in the exposed group as compared to the expected proportion derived from the standard population.

A standardized mortality ratio (SMR) compares the ratio of the observed number of deaths from a specific cause in the study population to the number of deaths from this cause that would be expected in the general or standard population. This ratio is then multiplied by 100. For example, if 8 deaths from leukemia were observed and 4 were expected, the SMR is 200 (8 divided by 4 times 100). The number of expected deaths is usually calculated from the known death rates in the standard population, adjusted to the study population for age, sex, race and calendar-time-period. A SMR of 100 indicates that the observed number of deaths equals the expected, 200 indicates twice as many deaths are observed as expected. Sometimes the ratio of the disease frequencies is expressed as the relative risk (RR). It represents how many times more (or less) likely disease occurs in the exposed group as compared with the unexposed. In the above example where the SMR was 200, the RR would be 2.0.

A case-control study compares individuals who have a specific disease (cases) with similar individuals who do not have the disease (controls). The purpose is to determine if the two groups differ in relation to exposure to a specific factor, in this case, benzene. The statistic calculated is called the odds ratio (OR) or the relative odds. For rare diseases such as cancer the OR approximates the RR. For purposes of discussion in this preamble an SMR of 200 will be equated with a RR of 2.0, an OR of 2.0, and a PMR of 2.0.

Statistical power (or power) is related to the number of individuals in the study population and is the ability of the study to detect a statistically significant increase in an effect, such as leukemia, if, in fact, it exists in the population. Most epidemiological studies are observational and differ from experimental studies in the degree of control of extraneous variables. Their advantage over experimental studies is that the effects are observed in humans.

In order to make public health decisions, statistical associations from observational data can be interpreted as cause-effect relationships when certain factors add to our confidence in the conclusion. In general, the stronger the association, the more likely it represents a cause-effect relationship. The strength of an association can be measured by the RR, the OR, the PMR, or the SMR which all essentially represent the ratio of the disease rate in those with a factor (e.g. exposure to benzene) to the rate in those without it. If the association makes sense in terms of biological plausibility, if there is a dose-response relationship, or, if the same association is found in several studies, confidence in the conclusion that there is a cause-effect relationship is increased. Other

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factors to be considered when determining whether an association is real, or spurious, are discussed in the description of individual studies..

The concept of statistical significance relies upon arbitrarily chosen but traditional significance levels (e.g., 0.05. 0.01, etc.) indicating that the statistical relationship observed has a less than 5% (or 1%) probability of being due to chance. OSHA's expert witness, epidemiologist Dr. David Savitz, pointed out that "Such a cutoff is arbitrary in that risk estimates which do not attain such a level of statistical significance still contribute to a characterization of the presence of a potential threat to human health. For example, an 80% level of certainty may be sufficiently convincing that a result is not likely to be due to chance" (Ex. No. 222, p.12).

An association between occupational exposure to benzene and the occurrence of leukemia was suggested in 1928 by Delore and Borgomano (Ex. No. 144–178), who described acute lymphoblastic leukemia in a worker who had been exposed to benzene for five years. Since that time, numerous reports of cases and case series have described leukemia in workers exposed to benzene, either alone or in combination with other chemicals (Hunter, 1939, Ex. No. 144–143; DeGowin, 1963, Ex. No. 144–155; Tareef et al., 1963, Ex. No. 2–28; Vigliani and Saita, 1964, Ex. No. 128–12; Goguel et al., 1967, Ex. No. 144–146; Aksoy et al. 1972 1974, 1976, Ex. Nos. 128–9, 10, 11; Vigliani, 1976, Ex. No. 128–5; Girard and Revol, 1970, Ex. No. 144–177; Aksoy, 1977, 1980, Ex. Nos. 144–39, 160; and those reviewed by Goldstein, 1977, Ex. No. 128–59). The leukemia cases reported have been myelogenous, monocytic, erythroblastic, and lymphocytic leukemias. Reports of other diseases associated with benzene exposure have included malignant lymphoma, multiple myeloma, myeloid metaplasia, myelofibrosis, and paroxysmal nocturnal hemoglobinuria.

Aksoy and coworkers (1974, 1976, 1977, 1980, Ex. Nos. 22, 128–72, 11, 43) reported the crude incidence of leukemia between 1967–1973 among 28,500 shoe, slipper and handbag workers exposed to benzene in Istanbul to be approximately 13.5 per 100,000, compared to an estimated annual leukemia incidence of 6 per 100,000 for the general population of Turkey, resulting in a relative risk of 2 for all cell types of leukemia combined. This risk estimate was based upon the diagnosis of leukemia in 26 shoeworkers at the Internal Clinic of Istanbul Medical School and did not take into consideration differences in the age structure of the population of shoeworkers and the general population. From the several reports by Aksoy et al., peak benzene exposures for the 28,500 shoeworkers were estimated to have varied between 210 and 640 ppm. Average exposure concentrations were estimated to be between 150–210 ppm when adhesives containing benzene were being used and between 15–30 ppm during other times. Duration of exposure is estimated to be 9.7 years based on the average length of exposure for the leukemia cases.

On the basis of the series of reports by Aksoy et al. the Carcinogen Assessment Group (CAG) of the Environmental Protection Agency (EPA) calculated a relative risk of 20 for non-lymphoblastic leukemia among Istanbul shoeworkers exposed to average benzene levels ranging from 15–250 ppm (CAG, 1979, Ex. No. 128–6). The difference between the relative leukemia risk of 2 as estimated by Aksoy et al. and 20 as estimated by CAG is related to adjustments made by CAG for the background incidence of leukemia in Turkey, attributed differences between the age structure of Turkish shoeworkers and the general population on which the national rate was based and adjustment for cell types of leukemia on which the CAG relative leukemia risk was based. These factors contributed equally to the difference between the Aksoy and the CAG estimates of risk. IARC (1982, Ex. No. 128–8) also evaluated the reports of Aksoy et al. and determined that the relative risk of acute non-lymphocytic leukemia among Istanbul shoeworkers was 24. This evaluation by IARC resulted in a relative risk 12 times higher than the 2-fold elevated risk reported by Aksoy et al. and is based on the ratio of acute non-lymphocytic leukemia to chronic forms of leukemia for benzene exposed versus non-benzene exposed individuals in the Aksoy studies of shoeworkers.

Vigliani and Saita (1964, Ex. No. 128–12) estimated the incidence of acute leukemia attributed to benzene exposure in the Provinces of Milan and Pavia during 1962 and 1963 to be at least 20 times higher than expected when compared to the general population, based on 11 cases among approximately 5,000 persons exposed to benzene in the rotogravure and shoe industries. Data were not presented in the report to allow for validation of the estimated risk.

Vigliani (1976, Ex. No. 128–14) summarized the cases of benzene hemopathy (leukemia and other blood disorders) treated at two clinics in Italy. Between 1942 and 1975, 66 cases of benzene hemopathy, 11 of which were leukemia, were seen at the Institute of Occupational Health in Milan. The affected individuals worked in rotogravure plants, shoe factories and other industries using benzene as a solvent. Benzene concentrations in air near rotogravure machines were calculated to range between 200 to 400 ppm, with peaks up to 1500 ppm.

At the Institute of Pavia, 135 workers with benzene hemopathy were seen, 13 of which were leukemia, during the period 1959–1974. All of these cases came from shoe manufacturing occupations where benzene concentrations in the workplace were reported to have ranged from 25–600 ppm but mostly in the range of 200–500 ppm.

Girard and Revol (1970, Ex. No. 144–177) examined the relationship between hematologic diseases and history of exposure to toxins, including benzene and toluene, by interviewing 401 patients hospitalized at their Hematology Department (cases) and several other groups of patients who had non-hematological diseases (124 "control" patients). Samples of toxic substances mentioned in the survey were collected from patients or their families. Information regarding exposure was also collected at workplaces. Hematology patients and controls were similar in distribution of age and gender. Exposure was defined as use of products containing benzene or toluene. The frequency of toxin exposure was statistically significantly greater than in controls for acute leukemia, chronic lymphoid leukemia, and aplasias. Among 257 patients with leukemia, 140 were identified as acute leukemias, 61 were chronic lymphocytic leukemias (CLL), 56 were myeloid leukemias. Thirteen cases of myelofibrosis were also observed. The exposure histories were compared with those for 124 control patients. Seventeen cases (12.1%) of acute leukemia, nine cases (14.7%) of CLL, 4 cases (7.1%) of myeloid leukemia, and 2 cases (15.3%) of myelofibrosis had evidence of previous exposure to benzene and toluene as compared with 5 (4.0%) controls, for relative risks (odds ratios) of 3.3, 4.1, 1.8, and 4.3, respectively. Regarding the possibility of these effects being due to exposure to toluene, it is assumed that hematologic effects are more likely to be due to benzene contained as a contaminant in toluene.

Studies of rubber workers. Because of numerous case reports of leukemia and other blood disorders associated with occupational benzene exposure, NIOSH

conducted a cohort mortality study to evaluate the relative risks of leukemia among workers exposed to benzene. Infante et al. (1977, Ex. No. 128–17), reported on a cohort of 748 white male workers occupationally exposed to benzene at any time between 1940 and 1949 in two manufacturing facilities producing rubber hydrochloride (Pliofilm ®). Vital status ascertainment at the time of the initial report was 75% complete. In order not to overestimate the risk, the authors conservatively assumed that those with undetermined vital status were alive until the follow-up cut-off date. (The resulting relative risks from cause-specific mortality were subsequently shown to have been underestimated when the follow-up was continued (Rinsky et al., 1981, Ex. No. 128–32)). Causes of death were ascertained from diagnoses given on death certificates as underlying cause of death. Although there were fewer deaths from all causes reported among the benzene exposed workers (140) than the number expected based on age and calendar period adjusted death rates for U.S. white males (187.6), a significant excess of leukemia deaths was observed (7 observed vs. 1.38 expected). All 7 leukemia deaths were from myelogenous or monocytic leukemia, constituting a 10-fold relative risk for deaths from the two cell types combined, based on estimates of leukemia cell-type distribution derived from incidence data from the Connecticut Tumor Registry. Monitoring data and existing industrial hygiene assessments led to the conclusion that the environment of the workers in Pliofilm ® production was not contaminated with other materials known to be associated with the induction of blood disorders. Infante et al. further stated that workers' exposures to benzene were generally within the recommended limits in effect at the time of employment, that is, they were between 100 ppm and 10 ppm during the years 1941–1975.

In reply to questions raised by Tabershaw and Lamm (1977, Ex. No. 159–81), the NIOSH investigators evaluated past exposures in both facilities in further detail, and reported that, although other solvents were used in various areas, benzene was found to be the only solvent used in the manufacture of rubber hydrochloride, except for chloroform, which was used between 1936 and 1949 in one plant (Ex. Nos. 128–17; 128–32). The authors agreed with Tabershaw and Lamm that occasional high excursions occurred in airborne benzene levels (up to several hundred ppm). They found, however, that the estimates of airborne concentrations for most of these excursions were based on area samples and not personal samples and occurred in areas entered only infrequently by workers. They estimated that workers' actual eight-hour time-weighted average breathing-zone exposures fell generally within then accepted limits of 10 to 100 ppm.

To evaluate the relative risk of death from leukemia at each of the two locations, the NIOSH investigators separately analyzed leukemia mortality in each (Ex. No. 128–17; 128–32). They found excess mortality in both locations: in one, 2 cases were observed versus 0.58 expected for a standardized mortality ratio (SMR) of 345; and in the other, 5 cases were observed versus 0.67 expected (SMR=746). However, the authors noted that the decision to examine mortality separately for the two locations was not made prior to initial analysis and therefore should not be given undue emphasis. In OSHA's opinion, it seems appropriate to combine data for the two facilities because the operations through which workers were exposed to benzene were virtually identical.

NIOSH agreed with Tabershaw and Lamm that the estimated 10-fold relative risk of death from myeloid and monocytic leukemias combined as presented initially (1977) was too high. The re-analysis by NIOSH resulted in a relative risk of 8.5 for these types of leukemia (Ex. No. 128–17). In OSHA's opinion, the slight reduction in the excess relative risk does not greatly influence the interpretation of the study results.

In their reply to Tabershaw and Lamm, the NIOSH Investigators (Ex. No. 128–17) also indicated that "pipefitters, mechanics, and maintenance personnel were not included because company records did not show which men had responsibilities in Pliofilm ® production." During the follow-up, it was learned that at least one pipefitter who had responsibilities in Pliofilm ® was known to have died from acute myelogenous leukemia. This leukemia death, however, could not be included in the statistical analyses because it did not fit the initial cohort definition.

Dr. Marvin Sakol, a hematologist who practiced in the community where one of the studied facilities was located, presented information during the 1977 OSHA benzene hearing indicating that at least five individuals, of whom 3 died from leukemia, one from thrombocytopenia and one from lymphosarcoma, were not included as such in the statistical analyses of the NIOSH study (Sakol, OSHA 1977, TR 285–329). If these individuals were included, the estimated excess risk would increase substantially. OSHA sought comment on whether these individuals should be included in the analyses for purposes of determining a "maximal estimate" of relative risk for lymphohematopoietic disease in the NIOSH cohort. In comments from the State of Wyoming, Occupational Health and Safety Administrator, Donald Owsley, stated:

> The 5 individuals should have been included in the statistical risk analyses for the determination of the maximal estimate. It is apparent from the information presented by Dr. Sakol, that benzene exposure played a significant role in attributing to their deaths (Ex. No. 201–2, p. 1).

Rinsky et al. (1981, Ex. No. 128–32) continued the follow-up of the cohort of Pliofilm ® workers through June 30, 1975. They reported a statistically significant excess of leukemias. There were seven cases observed, as compared to 1.25 expected resulting in a SMR of 560. The authors indicated that 58% of the cohort members had been employed for less than one year. When the data were analyzed by length of employment, a significant excess in leukemia was observed among workers employed 5 or more years, but not among workers employed for less than 5 years. Among the latter group, 2 workers had died from leukemia compared to 1.02 expected, an excess which was not statistically significant. However, among workers employed for 5 or more years, 5 had died from leukemia compared to 0.23 expected, yielding a SMR of 2100. Five additional cases of leukemia, four of them myelogenous, were reported among workers who had responsibilities in Pliofilm ® manufacturing. These deaths were not included in the statistical analysis of the original cohort (employed sometime between 1940–49) because they occurred either after the study end date of June 30, 1975 (one case), began employment in Pliofilm ® after 1950 (one case), were salaried rather than hourly employees (one case) or had incorrect underlying cause of death indicated on the death certificate (2 cases). (Four of these deaths are in addition to those mentioned by Dr. Sakol as not being included in the analysis. Case number 12 in Rinsky et al. (1981) was mentioned by Sakol.)

Rinsky et al. (1981, Ex. No. 128–32) provided further detail on atmospheric benzene concentrations to which the cohort was exposed. For one Pliofilm ® manufacturing facility, location 1, information on benzene concentrations between 1946 and 1976 was available

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from a series of reports by the Industrial Commission of Ohio, the Ohio Department of Health, the company, the University of North Carolina and a NIOSH survey. According to NIOSH investigators, most of the data in these reports appears to have been derived from area samples taken with detector tubes with the exception of the company surveys of 1973–75 and the NIOSH walk-through survey conducted in 1976 when personal breathing zone air samples were measured. While the short-term area samples measured over the years indicated that some benzene levels were above 100 ppm, most were below 100 ppm. Furthermore, short-term area peak exposures may not be indicative of actual breathing zone exposures. The Rinsky et al. (1981, Ex. No. 128–32) report cites several documents indicating that workers were required to wear respirators when exposed "even momentarily" to exposures considered above the recommended level at the time. For example, a report from 1955, when the recommended limit was an 8-hour average of 35 ppm, indicated that when workers entered areas where benzene exposures ranged from 19–680 ppm, respirator usage was required. However, one evaluation of benzene exposure made in 1973–74 at the same facility, when the exposure limit was 10 ppm as an 8-hour average, indicated that respirators were required but were often not worn when workers entered areas where high benzene levels were found (Rinsky, et al. 1981, Ex. No. 128–32). Thus, available information indicates that respirators were generally used when workers entered areas above the recommended limit.

Limited information on exposure levels was available for the second location. One report from the Ohio Department of Health dated 1948 indicated there were "a few conditions wherein an employee might be subjected to an extremely high concentration of benzol," but that employees were "well aware of the toxicity of benzol and have been instructed to, and do, wear respirators when they are required to enter" these areas. Environmental data from this location believed to have been derived around 1957, when the recommended 8-hour TWA was 25 ppm, indicate atmospheric levels of benzene ranging between zero and 100 ppm based presumably on short-term area samples. Because respirators were used in this facility and management was aware of the toxicity of benzene, OSHA considers NIOSH's assessment reasonable that personal exposure to benzene at this facility as well as at Location 1 was generally within the recommended limits at the time of exposure.

Rinsky et al. (1986, Ex. No 250A) evaluated mortality from benzene exposure based on an estimate of cumulative dose for each individual in this cohort. Cumulative benzene exposures were calculated for each member of the cohort in ppm-years. They were also able to extend the follow-up of cohort members to 1982. A total of 1,165 white males with at least one ppm-day of cumulative exposure to benzene through December 31, 1965 were included in the cohort, for a total of 31,612 person-years at-risk. 16 persons (1.4%) lost to follow-up were considered to be alive as of the study end date.

A statistically significant increase in deaths from all lymphatic and hemopoietic neoplasms was observed in this cohort (15 deaths observed versus 6.6 expected, SMR=227). The SMR for leukemia in this cohort was 337 (9 observed vs. 2.7 expected); the SMR for multiple myeloma was 409 (4 observed vs. 1 expected); both were statistically significantly elevated. According to Rinsky et al. increases in cumulative exposure were associated with marked, progressive increases in the SMR for leukemia: among workers with less than 40 ppm-years cumulative exposure, the SMR=109; with 40 to 199.99 ppm-years cumulative exposure, the SMR=322; with 200 to 399.99 ppm-years, the SMR=1,166; with 400 or more ppm-years, the SMR=6,637 (400 ppm-years=40 years at 10 ppm average per year). Boundaries of the cumulative exposure categories were varied in order to check this trend and it remained strongly positive. Cumulative exposure, duration of exposure, and rate of exposure were each evaluated using a conditional logistic regression analysis to determine which measure of exposure most closely influenced the risk of death from leukemia. Cumulative exposure to benzene (ppm-years) was found to be the strongest predictor of death from leukemia. With regard to the latency, defined by Rinsky et al. as the time in years from the date of first exposure until death, seven of the nine leukemia deaths ocurred less than 20 years from initial exposure. All four deaths from multiple myeloma occurred after 20 years of latency. Three of the four multiple myeloma cases had less than 40 ppm-years of exposure. All four of these individuals had worked at location 1.

To further examine the exposure-response relationship, a case-control analysis was performed on a subset of the Pliofilm cohort, using a conditional logistic regression model. Ten controls were chosen from the cohort to match each leukemia death by year of birth and year first employed. In the analysis, cumulative exposure was found to be the strongest single predictor of death from leukemia.

The NIOSH investigators concluded from this study that a strongly positive exposure-response relationship exists between benzene and leukemia that extends downward to mean annual exposure levels of less than 1 ppm accumulated over a 40-year working lifetime. According to the model selected for the analysis, the odds of dying from leukemia for a worker occupationally exposed to average daily benzene concentrations of 10 ppm for 45 years would be 290 to one. In other words, their risk of dying from leukemia would be 280 times that of a population not exposed to benzene. At 1 ppm the odds would be about 1.7 to 1; at 0.5 ppm the odds would be 1.3 to 1.

Rinsky et al. (1986) also concluded that a statistically significant excess of deaths from multiple myeloma has occurred in this population of benzene exposed workers. Because three of the four persons who died from multiple myeloma had cumulative benzene exposures of less than 40 ppm-years, and all four cases had >20 years latency, these investigators hypothesized that "relatively low cumulative exposures to benzene may produce a relatively well differentiated malignancy such as multiple myeloma * * * " (Ex. No. 250A, p. 20).

During the 1986 hearings on the proposal, there was considerable discussion of the NIOSH study of rubber hydrochloride workers. In particular, the API was concerned that errors had occurred in exposure estimation. As a result of questions submitted by API to NIOSH during and following the hearings (Ex. No. 237) exposures to a small number of cohort members were corrected by Rinsky et al. Because some of the revisions were upward and some were downward, these changes did not result in any significant alterations to the findings of the study. The results described in this preamble are based on the draft of the report dated April 22, 1986, submitted to the record by NIOSH with its post-hearing comments, and based on the corrected exposure estimates for the cohort (Ex. No. 250A). In discussing the exposure estimates made for this study, the authors point out that although they are based on existing environmental data which are invariably incomplete in studies of this kind, these "data are unusually comprehensive in comparison to those typically available for retrospective

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cohort studies" and "permit a reasonable estimate of cumulative benzene exposure during rubber hydrochloride production for each member of this study population." (p. 17) Furthermore, they state:

> If the environmental data are in error, we believe they likely err by overestimating actual average exposures, for two reasons. First, the majority of the measurements were taken by industrial hygienists looking for trouble spots within the process rather than trying to document typical personal exposures. Second, the economic viability of the rubber hydrochloride manufacturing process depended upon efficient recovery of costly solvent; indeed, much of the process was dedicated toward this end. Continuous high level contamination by benzene of a large ventilated area would not have been economically acceptable (Ex. No. 250, p. 18).

In 1984, after the date set for the end of follow-up for this study, a tenth death from leukemia occurred among the cohort. This man had worked as a neutralizer operator at location 2 for approximately 3½ years. His cumulative benzene exposure was estimated to be 90.56 ppm-years. Because vital status for the cohort was determined only through 1981, this case did not meet the criteria for inclusion in the study cohort but the death was included in a subsequent regression analysis. The inclusion resulted in a slightly lower odds ratio, but increased the statistical significance of the dose response. Rinsky et al. did not include this 10th leukemia death in their preferred analysis because it occurred beyond the study cut-off date and the controls selected may not have met the criterion of being alive at the time of the case's death as did the controls matched to other cases. The analysis including the 10th case mentioned as additional corroborating evidence.

A number of studies have noted excesses of mortality from lymphatic leukemia, myelogenous leukemia and lymphosarcoma among persons exposed to benzene and benzene containing solvents while employed in the rubber industry (McMichael et al. 1975, Ex. No. 128–18; Monson and Nakano, 1976, Ex. No. 128–20; Tyroler et al. 1976, Ex. No. 144–21; Delzell and Monson, 1982 Ex. No. 144–32). The International Agency for Research on Cancer (IARC) (1982, Ex. No. 159–38A) has reviewed many of the epidemiologic studies of cancer risk among workers in the rubber industry. Excesses of cancer of the lymphoid and hematopoietic systems were observed among rubber workers in both the U.S. and the U.K. IARC concluded that there is sufficient evidence to indicate an excess occurrence of leukemia in rubber workers and to indicate a causal association with occupational exposures, presumably to solvents.

Studies of chemical workers. Ott et al. (1978, Ex. No. 128–33) conducted an historical prospective study of mortality among 594 white males occupationally exposed to benzene in a chemical manufacturing facility and employed at any time between 1940 and 1970. Two deaths from leukemia were observed versus one expected. The authors noted that a third death was categorized on the death certificate as bronchopneumonia with myeloblastic leukemia listed under "other significant conditions." (Since individuals with terminal leukemia often die from bronchopneumonia, the underlying cause of this death was listed incorrectly on the death certificate as due to pneumonia.) Ott et al. (1978) included this third case of myelogenous leukemia in their analyses and noted that 3 cases of myelogenous leukemia compared to 0.8 expected cases based on incidence data from the Third National Cancer Survey are statistically significant. With regard to other findings of interest in relation to benzene toxicity, the authors indicated that a fourth cohort member died from aplastic anemia while a fifth died from pernicious anemia. The time-weighted-average (TWA) exposures ranged from 0.1–35 ppm for various job categories.

Assessment of atmospheric benzene levels in the three production areas from which workers were selected for study indicated that exposures to the cohort had always been fairly low reflecting the use of closed, continuous systems. In production area one (I), estimated TWA benzene exposure based on breathing zone samples ranged between 0.1 and 6.2 ppm for the years 1944 to 1973. In production area two (II), TWAs ranged between 0.3 and 14.7 ppm between 1953 and 1972, while in production area three (III), the averages ranged between 4 and 35.5 ppm for the years 1952–1974. Ott et al. calculated cumulative dosage for each employee by multiplying the mean TWA exposure for each job category by the number of months spent exposed to each level.

Several witnesses and/or working groups have judged this study as having been well conducted. Dr. MacMahon, who was the major consultant for CMA on the epidemiologic evidence of leukemia risk at low benzene concentrations, commented that in the Ott study "there seems to be reasonably clear evidence of increased leukemia risk following benzene exposures at levels below the present standard of 10 ppm. Exposure measurements have been maintained over an unusually long period and there seems no reason to believe that the characterizations of exposure are inaccurate" (Ex. No. 201–33, p. 22).

Bond et al. (1986, Ex. No. 201–28) updated the mortality study conducted by Ott et al. (1978, Ex. No. 128–33) by extending the cohort definition to include employees who worked for at least one month between 1938 and 1978, by extending the observation period through 1982, and by examining monthly as well as annual census data for those employed at the facility. As a result, an additional 362 benzene exposed workers not studied originally were added to the cohort. Four deaths due to myelogenous leukemia were observed with 2.1 expected total leukemia deaths (SMR = 194) and 0.9 expected myelogenous leukemia deaths (SMR=444; $p<0.011$).

A fifth person with myeloblastic leukemia was classified as a death due to bilateral bronchopneumonia because it was listed as such on the death certificate. (This is the same case observed by Ott. et al.). Standard epidemiologic methodology required, therefore, that it be coded to pneumonia. A statistically significant excess of deaths due to myelogenous leukemia (4 observed versus 0.9 expected, $p=0.011$) was observed among these 956 benzene exposed workers.

Ott et al. had previously reported one death due to aplastic anemia and one due to pernicious anemia. After examination of the pathologist's report (Ex. No. 170A), OSHA is of the opinion that the latter cause of death was actually megaloblastic anemia. In the update, one additional death was observed due to myelofibrosis, a condition thought to be similar to myelogenous leukemia in overgrowth of fibroblasts (Ex. 201–28; Ex. 159–103). The identification of the latter death brings to three the total number of observed deaths from diseases of the blood or blood forming organs among these benzene exposed workers, as compared to 0.7 expected deaths from these causes ($p<0.05$, one-sided Fishers Exact Test), a statistically significant excess of deaths (Ex. No. 252A–19).

One case of multiple myeloma was also observed among these workers. The authors (Bond et al.) considered it noteworthy that the deaths from myelofibrosis and multiple myeloma occurred among workers from the same area of the plant (Alkyl benzene unit) where four out of the five individuals who had developed leukemia had worked. This observation is also noteworthy in view of the NIOSH study in which a significant excess of mortality due to multiple myeloma among benzene exposed workers was

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demonstrated (Rinsky et al., 1986, Ex. No. 250) as well as the excess of multiple myeloma cases observed by Decoufle et al. (1983, Ex. No. 128-30; 1984, Ex. No. 159-22) among a cohort of workers exposed to benzene in a chemical plant, the excess incidence of multiple myeloma cases observed by Shottenfeld et al. (Ex. 128-6) among petrochemical workers, and the excess of deaths due to multiple myeloma observed by Wong among benzene exposed chemical workers (Ex. No. 151A).

The mean duration of exposure for the Bond update of the Ott cohort was only 7 years, with half of the employees exposed for 2.6 years or less. OSHA has estimated the average exposure to benzene for the entire Dow cohort to be 5.5 ppm (Ex. No. 252A-19). Thus, this study demonstrates a significant excess of mortality from leukemia as well as from other diseases of the blood and blood-forming tissues as a result of average benzene exposures of about 5 ppm.

Robert Rinsky of NIOSH (Ex. No. 256) reviewed the update by Bond et al. In his comments, he pointed out that:

> four of the five leukemia cases (or three of the four if you do not count the pneumonia death) had cumulative exposures far less than one would receive under the current OSHA PEL of 10 ppm over a 40 year working career (400 ppm-years). Case 1, had only 54 ppm-years; case 2 had 1.5 ppm-years; case 3 had 25.4 ppm-years; case 5 had 28.5 ppm-years. Only Case 4 had a cumulative exposure greater than that which would be allowed with a PEL of 2 ppm TWA. It would be difficult for any trend to be seen under such fine stratification. For this reason, if the objective is to evaluate a dose/response relationship, it would be more desirable to have conducted analyses using continuous exposure data rather than categorical data. I believe that the observation of the other hematopoietic diseases (specifically the multiple myeloma and the myelofibrosis) is very important * * * Multiple myeloma is and has been consistently associated with benzene exposure.

In a post-hearing statement submitted to OSHA by the Chemical Manufacturers Association, G.G. Bond stated, "I do not believe it is appropriate to interpret the Dow Update as demonstrating a significant increase in deaths from non-malignant blood abnormalities among workers exposed to low levels of benzene" (Ex. No. 242, Appendix 1). OSHA concludes that the study does demonstrate a significant excess of mortality from these diseases, using a one-sided Fisher Exact Test. OSHA concludes that this test is more appropriate than the two-sided test used by the authors (Ex. No. 252A-19).

Bond also argued that arsenic exposure may have been a cause of the leukemia and non-malignant blood disease deaths. There is, however, relatively little evidence in the many arsenic studies indicating that arsenic is associated with leukemia. Bond refers to an earlier study of a cohort of Dow workers exposed to arsenicals (Ott et al., Arch. Environ. Health 29:205-55, 1974). However, OSHA notes that in that study, the increased risk among these arsenical exposed workers was due largely to four cases of Hodgkins disease out of the six total lymphopoietic cancers (with no leukemias observed). Furthermore, the report of this study of arsenic exposed workers does not indicate any increase in the risk of aplastic anemia.

OSHA concludes that this study represents direct observation of a leukemogenic risk from low level benzene exposure. The average benzene exposure of the group was low and exposures of the employees who died from leukemia were low. Only one had an average exposure greater than 55 ppm years (5 ppm for 11 years).

Decoufle et al. (1983, Ex. No. 128-30) reported on an historical cohort mortality study of 259 male employees employed from January 1, 1947 through December 31, 1980 at a chemical plant where benzene had been used in large quantities. Followed to December 31, 1977, four deaths from lymphoreticular cancers had occurred when 1.1 would have been expected based on the national rate, for a relative risk of 3.7 (SMR=364). Three of the deaths were due to leukemia as compared to 0.4 expected, resulting in a relative risk of 6.8. One of the leukemia deaths had initiated treatment for multiple myeloma 2 years prior to his development of leukemia. The authors did not present information on benzene exposure levels for these workers.

The expected number of deaths from multiple myeloma, polycythemia-vera, and other neoplasms of lymphoid tissue combined which was not presented in the published study was estimated by the authors to be 0.23 (Decoulfe, 1984, Ex. No. 159-22). The two cases of multiple myeloma observed in the study plus previous reports of multiple myeloma associated with benzene exposure suggested to the authors an etiologic role for benzene in the pathologies of tumors of B-cell lineage (multiple myeloma and chronic lymphatic leukemia. Evidence that benzene plays a role in alterations of B-cell populations and in immunosuppression has also been obtained from experimental studies of animals exposed to benzene.

An historical prospective mortality study was conducted by Wong et al. (1983) for the Chemical Manufacturers Association (CMA) (Ex. No. 151-A). The mortality experience of 4602 male chemical workers from seven plants who were occupationally exposed to benzene for at least 6 months between 1946 and 1975 was compared with that of 3074 chemical workers from the same or similar plants who had no known occupational exposure to benzene. Vital status was followed through December 31, 1977. Death certificates were obtained for 1013 (97.8%) of the 1036 deceased employees. Those lost to follow-up were included in the analysis only until the last date of contact and their mortality experience was assumed to be similar to the rest of the cohort.

Exposure to benzene was divided into continuous (with some intermittent) exposure (3536 men) and intermittent or casual exposure (1066 men). Continuous exposure was divided into 4 categories of 8-hour TWAs and 3 categories of peak exposures:

8-hour TWA

Low	<1 ppm
Medium	1-10 ppm
High	11-50 ppm
Very High	>50 ppm

Peak

Low	<25 ppm
Medium	25-100 ppm
High	>100 ppm

Intermittent exposure was characterized by peaks only. Each job was divided into 34 uniform tasks and the amount of time spent at each task was determined. Benzene exposure for each task was based on available industrial hygiene measurements and production and process changes. These were summed for each job. Industrial hygiene data for some plants were limited prior to 1970. Two plants (6 and 7) did not use the uniform task approach and exposures were estimated by supervisors or an industrial hygienist.

The standardized mortality ratio (SMR) was used to compare cause-specific mortality for both those exposed and unexposed to benzene with the general U.S. population. Expected values were based on U.S. national age-cause-race-specific mortality rates for 5-year time periods from 1946-1977. For some site-specific cancers that appeared to be in excess among the benzene exposed cohort, further analyses were conducted contrasting observed deaths in the exposed group with observed deaths among workers at the same plants who were not exposed to benzene. The Mantel-Haenszel chi-

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square and relative risks were used for these comparisons.

Age and race adjusted Mantel-Haenszel chi-squares and relative risks, for all lymphatic and hematopoietic cancers combined, indicated a significantly increased risk for benzene exposed (continuous and intermittent) white males (RR=4.66, p=0.03) when compared to the non-exposed workers. This excess was primarily due to seven leukemia deaths observed in the exposed group and none observed in the nonexposed group. When only continuously benzene exposed workers were compared with the nonexposed group, the excess of lymphopoietic cancer was significant for white males and all males, respectively (RR=5.3, p=0.02, RR=3.2, p=0.04). None of the seven leukemia deaths were of the acute myelogenous cell type. Two were chronic myeloid leukemia, two were chronic lymphatic leukemia, and one each was from unspecified lymphatic leukemia, acute lymphatic leukemia, and acute other unspecified leukemia. The remaining lymphatic and hematopoietic cancer deaths in benzene exposed workers were due to multiple myeloma (3), reticulum cell sarcoma (3), Hodgkin's disease (2), lymphosarcoma (1), and other lymphoid tissue neoplasms (3).

Of the 3 deaths from multiple myeloma observed among the benzene exposed workers, 2 were identified among the intermittent exposure group as compared to 0.56 expected (RR=3.8) based on U.S. rates. Deaths from multiple myeloma were not observed among the non-benzene exposed workers.

Analysis by length of exposure indicated to the authors that it was not a particularly sensitive parameter for quantification of either leukemia or lymphopoietic cancer mortality risk. However, when the data were analyzed by cumulative exposure, statistically significant dose-response relationships were detected for leukemia as well as for the broader category of all lymphopoietic cancer. (Rinsky et al. (1986, Ex. No. 250) also have found that cumulative exposure is the best predictor of leukemia risk.) Wong et al. found that for those with less than 180 ppm-months of exposure, a 2-fold risk of all lympho-hematopoietic cancers was observed, whereas for those with more than 720 ppm-months of benzene exposure, a 4-fold relative risk of all lymphatic and hematopoietic cancers combined was observed when compared to the mortality experience of non-benzene exposed employees. The Mantel-Haenszel chi-square was significant for an upward trend analysis for all lymphohematopoietic cancers (p=0.02) and for leukemia (p=0.01) and of borderline significance (p=0.057) for non-Hodgkin's lymphopoietic cancer.

Analyses were also performed to determine the relationship between peak exposure to benzene, i.e., maximum peak below 25 ppm, or between 25–100 ppm, or about 100 ppm, and relative risk. No significant peak exposure-response relationship was observed. These findings suggest that a cumulative dose concept may be better than a maximum peak exposure concept when trying to determine dose-response relationships. It should be noted, however, that those experiencing peak exposures below 25 ppm had a relative risk of 3.4 while those subjected to peaks exceeding 100 ppm had a relative risk of 3.1. Thus, lack of a peak exposure-response relationship in the study may be the reflection of a high relative risk among those experiencing relatively lower peak benzene exposures.

As a result of the analyses, Wong et al. concluded that there was a significant association between occupational exposure to benzene and leukemia, all lymphopoietic cancers, as well as non-Hodgkin's lymphopoietic cancer.

It has been suggested that the seven deaths from leukemia observed in the study by Wong and his associates (1983, Ex. No. 151–A) do not really represent an excess, the relative risk being inflated because of a deficit of deaths in the comparison group. However, the comparison group is the most appropriate group one can compare, a group of workers at the same plants, differing only in not having benzene exposure. It is a better comparison group than the general population because it has clearly more similar environmental, socioeconomic and other characteristics. The general population also includes sick people (workers are a healthy group overall) which tends to minimize excess risk. Wong et al. have made it clear in their report that "the overall SMRs for the occupationally exposed groups and the comparison group were not dissimilar (86.6 vs. 75.2)" (Ex. 151–A, p. 66). As expected, both groups overall were healthier than the general population. Most important, the clear dose-response demonstrates a strong relationship between benzene exposure and leukemia in this study. This relationship is confirmed by many other studies.

Several individuals commented on the CMA study conducted by Wong et al. (Ex. No. 151A). Drs. MacMahon and Enterline were asked by CMA and Drs. Lilienfeld and Rockette were asked by Dr. Wong to comment on an earlier draft of the report of this study (Ex. No. 151A–4, 3, 1, 2), and many of these comments were addressed in the final report. Drs. MacMahon and Enterline also commented on the final report at the request of CMA (Ex. No. 201–33, Appendix B; review cited by Wong in Ex. No. 235). Dr. Wong responded to the comments of these and other reviewers in his testimony for the OSHA hearing (Ex. No. 235). The major comments of these reviewers and Dr. Wong's response are summarized below.

In response to Dr. MacMahon's contention that analyses of leukemia and lymphatic cancers together might be inappropriate. Dr. Wong replied that a good deal of overlap occurs, not only in diagnoses and through changes in nomenclature, but through transitions from one of these cancers to another. He cites examples from the medical literature of transitions from lymphoma or multiple myeloma to leukemia, a leukemic phase in non-Hodgkin's lymphomas, or a leukemic transformation of lymphoid cells in lymphoma. Dr. Wong cited the views of hematologists that certain lymphomas and leukemias "simply represent different clinical expressions of the same neoplastic process" (Berard et al. 1976) and that lymphoma and lymphoblastic leukemia "simply seem to be different initial manifestations of a single neoplastic disorder" (Jaffee and Berard, 1978). Furthermore, Dr. Wong points out that recent research indicates that there are hemopoietic stem cells which have the capacity to develop into different cell lines and that transformation events at an early multi-potential stem cell level is indicated by the demonstration by Bakhshi et al. (1983) that "the major clone in chronic myelocytic leukemia involved cells capable of lymphocyte, granulocyte and erythrocyte differentiations." Based on these considerations, Wong et al. considered it appropriate to combine lymphoma and leukemia for some of the analyses.

Dr. MacMahon and some other reviewers commented about the lack of leukemia deaths in the non-exposed group, suggesting it might indicate problems with the data collection. Dr. Wong responded that the data had been carefully gathered and checked. Participating companies collected the data according to a common protocol and supplied the data to Dr. Wong and his colleagues at Environmental Health Associates. Data audits included verification of completeness of cohort and of coding accuracy. Dr. MacMahon

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found these checks to be satisfactory. Furthermore, 95% completeness of follow-up was required for each plant. Thus, Dr. Wong stated, "although questions could be raised regarding the validity of the data, no obvious problems could be detected through our extensive data audits" (Ex. No. 235, p. 5).

Dr. Wong pointed out that both the exposed and comparison groups were very close in characteristics. The comparison group was slightly younger, had slightly shorter length of employment, and percentage of missing death certificates was similar. According to Dr. Wong, all of the analyses were age-adjusted so a minor age difference should not be important. The impact of a difference of two years in average length of employment was not clear to Dr. Wong, and some bias might have been introduced, particularly if one or more of the 14 deaths without death certificates in the comparison group were due to leukemia (Ex. No. 235, p. 6). If this were so, "then we would have overestimated the risk of the exposed group when we use the nonexposed group as comparison. On the other hand, some the (9) unobtainable death certificates in the exposed group could have been leukemia as well. So it goes both ways . . . Then the risk would be even higher" (Tr. 4/2/86, p. 107).

Dr. MacMahon suggested that cancer in general tends to have a less marked "healthy worker effect" than other causes of death (Ex. No. 151A–4). Dr. Wong reviewed several studies of industrial cohorts and found that this generalization did not hold: some groups of workers including some subgroups at petroleum refineries had been observed to have deficits in leukemia mortality or in overall lymphopoietic cancer mortality. Dr. Wong concluded from his review of these other studies that similar deficits (to that in his unexposed comparison group) have been reported by other investigators, raising the question of whether internal or external comparison groups are more appropriate. They both appear to have advantages and disadvantages for epidemiologic studies.

Dr. Wong compared SMRs for a number of diseases for the comparison and exposed groups (Ex. No. 151A, Table 24) and found that both groups "were similarly healthy with regard to a large number of diseases," and "there was no obvious reason to suspect that the comparison group was any different from the exposed group." (Ex. No. 235, p. 6). With regard to selection related to which of the seven plants an employee was from, Dr. Wong found it "unlikely that some unrecognized bias could affect the comparison group and not the exposed group to a similar extent for each and every plant." (p. 7) Dr. MacMahon had recommended a plant specific analysis in his comments on the earlier draft, as had Dr. Enterline. A plant-adjusted analysis was done on a preliminary data set. The results were very similar to those without plant-adjustment. "In the final data set, at CMA's request, no plant adjustment was made" (Ex. No. 235, p. 7).

At the hearings, the American Petroleum Institute questioned Dr. Wong about the possibility that the unexposed comparison group was predominantly from 2 other plants than the one from which much of the benzene exposed group was drawn, and thus may have experienced exposures to different other chemicals than the benzene exposed group. The API's concern was the chemicals other than benzene may have been responsible for the differences in mortality between exposed and unexposed groups. Dr. Wong replied that in order to examine this possibility, comparisons were made between benzene exposed and unexposed employees within each plant, for a "plant-adjusted" analysis. No differences were found between the results of this analysis and an analysis without such an adjustment for plant. The investigators concluded that differences between plants did not confound the differences between exposed and unexposed groups (Tr. 4/2/86, pp. 101–103). The study was a proper comparison between benzene exposed and non-exposed employees, and other chemicals had not confounded the results.

Dr. MacMahon argued that he did not believe the dose-response relationship to be impressive. Dr. Wong replied that even though it was not impressive to Dr. MacMahon, "the trend in all lymphatic and hematopoietic cancer was statistically significant * * *. There was still a positive trend, even after the comparison group was removed (SMR=91.3, 146.8 and 175.2 by cumulative exposure; Table 37). My opinion is that a dose-response relationship for all lymphatic and hematopoietic cancer has been demonstrated" (p.7).

Finally, in response to Dr. MacMahon's comment that Dr. Wong and his associates had done too thorough an analysis, Dr. Wong pointed out that "All the analyses done were specified in our proposal to CMA prior to the start of the project, which were accepted by CMA and made part of the subsequent contract. It should also be pointed out that Dr. Enterline, the second CMA reviewer, commented that more analyses should be done * * *" (p. 7). These extra samples were not done because they would have involved further reductions in sample size.

Dr. Philip Enterline found the data on cumulative benzene exposure (Table 37) to be the most impressive evidence in favor of a relationship between benzene exposure and lymphatic and hematopoietic cancer.

Dr. Lilienfeld suggested adding 0.5 leukemia death to the comparison group so the relative risks could be calculated. Dr. Rockette, however, felt that this procedure might result in unacceptable bias.

Mr. Rinsky of NIOSH suggested that the latency for the cohort may have been too short, that is, the time available between first benzene exposure and the end of study follow-up dates for observation of deaths due to leukemia was too short. Dr. Wong replied that 67% of the exposed cohort had a latency longer than 17 years which he assumed was quite an adequate latency for leukemia.

Dr. Kenneth Rothman, a consultant to Texaco, Inc., commented that bias was introduced by "unsupervised data collection" by the participating companies. Dr Wong disagreed that data collection was unsupervised: "Many of the individuals at the companies responsible for data collection are professional epidemiologists" (Ex. No. 235, p. 11). Dr Rothman also commented that SMRs should not be used when comparing two groups. Dr. Wong replied that, in order to avoid a problem of comparing SMRs when age distributions of the group being studied are very dissimilar, "the age distributions were examined thoroughly in the study and found to be similar. In our study, we used the same standard population (U.S.), which should further minimize any problems associated with comparing SMRs. Furthermore, direct comparisons based on the Mantel-Haenszel chi-square were also made" (p. 11).

In his concluding remarks Dr. Wong stated.

> I believe that I have responded to all the major comments on the study in this document. It is my opinion that none of the comments would detract or invalidate the major conclusion of the study. * * * the study has demonstrated that chemical workers occupationally exposed to benzene experienced significant mortality excess from leukemia, as well as the broader category of all lymphatic and hematopoietic cancer, when compared to chemical workers who were not occupationally exposed to benzene

. . . . The data further show statistically significant dose-response relationships between cumulative benzene exposure and excess mortality from leukemia and the broader category of all lymphatic and hematopoietic cancer (Ex. No. 235, p. 12).

OSHA agrees with these conclusions.

Studies of refinery and petrochemical workers. Several epidemiological studies of refinery workers have been reported since 1977. It should be noted that several of these were studies of all employees or hourly employees at a facility, not just of benzene exposed employees. Consequently, any excess risk of leukemia would be diluted and possibly not identified because many of the employees studies would not have been exposed to benzene over background. The details of some of the studies which have been discussed in the proposal (50 FR 50520–50524) have not been repeated here.

Thomas et al. (1982, Ex. No. 144–71) studied the proportional mortality for 2,509 active and retired members of the Oil, Chemical and Atomic Workers International Union (OCAW) who worked at three oil refineries in the Beaumont-Port Arthur, Texas area for Texaco, Mobil and Gulf Oil. With data for the three refineries combined, deaths due to leukemia (PMR=1.83), multiple myeloma (PMR=1.96), Hodgkin's disease (PMR=1.34), and non-Hodgkin's lymphoma (PMR=1.32) were elevated, especially among retired workers. Deaths from cancers of the brain (PMR=2.21), prostate (PMR=1.38), stomach (PMR=1.52), pancreas (PMR=1.42) and circulatory disease (PMR=1.04) were significantly elevated.

Thomas et al. (1984, Ex. No. 159–84) followed this cohort mortality study with a case-control study to examine work histories of cases for evidence of any unusual distributions of cause-specific mortality by work category. The relative risk (odds ratio) of leukemia was elevated among persons exposed to two job categories: treating and boilermaking. The risk of leukemia increased with increasing duration of employment. Stomach cancer risk was elevated among maintenance workers and workers exposed to lubricating oils and paraffin wax processing. No strong associations for brain tumor risk were seen with any work category. In comparisons with pooled controls, no unusual distributions with work category were noted for the cases of multiple myeloma, Hodgkin's disease, or non-Hodgkin's lymphoma. For this study the number of cases of each cancer type was small; consequently the ability to detect excess risk was low unless the actual risk was very high. The authors stated several limitations about the ability to associate specific cancers with specific chemicals because of changes in job classifications over time, lack of sensitivity and specificity of chemical exposures associated with job categories, and job mobility resulting in study subjects being classified as exposed to multiple work categories.

Wen et al. (1983, Ex. No. 159–100) studied male hourly and salaried workers employed for any length of time on any job at a refinery in Port Arthur, Texas, between January 1937 and January 1978. Thirty deaths from leukemia were observed among male hourly workers employed for one year or more, whereas 21.3 would have been expected. Using the Poisson distribution in a one-tailed test of significance, a statistically significant excess of leukemia is indicated.

The study by Wen et al. was comprised of all Gulf employees and included many non-benzene exposed persons in the population at risk, such as clerical and managerial employees. Because Wen et al. did not identify the population at risk of exposure to the refinery process, the SMR's might have been diluted.

Theriault and Goulet (1979, Ex. No. 159–81A) reported the results of a mortality study of 1205 men who had worked at an oil refinery in Quebec, not necessarily exposed to benzene, for more than 5 years between 1928 and 1975. Sixteen percent (190) were lost to follow-up, a relatively high amount. An increase in deaths due to leukemia and lymphoma (SMR=127) was observed among these workers when compared with the number expected among the Quebec population, although this excess was not statistically significant.

Hanis et al. (1979, Ex. No. 159–34A) studied the risk of mortality from cancer among 15,032 men who were active employees or annuitants of Imperial Oil Limited during 1964 to 1973. 865 employees with 5 to 15 years of service were lost to follow-up. 6,681 short-term employees with less than 5 years of employment were excluded from the study population because it was not considered practical to trace these employees. Information on job title, function, and location was used to classify workers as to exposure, moderate exposure or nonexposure to petroleum or its products, but not specifically to benzene, or as refinery/non-refinery workers. (Some petroleum contains benzene and some does not.) Mortality rates for cancers of the lymphatic and hematopoietic system were increased among those moderately exposed employees as compared with nonexposed (RR=1.88) but not among those exposed every day to petroleum or its products. No analysis was done specifically for leukemia deaths in this cohort.

Hanis et al. (1982, Ex. No. 159–34B) examined the mortality experience of 8,666 employees and retirees of Exxon's Baton Rouge, Louisiana refinery and chemical plant who worked at least one month between 1970 and 1977. Among these employees, there were 1,199 known deaths and 835 persons (9.6% of the cohort) were lost to follow-up. Mortality due to all causes was less than expected when compared with age, gender, race, and calendar-year specific U.S. death rates. Although not statistically significant, increases were observed for deaths due to diseases of the blood and blood forming organs (SMR=222), all lymphopoietic cancers (SMR=109), lymphoreticular sarcoma (SMR=119), and several other cancer sites.

In a preliminary report of a prospective study of the morbidity and mortality of petroleum industry employees in the U.S., Schottenfield et al. (1981, Ex. No. 128–26) observed statistically significant increases in the incidence of acute and chronic lymphocytic leukemias among refinery workers, of multiple myeloma among petrochemical workers, and of cutaneous melanoma among workers in the Middle Atlantic region of the U.S. Expected values were derived from U.S. age-specific cancer incidence rates from the Surveillance, Epidemiology, and End Results (SEER) program of the National Cancer Institute for 1977. Seven cases of acute and chronic lymphocytic leukemias were observed among refinery workers compared with 2.6 expected for a standardized incidence ratio (SIR) of 274. Nonlymphocytic leukemias were increased in petrochemical and refinery workers (SIR=113) but not significantly. Multiple myeloma was elevated significantly among the petrochemical workers (SIR=552). The authors stated that these results should be viewed as preliminary because the period of observation was quite short, the number of older workers included in the analysis was limited, and the degree of underreporting of mortality was unknown. In other words, the observed risks may have been underestimated.

OSHA believes that the evidence for an association between benzene exposure and multiple myeloma continues to be replicated. Multiple myeloma has been observed in several cohorts of workers potentially exposed to benzene (Rinsky et al., 1986, Bond et al., 1986, Decoufle et al., 1983, Wong et

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al., 1983, Thomas et al., 1982. Schottenfield et al., 1981).

Rinsky et al. (Ex. No. 250A) demonstrated a significant excess of deaths from multiple myeloma among their cohort of workers exposed to benzene. Wong et al. (Ex. No. 235) and Decoufle et al. (Ex. No. 128–30) also commented on elevated risk of multiple myeloma in their studies of benzene exposed workers. While the relative risks of multiple myeloma were elevated, the excesses were not statistically significant because the number of observations were small. Decoufle suggested a link between benzene exposure and multiple myeloma because of his study findings and the findings of McMichael et al. (1975, Ex. No. 128–18) of increased risk of chronic lymphatic leukemia among rubber workers exposed to organic solvents (containing benzene). Because multiple myeloma and chronic lymphatic leukemia are disorders of B-lymphocyte lineage, Decoufle concluded that low level organic solvent exposure may induce B-cell neoplasms through a chronic immunosuppressive mechanism.

The study by Bond (Ex. No. 201–28) identified one multiple myeloma death. It occurred among workers who were employed in the same area of the facility where a death from myelofibrosis (also related to benzene exposure) occurred and where the signficant excess of leukemia was observed. Thus, the observations of Wong, Decoufle and Bond support the findings by Rinsky of an excess risk of multiple myeloma related to benzene exposure.

In the four cohort studies of workers exposed specifically to benzene (Rinsky, Bond, Decoufle and Wong), the ratio of leukemia to multiple myeloma is 22:10 or 0.45. If multiple myeloma is included, the cancer risk of workers exposed to benzene would be increased by an estimated 45%. OSHA did not include death from multiple myeloma in its estimates of cancer risk related to benzene exposure. The lack of inclusion of these data gives the Agency further confidence that the projected cancer risks (based on leukemia only) would be unlikely to overestimate the risk of total cancer among workers exposed to benzene.

Rushton and Alderson (1981, Ex. No. 159–69) reported the results of a case-control study of leukemia deaths among men employed at 8 oil refineries in the United Kingdom. Two sets of controls were selected from the total refinery population: one was matched with cases by refinery and year of birth, the other was matched by refinery, year of birth and length of service. Job histories obtained from refinery personnel records were used to categorize each person's benzene exposure as low, medium, or high, and the potential benzene exposure of cases was compared with that of controls. Although no overall excess of deaths from leukemia was found when compared with expected numbers based on national rates, the risk of leukemia for men with medium or high benzene exposure was significantly greater ($p=0.05$) than the risk for men with low benzene exposure.

Devine and Barron (1983) reported the results of a case-control study (Ex. No. 142–32B) within a cohort mortality study (Ex. No. 142–32A) of white male employees at a Texaco refining, petrochemical or research facility. Among 19,077 white males, slightly elevated SMRs were observed for leukemia (SMR=113), cancer of other lymphatic tissue (SMR=111) and other sites. The case-control study demonstrated significantly elevated rate ratios for leukemia deaths among workers in utilities (RR=4.6); and among pipefitters (RR=2.7) and utilities controlmen (RR=5.1). A significantly elevated rate ratio for other lymphatic cancer was found among persons employed in fluid catalytic cracking units (RR=3.1). It is highly likely that pipefitters and utility personnel have the relatively highest intermittent exposures to benzene.

In 1983, Shell Oil Company reported the results of an evaluation of mortality among active employees and retirees from two manufacturing locations (Ex. No. 142–13–A). Deaths occurred between January 1, 1973 and December 31, 1982. At the Deer Park, Texas Refinery facility, 6 deaths from all forms of leukemia were noted among refinery workers as compared to 2.60 expected, SMR=230. Three acute myelogenous leukemia deaths were observed versus about 0.8 expected, SMR=375. These results were of borderline statistical significance. The study of mortality at both of these facilities examined causes of death for "active" employees and retirees and excluded "terminees" who were not followed after termination of employment at Shell. Thus, the actual number of cases of leukemia related to exposure in this occupational setting may have been greater.

At the Wood River, Illinois Refinery, a significant excess of deaths due to leukemia was observed (14 observed; 6.4 expected) resulting in a SMR of 219 for all leukemia. Eight deaths were observed from acute myelogenous leukemia (AML) whereas 2.0 were expected, resulting in a SMR of 400. On the basis of these observations, an epidemiologic consultant to the company concluded:

> There is no reasonable possibility that the data are the result of any error or errors or random variations of consequence; nor is it likely that these findings can be attributed to confounding by a non-occupational cause of AML * * *. The specific cause of the excess of AML at Wood River is unknown. However, benzene is an established cause of AML, and there is anecdotal evidence that in years past benzene was present in the ambient air at Wood River at levels that exceed the current standard. Thus, benzene is the most likely cause of the excesses seen (Ex. No. 142–13–A).

Further analysis by job category for the 14 leukemia deaths identified among the 3,976 white males included in the Wood River Refinery was submitted to OSHA in May 1984 (Ex. No. 160–12). Of 14 leukemia deaths identified (versus 6.6 expected) in the study, 3 had worked in laboratory jobs where benzene was used, 5 spent most of their careers as maintenance workers, but it was not known if they were assigned to benzene units, while 6 were categorized as probably having no benzene exposure above refinery background levels.

In December 1984, the results of a case control study of the 14 leukemia deaths identified between 1973–1982 at the Wood River Refinery were submitted to OSHA (Ex. No. 165). A statistically significant relative risk of 9.5 for acute myelogenous leukemia was observed for engineering field foremen. Relative risks for leukemia for other department/job categories ranged between 1.5 and 4.6, but were not statistically significant. In the authors' opinion, the former observation met all criteria for a positive result. However, they felt its interpretation remained unclear. As a result of the statistical analyses presented, the authors concluded that the study produced no distinctly positive result and that the reason for the excess leukemia among the refinery workers remained unexplained. The authors raised several possible explanations for what they viewed as a failure to statistically associate the leukemia with any specific chemical. Among the limitations listed were small sample size, the jobs and departments described did not specify distinct substance exposures, and the substance of greatest interest to the authors, benzene, is volatile and could have drifted from location to location causing ostensibly unexposed jobs actually to entail exposure.

Dr. David Savitz of the Department of Epidemiology of the University of North Carolina School of Public Health evaluated and commented on the

epidemiologic studies concerning occupational benzene exposure and lymphatic and hematopoietic cancers, especially leukemia, with special emphasis on the studies of cancer risks among oil refinery workers (Ex. No. 222). Dr. Savitz updated a previous review of the literature (Savitz and Moure, 1984, Ex. No. 252A–17–69) to include studies reported through 1985. Regarding the studies of refinery workers, he concluded that "several studies . . . show notably elevated rates of mortality from lymphatic and hematopoietic cancers, . . . convincingly linked to benzene exposure (Ex. No. 222, p. 2). In hearing testimony he summarized his findings:

A number of the studies of refinery workers have indicated an increased risk of lymphatic and hematopoietic cancers. The studies most convincing of excess risk are: (1) Rushton and Alderson's (1981b) case-control study indicating risk ratios of 2.0–2.3 for benzene exposure among refinery workers with leukemia; (2) Schottenfeld et al.'s (1981) data on excess incidence of several lymphatic and hematopoietic cancers, including leukemia (standardized incidence ratio of 145); (3) Thomas et al.'s (1982) elevated PMRs for lymphatic and hematopoietic cancers and specifically for leukemias (PMR=189); (4) Tabershaw, Occupational Medicine Associates (1980) data on increased leukemia (SMR=322) in the 10% cohort sample; (5) Morgan and Wong's (1984) leukemia excess (SMR=173); (6) McCraw et al.'s (1985) observation of a 4-fold excess of acute myelogenous leukemia; and (7) Decoufle et al.'s (1983) report of a 4-fold excess of lymphatic and hematopoietic cancers among oil refinery and chemical plant workers exposed to the benzene. Other studies of refinery workers have provided data which does not indicate increased risk of lymphatic and hematopoietic cancers; most of these made little or no attempt to pinpoint persons exposed to benzene, so that the results may accurately reflect the overall experience of refinery employees but do not specifically address the effects of benzene.

Even though some of the refinery studies have limitations in exposure characterization, they provide presumptive evidence that benzene operates as a leukemogen in this workforce. The more direct evidence regarding benzene's leukemogenic properties as demonstrated by studies of benzene-exposed cohorts per se and case series (Aksoy et al., 1974; Vigliani & Saita, 1964) provides the other critical line of evidence to indicate that benzene in particular is the agent which is responsible. The complexity of the refinery environment leaves open the possibility that some other solvent or refinery product is also a leukemogen, but no other agent has the degree of laboratory or epidemiologic data which exists for benzene to support this possibility (Ex. No. 222, pp. 13–14).

Neal King, representing CMA, questioned Dr. Savitz as to whether he was just speculating that the methodological difficulties in the . . . refinery studies have masked an increase in cancer. Dr. Savitz replied that, "* * * based on epidemiologic principles * * *" and "the known inaccuracies that would occur, one can predict with a high degree of confidence which direction the error would tend to be in, and for a number of those problems which I have cited . . . , the direction of that error is towards a failure to find associations with benzene that may be present. So it is * * * speculation with a rather firm methodologic basis" (Tr. 3/24/86, p. 57).

It is OSHA's opinion that the elevated risks of leukemia observed among the studies of refinery workers are most likely the result of exposure to benzene, the only substance found in refineries that is known to cause leukemia. Some studies of refinery workers did not demonstrate elevated risks of leukemia. In these situations, the studies suffered from methodologic deficiencies such as, but not limited to, dilution of results through inclusion in the study of those individuals not exposed to benzene (the large majority) along with those exposed to benzene. For some of the studies of refinery workers where an elevated risk of leukemia was not observed overall, nested case-control studies of leukemia deaths demonstrated significant associations with benzene exposure or with jobs likely to experience a relatively greater amount of benzene exposure.

Some case-control studies were not able to link leukemia deaths among refinery workers to benzene exposure. The authors of these studies, however, gave several possible explanations for why an association may not have been detected. Consequently, study results of refinery workers that do not demonstrate an increased risk of leukemia do not challenge the causal connection between low dose benzene exposure and leukemia.

Epidemiologic studies demonstrate that benzene exposure can cause leukemia, multiple myeloma and perhaps other hemopoietic and lymphatic cancers. Aplastic anemia and several other blood diseases are also known to be caused by benzene exposure. Observations related to the above findings have been demonstrated by a number of high quality epidemiologic studies and case reports, such as those by Rinsky, Wong, Ott, Decoufle, Infante, Aksoy, Vigliani and others. The more ambiguous studies had serious methodologic weaknesses or were not specific studies of benzene exposed workers but rather of industrial workers, some of whom may have been exposed to benzene. Consequently, for these studies it was difficult to evaluate the effect of benzene exposure on the study populations. The conclusion that leukemia is caused by benzene exposure is agreed upon by most scientists and was not seriously contested during this rulemaking proceeding.

C. Cytogenetic Effects in Humans

Cytogenetic changes indicate an alteration in the genetic material (DNA) of a cell. An increasing amount of evidence indicates that latent diseases such as cancer, birth defects, and genetic disease may be initiated by alterations in cellular DNA (Bloom et al., 1981, Ex. No. 159–12). Thus, cytogenetic studies analyze alterations in the structure or number of chromosomes, called chromosomal aberrations, and exchanges of segments between the two chromatids or arms of a chromosome, called sister chromatid exchanges (SCE). These changes in the chromosomes indicate that the DNA or genetic material of the cell has been altered by some geotoxic agent.

Induced cytogenetic changes in lymphocytes have been shown to be a sensitive indicator of low level exposure, brought about by such factors as occupational exposure to radon daughters and exposure to ionizing radiation. Although such undesirable changes cannot be used to predict specific health effects in an individual, they do give an estimate of the magnitude of an exposure that could increase the risk of disease in the exposed population. Consequently, as stated by an expert panel on cytogenetics, "* * * cytogenetic study of both chromosomal aberrations and SCEs has a clear place in the evaluation of human populations exposed to known or suspected mutagens * * *. Furthermore, many, if not most, agents causing aberrations, or clastogens, are also carcinogens, at least in animals" (Bloom et al., 1981, Ex. No. 159–12). In addition to benzene, several substances known to cause chromosomal aberrations in humans are also known to cause cancer in humans, i.e., vinyl chloride, radon daughters, ionizing radiation arsenic, myleran, melphalan, and chromium (IARC, Suppl. 4, 1982, Ex. No. 159–38). Moreover,

(e)vidence for the involvement of chromosomal rearrangement in human carcinogenesis also stems from the finding that the nonmalignant somatic cells of patients with one of several syndromes that predispose them to cancer have a high incidence of chromosomal rearrangement. The three best characterized of the so-called chromosomal breakage syndromes are Bloom's syndrome, Fanconi's anemia, and ataxia telangiectasia. The type of

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chromosomal rearrangement present in cells of patients with each of these syndromes (homologous exchange, nonhomologous exchange, and increased chromosomal breaks, respectively) is found in all patients with the syndrome (Yunis, 1986, p. 120, Ex. No. 252A–17–95).

Yunis (1986, Ex. No. 252A–17–95) summarizes the recent evidence regarding the mechanistic relationship between specific rearrangements of the genetic material and human cancers.

Until recently, little was known about how specific chromosome defects occur in cancer and why some people and families have a higher incidence of the disease. Now it is possible to suggest how this may occur.

Oncogenes and some very active genes of differentiated cells may be located at or near hypersensitive or fragile sites where carcinogenic agents can act and where chromosomes break and rearrange in cancer. Some of these chromosomal rearrangements may be random but provide the cell with a proliferative advantage. Others may recur preferentially and characterize a given disease (p. 117).

The initial DNA damage induced by radiation, chemicals, viruses, or unknown agents often may occur at chromosomal fragile sites. As a result, specific chromosome defects, often following breakage and rearrangement at fragile sites, may lead to monoclonal proliferation of a cell with a specific reciprocal translocation or deletion that has a proliferative advantage. In subsequent cell divisions of uncontrolled growth, random and nonrandom secondary chromosome defects (more frequently a duplication or deletion) or point mutations that represent advantageous changes, or both, are selected. Finally, in the advanced stage of cancer, gene amplification or a cascade of genomic rearrangements may generate new phenotypes and treatment resistance (p. 121).

The best understood mechanism operates in leukemias and non-Hodgkin's lymphomas in which a specific clonal structural chromosomal defect is often observed in malignant cells. This defect may be a reciprocal translocation, an inversion, or a partial deletion, each involving two precise breakpoints—one of them the likely site of a proto-oncogene that becomes deregulated as a result of a chromosomal rearrangement. . . We now suspect that some proto-oncogenes and very active genes of differentiated cells may have a hypersensitive or fragile site that facilitates such chromosomal rearrangements and may represent sites where carcinogens often attack. . . In the lymphohematopoietic malignancies, such [specific chromosomal] defects are so important to the disease process that they have made it possible to subdivide leukemias and myelodysplasias into distinct categories * * * (p 93).

Due to advances during the past ten years in the techniques for identifying structural defects in chromosomes,

[m]ore than 70 clinical types of neoplasia are now known to have one of more than 40 specific recurrent chromosomal lesions * * *. These lesions generally fall into four categories: [1] a reciprocal translocation, in which segments from two chromosomes break and exchange places; [2] a deletion, in which a piece of a chromosome breaks off and is lost; [3] a trisomy or extra copy of a chromosome; and [4] an inversion in which a segment flips over in the same chromosome * * *. A translocation is seen more often in leukemias and non-Hodgkin's lymphoma; and a deletion is found more frequently in myelodysplasia and solid tumors (Yunis, 1986, pg. 97).

Because of new techniques, it is now possible to find specific chromosomal defects in more than two thirds of patients with acute leukemia, myelodysplasia, or non-Hodgkin's lymphoma. Many carcinomas have multiple chromosomal aberrations that appear to play an important role in tumor invasiveness and resistance to chemotherapy. Yunis' analysis of leukemias and lymphomas revealed that the cytogenetic abnormality in these well-studied malignancies is shared by related disorders; the best known of these abnormalities is a translocation identified as t(9:22) (also known as the Philadelphia chromosome) found in most patients with chronic myelogenous leukemia and in some patients with either acute nonlymphocytic leukemia or acute lymphocytic leukemia. Commonly, two to five related malignancies share a primary chromosomal defect. Furthermore, at the molecular level, different activated transforming genes have been found in human pre-B, B, and mature B-cell malignancies. This observation may explain why malignancies with a shared chromosomal defect may differentiate into one or another type of related tumor. Such activated genes may be involved in the control of cell proliferation. A specific genomic rearrangement, therefore, can be seen as a crucial event that sets a stem cell toward malignancy or commits a stem cell to one or another type of cancer (Yunis, 1986. Ex. No. 252A–17–95).

The finding of recurrent chromosomal defects in so many human cancers supports the idea that chromosomal rearrangements play a crucial role in carcinogenesis. Such rearrangements also have been found to be associated with tumors induced in laboratory animals. In rodents, these rearrangements appear to be characteristic of the type of tumor and the particular compound or treatment used (Yunis, 1986, p. 119–120).

Numerous investigators have studied chromosomal aberrations in bone-marrow cells and peripheral lymphocytes from persons known to have been exposed to benzene, including patients with either a current or a past history of benzene-induced blood dyscrasias. Studies have repeatedly demonstrated significant increases in chromosomal aberrations in both bone marrow cells and in peripheral lymphocytes of workers exposed to benzene. This literature has been reviewed by IARC (1982, Ex. No. 128–8). The earlier studies demonstrated chromosomal aberrations not only in workers who had severe benzene-induced pancytopenia, but also in workers who had recovered from benzene hemopathy and in workers exposed to benzene who did not manifest overt signs of blood damage (Forni et al., 1971, Ex. No. 128–48). These individuals had been exposed to benzene levels exceeding 10 ppm as the reports indicate their benzene exposures ranged between 25 and 530 ppm.

Forni and collaborators (Forni et al., 1971a,b, Ex. Nos. 128–48, 144–93) examined two groups of workers with chronic benzene poisoning. One group included 25 subjects who had recovered from benzene hemopathy one to 18 years previously, plus four others showing acute toxicity at the time of first chromosome examination. The other group was comprised of 34 workers in a rotogravure plant who had been exposed in 1952–1953 to concentrations of 125–532 ppm benzene in air, leading to toxic effects. Lymphocytes from both groups showed significantly higher levels of chromosomal aberrations than those from age-matched controls. Follow-up cytogenetic studies indicated a tendency toward a decrease in unstable aberrations and a persistence or increase in stable aberrations (Forni et al., 1971, Ex. No. 128–48), indicating that the genetic lesions induced by benzene may persist for years after the cessation of exposure (Legator, 1986, Ex. No. 233).

The finding of significant increases in chromosomal aberrations in blood and bone marrow (Forni and Moreo, 1967, 1969, Ex. Nos. 128–46, 128–47) and in lymphocytes from clinically symptomatic subjects exposed to benzene has been confirmed in several other investigations (Hartwich et al., 1969, Ex. No. 128–51; Sellyei and Kelemen, 1971, Ex. No. 128—58; Erdogen and Aksoy, 1973, Ex. No. 128–53; Hudak and Gombosi, 1977, Ex. No. 128–54; Van den Berghe et al., 1979, Ex. No. 128–55). Forni and Moreo (1967, 1969, Ex. Nos. 128–46, 128–47) hypothesized that such aberrations are involved in the eventual development of leukemia in benzene-exposed individuals.

Tough and others (Tough and Court Brown, 1965. Ex. No. 144–136; Tough et al., 1970, Ex. No. 128–49) studied workers in three different factories who had been exposed to benzene in the atmosphere for approximately one to 25

years. The workers showed no evidence of acute benzene toxicity. Among the 38 workers who had been exposed to 25–150 ppm benzene until two to four years prior to blood sampling, the incidence of cells with unstable chromosomal aberrations was higher than was expected in the general population. Other workers exposed intermittently to approximately 12 ppm benzene for 2–26 years showed no increase in chromosomal abnormalities in their lymphocytes. The authors hesitated, however, to relate these effects to benzene exposure alone, since there was evidence that age and other environmental factors may also have been contributory.

Other studies report increased levels of chromosomal aberrations in asymptomatic workers who had been exposed to benzene (Hartwich and Schwanitz, 1972 (Ex. No. 128–52); Khan and Khan, 1973 (Ex. No. 128–56), Fredga et al., 1979 (Ex. No. 128–57)). In one study, although the rate in individual workers was at the upper limit of normal (Hartwich and Schwanitz, 1972 (Ex. No. 128–52)), the mean aberration rate of cells from nine refinery workers exposed to relatively low levels of benzene was significantly elevated when compared with that in controls. In a study of lymphocytes from 12 industrial gasworks workers exposed to benzene, a statistically significant increase in chromosomal aberrations was found (Fredga et al., 1979, Ex. No. 128–57) among 12 industrial workers exposed to benzene for several hours a day at levels between five and ten ppm, when compared to 15 control subjects.

Watanabe et al. (1980, Ex. No. 144–46) found no evidence of an increased frequency of chromosomal aberrations but reported a low frequency of sister chromatid exchange among nine female workers engaged in painting ceramics who had been exposed to 1–9 ppm for 1–20 years or in seven female workers who had been exposed to 3–50 ppm benzene for 2–12 years. However, urinary excretion of phenol was not elevated in post-shift samples when compared with pre-work samples in the same workers, indicating atmospheric exposures below 10 ppm at the time of the survey (NIOSH, 1974, Ex. No. 84B–3).

A study of Dow Chemical Company workers indicates a significant increase in chromosomal aberrations in workers whose average benzene exposures were below 10 ppm (Kilian and Daniel, 1978, Ex. No. 159–45). 52 benzene exposed workers whose average exposure was less than 10 ppm were compared with 44 pre-employment controls. Workers who had been exposed to low-level benzene for an average of 56.6 months were found to have twice the percentage of chromosomal breaks and three times more marker chromosomes than the control group. Almost twice as many benzene workers as controls had both breaks and markers (p less than 0.01).

In 1978, when DOW Chemical company released the results of its cytogenetic studies of workers exposed to benzene (Holder, 1978, Ex. No. 159–45), Dow stated, "since increased rates of chromosomal aberrations are often associated with increased risk of malignancies—including leukemias—we have cytogenetically studied a group of 52 employees exposed to benzene for one month to 26 years." The results demonstrate a significant excess of chromosomal aberrations among the benzene exposed workers as compared to controls. Average benzene exposures of these workers were initially reported as being below 10 ppm with peak exposures exceeding 100 ppm, but the frequency of peaking was unknown (Holder, 1978, Ex. No. 159–45).

In response to a request from OSHA in 1980, Dow supplied more detailed supplemental information on benzene exposures for these individuals (Docket No. H–059, Ex. No. 230X–10). The report states that sufficient data, defined as one data point per person-year experience, were available to characterize exposures for 32 of the 52 individuals in the benzene-exposed group. Personal monitoring data from 1973 to 1976 showed that average 8-hr TWA exposures ranged from less than 0.1 ppm to 7.4 ppm, with the maximum TWA observed for one job classification being 18.3 ppm. Because the job classifications that were selected for the monitoring were those where the estimated potential for benzene exposure was greatest, it is possible that the exposures for job classifications without monitoring data, such as foreman and production superintendent, were less than those measured for other job classifications. In addition, the report states that 9 of the 52 examined workers were employed in job classifications where they may have been exposed to benzene at levels of 35 ppm to 100 ppm for periods of several minutes. It is not stated, however, whether respirators were worn during these operations. There is no evidence to indicate that any of the remaining 43 workers had ever been exposed to similar peak exposures. In addition, 9 of the 52 workers had been previously employed in another ethylbenzene plant, but no exposure data were provided for that plant.

Picciano (1979, Ex. No. 144–118) further analyzed the data from the Dow study; he addressed the distribution of individuals with both chromosome breaks and markers by benzene exposure levels and compared them with data for controls. Thirty-eight exposed workers (73.1 percent) had chromosome breaks as compared to 18 nonexposed individuals (40.9 percent) with chromosome breaks. When individuals with both chromosome breaks and markers were compared, less than 3 percent of the non-exposed individuals showed changes while 27% of the workers exposed to benzene revealed such aberrations (p less than 0.001). These workers were also exposed to other aromatic hydrocarbon solvents. The degree of contact with those solvents was less than with benzene. Moreover, less than three percent of non-exposed individuals showed these aberrations in contrast to more than 20 percent of those exposed to average levels below 1 ppm, to more than 25 percent of those exposed to average benzene levels between 1–2.5 ppm, and to more than 30 percent of those exposed to levels averaging between 2.5–10 ppm. Thus, a linear dose-response relationship between chromosomal damage and benzene levels ranging between less than one ppm and 10 ppm was observed. This study demonstrates an exposure level-response for chromosomal breakage resulting from average benzene exposures below 10 ppm and perhaps below 1 ppm. Whether this damage to chromosomes is due to average low level exposure or to short-term peak exposures is not known. Dow is of the opinion that the damage may be the result of short-term peak exposures to benzene and stated "considering the peak exposure levels for the group as a whole, the results appear consistent with indications of cytogenetic effects previously reported in the literature" (Holder, 1978, Ex. No. 159–45).

Sarto and his colleagues (1984, Ex. No. 252A–17–68) performed a cytogenetic study of 22 healthy employees working in a benzene production plant. Concentrations of benzene ranged between 0.2 and 12.4 ppm. A paired T-test was used to compare aberration frequency with controls from another factory who were unexposed to benzene but were matched for age, sex, residence, and smoking habits with each benzene exposed worker. A statistically significant increase in chromosome-type aberrations (breaks, acentric fragments, and 2 dicentrics). This increase was still significant when gaps were discarded. The majority of these workers had only been working since airborne benzene

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levels in the factory were reduced in 1971 by automation of processes, so they were exposed only to low levels of benzene. Furthermore, most of the aberrations seen were unstable and would not have persisted since 1971 among those few workers employed previous to 1971.

As mentioned earlier, there is expert scientific opinion that the induction of chromosomal aberrations serves as an estimate of the magnitude of an exposure that could increase the risk of disease (Bloom et al. 1981). Thus, OSHA has concluded that the cytogenetic studies by Fredga et al. (1979, Ex. No. 128–57) and Dow Chemical Company (Holder, 1978; Picciano, 1979; Venable, 1980; Daniel, 1980; Ex. Nos. 159–45, 144–115, Docket H–059, Ex. Nos. 230X–9, 230X–10) and Sarto et al. (1984, Ex. 252A–17–68), showing increased incidence of chromosomal aberrations for workers exposed to benzene, add to the growing body of evidence that there is an elevated risk of disease associated with average benzene exposure levels at and below 10 ppm.

D. Experimental Evidence of Carcinogenicity

Since the publication of the 1978 benzene standard, new experimental results demonstrating benzene induced cancer in animals have been reported. These studies were carried out in three independent research centers: the University of Bologna, Italy, under Dr. C. Maltoni, the New York University under Dr. C.A. Snyder and the National Toxicology Program (NTP) with Dr. James Huff as project manager. All three studies found benzene to be carcinogenic in animals.

Maltoni and Scarnato (1979, Ex. No. 144–76) reported that doses of 50 and 250 mg/kg of body weight of benzene given orally to Sprague-Dawley rats 4 to 5 days weekly for 52 weeks were carcinogenic, in a dose-response manner. Benzene was found to cause Zymbal gland carcinomas, mammary carcinomas and leukemias. Among the female rats, 0/30, 2/30 and 8/22 of the control, low and high dose groups, respectively, developed Zymbal gland carcinomas. Using the Cochran-Armitage test, the positive trend was statistically significant ($p=0.001$). Using the Fisher exact test, the difference in frequency of Zymbal gland carcinomas between the control and high-dose group was also significant, $p=0.003$. Among the same groups of female rats 3/30, 4/30 and 7/32, respectively developed mammary gland carcinomas, and 1/30, 2/30 and 1/32, respectively, developed leukemias.

Male rats developed leukemias (unspecified) as follows: control (0/30), low dose (0/30) and high dose (4/33). Using the Cochran-Armitage test the positive trend was statistically significant ($p=0.008$) but the difference between the control and high dose groups was not significant using the Fisher exact test ($p=0.069$) (IARC, 1982, Ex. No. 128–8). No Zymbal gland carcinomas were observed in either the control or benzene treated male rats. In the high dose group, Maltoni and Scarnato (1979, Ex. No. 144–76) also observed two female rats with skin carcinomas and one male rat each with a hepatoma and a subcutaneous angiosarcoma. These types of tumors were not observed in the control or low dose groups.

In another study by Maltoni et al. (1982, Ex. No. 144–30), Zymbal gland carcinomas were induced in rats exposed to airborne concentrations of benzene. In these studies benzene was administered by inhalation at a concentration of 200 ppm, 4-hours daily, 5-days a week to pregnant Sprague Dawley rats from the 12th day of pregnancy up to the delivery of the offspring. The offspring were then exposed by inhalation to 200 or 300 ppm of benzene for 4 or 7 hours per day, respectively, for 5 days a week for up to 104 weeks. At 104 weeks, of the 137 male and female rats at risk, eight (5.87%) had developed Zymbal gland carcinomas as compared to 0% for the concurrent controls.

Snyder et al. (1978, Ex. No. 144–127) published a preliminary report on inhalation studies of benzene in CD–1 mice. Groups of 40 CD–1 mice were exposed for 6 hours/day, 5 days/week, for life to atmospheric concentrations of 0 (control), 100 ppm or 300 ppm benzene. Two mice in the 300 ppm benzene exposed group developed myelogenous leukemia. No leukemias were observed in the control or 100 ppm benzene exposed groups.

Snyder et al. (1980, Ex. No. 128–77) reported 8 cases of lymphoreticular neoplasm (6 thymic lymphocytic lymphomas, 1 plasmocytoma, and 1 hemocytoblastic leukemia) among 40 C–57 black mice exposed to airborne concentrations of 300 ppm benzene for 6 hours a day, 5 days a week for life. Among the control mice, two developed hemolymphoreticular neoplasms (lymphocytic lymphomas). The increase in these neoplasms among the treated mice was statistically significant ($p=0.005$).

In 1983, the National Toxicology Program (NTP) completed a 2-year chronic toxicity study of benzene in mice and rats (Ex No. 148). Male rats were administered benzene doses of 50, 100 and 200 mg/kg of body weight by oral gavage for two years. Female rats were administered 25, 50 and 100 mg/kg. Mice of both sexes were administered benzene doses of 25, 50 and 100 mg/kg. There were 50 animals per sex per treated group plus 50 animals per sex for the control group. Benzene was carcinogenic for male and female F344 rats and male and female B6C3F1 mice. Leukopenia also was induced in both sexes of mice and rats.

Because the body weights of the female and male mice throughout the experiment were approximately 32 and 42 grams respectively and their minute volumes were approximately 27 and 34 ml of air, assuming 100% absorption of benzene, the mice were given doses of benzene equivalent to an 8-hour inhalation of 18.9 ppm (low dose female mice) to 80 ppm (high dose male mice).

Because the body weights of the female and male rats were approximately 250 and 400 grams respectively and they breath either 168 ml (females) or 251 ml (males) of air per minute, their doses of benzene were equivalent to 8-hour exposures ranging from 24.2 ppm (low dose female rats) to 234 ppm (high dose male rats). This conversion does not take into consideration adjustments for differences in surface area between rodents and humans which would result in lower equivalent doses to humans and therefore higher risks.

Significantly increased incidences of neoplasms were observed at multiple sites for both sexes of mice and rats. In addition to the findings of benzene induced cancers of the Zymbal gland, oral cavity and skin in rats, six sites or types of tumors such as malignant lymphoma and lung cancer were induced in male mice while seven sites or types of tumors such as lymphoma, lung cancer, ovarian cancer, mammary (breast) cancer and liver cancer were induced by benzene in female mice. Such multiple site carcinogenic response in both sexes of two species of rodents is unusual and should be considered as further evidence of the carcinogenic potency of benzene. Further concern for the carcinogenic potency of benzene is raised in the NTP study by the observation of effects at multiple sites at the lowest dose tested in mice (equivalent to 8-hour, 19 ppm exposure to humans without correction for surface area).

NTP (Ex. No. 148) concluded the following:

Under the conditions of these studies, there was clear evidence of carcinogenicity of

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benzene for male F344/N rats, female F344/N rats, male B6C3F$_1$ mice and female B6C3F$_1$ mice. For male rats, benzene caused increased incidences of Zymbal gland carcinomas, squamous cell papillomas and squamous cell carcinomas of the oral cavity, and squamous cell papillomas and squamous cell carcinomas of the skin. For female rats, benzene caused significantly increased incidences of Zymbal gland carcinomas and squamous cell papillomas and squamous cell carcinomas of the oral cavity. For male mice, benzene caused increased incidences of Zymbal gland squamous cell carcinomas, malignant lymphomas, alveolar/bronchiolar carcinomas and alveolar/bronchiolar adenomas or carcinomas (combined), Harderian gland adenomas, squamous cell carcinomas of the preputual gland. For female mice, benzene caused increased incidences of malignant lymphomas, ovarian granulosa cell tumors, ovarian benign mixed tumors, carcinomas and carcinosarcomas of the mammary gland, alveolar/bronchiolar adenomas, and alveolar/bronchiolar carcinomas.

Tables I through IV summarize the major increases in the incidence of tumors found in the NTP study.

TABLE I.—INCIDENCE OF SELECTED TUMORS IN THE MALE F344/N RAT *

Types of tumor	Dose			
	Vehicle control (0 ppm)	50 mg/kg (57 ppm)+	100 mg/kg (117 ppm)	200 mg/kg (234 ppm)
Zymbal Gland Carcinoma	2/50 (4%)	6/50 (12%)	10/50 (20%)	17/50 (34%)
Squamous Cell Papillomas (Oral Cavity)	1/50 (2%)	6/50 (12%)	11/50 (22%)	13/50 (26%)
Squamous Cell Carcinomas (Oral Cavity)	0/50 (0%)	3/50 (6%)	5/50 (10%)	7/50 (14%)
Squamous Cell Papillomas (Skin)	0/50 (0%)	2/50 (4%)	1/50 (2%)	5/50 (10%)
Squamous Cell Carcinomas (Skin)	0/50 (0%)	5/50 (10%)	3/50 (6%)	8/50 (16%)

* NTP Study, 1983.
+ Equivalent 8-hour atmospheric exposure level for 5 days per week assuming 100% absorption.

TABLE II.—INCIDENCE OF SELECTED TUMORS IN THE FEMALE F 344/N RAT *

Types of tumor	Dose			
	Vehicle control (0 ppm)	25 mg/kg (24 ppm) +	50 mg/kg (48 ppm)	100 mg/kg (97 ppm)
Zymbal Gland Carcinomas	0/50 (0%)	5/50 (10%)	5/50 (10%)	14/50 (28%)
Squamous Cell Papillomas (Oral Cavity)	1/50 (2%)	4/50 (8%)	8/50 (16%)	5/50 (10%)
Squamous Cell Carcinomas (Oral Cavity)	0/50 (0%)	1/50 (2%)	4/50 (8%)	5/50 (10%)

* NTP Study, 1983.
+ Equivalent 8-hour atmospheric exposure level for 5 days per week assuming 100% absorption.

TABLE III.—INCIDENCE OF SELECTED TUMORS IN THE MALE B6C3F1 MOUSE *

Types of tumor	Dose			
	Vehicle control (0 ppm)	25 mg/kg (20 ppm) +	50 mg/kg (40 ppm)	100 mg/kg (80 ppm)
Zymbal Gland Squamous Cell Carcinomas	0/49 (0%)	1/48 (2%)	4/50 (8%)	21/49 (43%)
Malignant Lymphomas	4/49 (8%)	9/48 (19%)	9/50 (18%)	15/49 (31%)
Alveolar/Bronchiolar Carcinomas	5/49 (10%)	11/48 (23%)	12/50 (24%)	14/49 (29%)
Alveolar/Bronchiolar Adenomas or Carcinomas (combined)	10/49 (20%)	16/48 (33%)	19/50 (38%)	21/49 (43%)
Harderian Gland Adenomas	0/49 (0%)	9/48 (19%)	13/50 (26%)	11/49 (22%)
Squamous Cell Carcinomas (preputual gland)	0/49 (0%)	3/48 (6%)	18/50 (36%)	28/49 (57%)

* NTP Study, 1983.
+ Equivalent 8-hour atmospheric exposure level for 5 days per week assuming 100% absorption.

TABLE IV.—INCIDENCE OF SELECTED TUMORS IN THE FEMALE B6C3F1 MOUSE *

Types of tumor	Dose			
	Vehicle control (0 ppm)	25 mg/kg (19 ppm) +	50 mg/kg (38 ppm)	100 mg/kg (76 ppm)
Malignant Lymphomas	15/49 (31%)	24/25 (53%)	24/50 (48%)	19/49 (39%)
Ovarian Granulosa Cell Tumors	1/47 (2%)	1/44 (2%)	6/49 (12%)	7/48 (15%)
Ovarian Benign Mixed Tumors	0/47 (0%)	1/44 (2%)	12/49 (24%)	7/48 (15%)
Mammary Gland Carcinomas	0/49 (0%)	2/45 (4%)	5/50 (10%)	10/49 (20%)

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TABLE IV.—INCIDENCE OF SELECTED TUMORS IN THE FEMALE B6C3F1 MOUSE *—Continued

Types of tumor	Dose			
	Vehicle control (0 ppm)	25 mg/kg (19 ppm) +	50 mg/kg (38 ppm)	100 mg/kg (76 ppm)
Alveolar/Bronchiolar Adenomas	4/49 (8%)	2/42 (5%)	5/50 (10%)	9/49 (18%)
Alveolar/Bronchiolar Carcinomas	6/49 (12%)	0/42 (0%)	3/42 (7%)	6/50 (12%)

* NTP Study, 1983.
+ Equivalent 8-hour atmospheric exposure level for 5 days per week assuming 100% absorption.

At the time of the 1978 rulemaking, there was controversy on whether benzene had been clearly demonstrated to cause cancer in experimental animal studies. The studies conducted at the University of Bologna, New York University and the National Toxicology Program have clearly demonstrated that benzene is a carcinogen at multiple sites in animals through the oral and inhalation routes. CMA and API as well as the scientific reports submitted by their consultants are in agreement that benzene is a carcinogen in animals (Ex. Nos. 201–33, 204–7, 258, 260).

Dr. James Huff, the toxicologist in charge of the study, testified on the effects of benzene in the NTP animal bioassay study. He indicated that the consistency and magnitude of the responses in their studies would lead him to speculate that there may be other types of cancers as well as leukemia that one would suspect to occur in humans (Tr. 3/19/86, pp. 186–7). Dr. Huff pointed out that it is very unusual to have leukemia in the B6C3F1 mouse. The study demonstrated a substantial increase in lymphoma at all dose levels of benzene in mice. Dr. Huff pointed out that both leukemia and lymphoma have their origin in the hematopoietic system and there is a reasonable correlation between lymphoma in mice in this case and leukemia in humans (Tr. 3/19/86, p. 190).

Dr. Huff summarized the results of the NTP study by stating,

> under the conditions of these four separate yet concurrent experiments (male rats, female rats, male mice, female mice), there was clear evidence of carcinogenicity that benzene induced a variety of malignant and benign neoplasms in these rodents . . . To place these results in some program perspective, of the 330 chemicals studied since the early 1970s using experimental designs similar to that described for benzene only 33 have given positive results in each of the four experiments. The number of organs/systems affected in the benzene studies are also unusually many, showing positive effects in 11 sites (Huff, 1986, Ex. No. 215).

Dr. Huff further noted, the lowest dose that was used in the experiments was 25 mg/kg which is somewhere in the range of 20 to 25 ppm if one would expose animals by inhalation. Carcinogenic responses were observed at that level (Tr. 3/19/87, p. 195).

Dr. Kim Hooper, a toxicologist with the California Department of Health Services, stated in his prepared testimony that:

> In the NTP animal cancer bioassay, benzene produced significant increases in malignant tumors at several sites in rats and mice of both sexes. Significant sites in these test animals included lung, ovary, mammary, skin, lip, oral cavity, hematopoietic system, preputial gland, Zymbal gland, and Harderian gland. Thus, benzene is clearly a multi-tissue carcinogen in test animals (Ex. No. 236).

Dr. Hooper also pointed out the linearity of the dose-response effects of benzene on the tumor incidence in the NTP study. OSHA's analysis of the NTP data shows that the incidence of preputial gland carcinomas and malignant lymphomas in male mice and mammary gland carcinomas in female mice show statistically significant linear dose-response relationships. The other responses demonstrated significant excesses of tumors but the shape of the curves varied. Data from the study by Maltoni et al. (1985, Ex. No. 252 A–17–46) showed that the incidence of Zymbal gland carcinomas in male and female rats gave a linear dose response with oral levels of 250 and 50 mg/kg benzene. OSHA concludes that the data on tumor incidence show good dose-response and several cancers showed linearity in the response to dosage.

Cronkite et al. (1984, 1985, Ex. Nos. 252A–17–15, 252A–17–17) demonstrated that exposure of mice for 16 weeks to benzene by inhalation followed by cessation of exposure resulted in a high incidence of benzene-induced lymphomas. The animals were exposed to 300 ppm benzene by inhalation for 6 hr/day, 5 days/week for 16 weeks and then held for lifetime observation. Among the exposed animals that dies, there were 6 with thymic lymphoma and 2 with unspecified lymphoma. This represented an overall lymphoma-leukemia incidence of 8%. No cases of lymphoma-leukemia were observed in the control group. A comparison of 118 benzene-exposed mice with 354 historical controls revealed that benzene exposure was the significant variable ($p < 0.0001$) leading to death due to lymphoma-leukemia as described in these studies.

Snyder and Laskin (1986, Ex. No. 248) concluded in their report to CMA that a comprehensive evaluation of the evidence indicates that benzene is, in fact, a carcinogen. In man, this carcinogenic activity is expressed as one of several types of leukemia. Lymphomas are a variety of leukemia, and the fact that they are seen, as the predominant form of benzene-induced hematological neoplasia in rodents may represent species-specificity. They also stated that it is not known which of the benzene metabolites is responsible for the induction of leukemia in man. However, the finding that guanine-hydroquinone and guanine-benzoquinone are the major DNA adducts detected following benzene exposure (Jowa *et al.*, 1985) suggests that these metabolites might be involved in leukemogenesis.

OSHA concludes there is evidence that benzene is a potent carcinogen in animals on the basis of multiple site carcinogenicity in both sexes of 2 species of experimental animals and at the lowest dose tested, which is equivalent in humans to 19–24 ppm benzene inhaled over an 8-hour workday. This is further supported by the clear dose-response relationships for many of the cancers. These findings add support to the evidence that benzene is a human carcinogen and suggest that cancers other than of the lympho-hematopoietic system also may be involved in humans.

E. Experimental Evidence: Subchronic Effects

The reader is referred to the discussion in the preamble to the proposed standard at 50 FR 5027.

F. Experimental Evidence: Cytogenetic and Other Effects

Numerous studies have demonstrated the induction of chromosomal aberrations as a result of benzene exposure in several species of experimental animals. These data have been reviewed by IARC (1982, Ex. No. 128–8). Several recent experimental studies, completed since the IARC review, have demonstrated adverse effects on chromosomes and bone marrow cells resulting from low level benzene exposure.

At a meeting of the Permanent Commission and International Association on Occupational Health in August 1983 (Ex. No. 159–87), Tice summarized results from a series of cytogenetic studies in mice exposed to benzene by various routes of administration at Brookhaven National Laboratory. Among the findings were the observations that:

1. One four-hour inhalation exposure to benzene at concentrations ranging from 28 ppm to 3000 ppm induced a linear increase in SCEs in mouse bone marrow cells as benzene exposure level increased. A single atmospheric exposure to 28 ppm, the lowest dose tested in this experiment, resulted in a 2-fold elevation in SCEs (Tice et al., 1982, Ex. No. 159–88). 2. Modification of the magnitude of the SCE response to inhaled benzene by age (3–12 mo.), gender (male vs female), and genetic constitution (DBA/2 vs C57B1/6) emphasized the importance of these factors when attempting to extrapolate animal data to human health risks and suggested that segments of the population sensitive to one or more of the genotoxic/cytotoxic effects of benzene probably exist (Tice et al., 1982, Ex. No. 159–88). 3. Exposure to benzene at concentrations ranging from 10 to 400 ppm for 9 days (6 hr/day) induced a significant increase in micronuclei (a measure of bone marrow chromosomal damage) in peripheral blood cells of C57B1/6 male mice (Ex. No. 159–87).

Tice commented on the ability of benzene to induce genotoxic/cytotoxic damage in mice and provided additional data from which he concluded that more bone marrow damage can result from less exposure to benzene (Ex. No. 201–37). C57B1/6, B6C3F1, and DBA/2 mice were exposed to 300 ppm benzene for 6 hours per day for 13 weeks. Two exposure regimens were used: either 3 or 5 exposure days per week. The frequency of micronucleated polychromatic erythrocytes (MN–PCEs) and normochromatic erythrocytes (MN–NCEs) reflect damage to the DNA of bone marrow cells, induced recently (1–2 days earlier for PCEs) or accumulated throughout the duration of the exposure period up to a maximum of 7 weeks (the lifespan of an NCE). The percentage of PCEs in the peripheral blood reflects the rate of erythrocyte (red blood cell) production. In DBA/2 mice, a sex difference in response was observed, with male mice exhibiting more damage (100 MN–PCEs/1000 cells) than female mice (20 MN–PCEs/1000 cells). The benzene induced frequency of micronucleated PCEs did not change significantly over the 13 week period, nor did it differ between exposure regimens. However, depression of the bone marrow erythropoiesis, as measured by a decrease in the percentage of circulating PCEs themselves, was greater when animals were exposed to benzene for 3 days/week than for 5 days/week, particularly in male DBA/2 mice. Tice concluded that "more bone marrow cytotoxic damage occurs in mice under the more intermittent exposure conditions." A comparison of micronucleated NCE results from male B6C3F1 mice used in Tice's study and in the NTP gavage cancer bioassay lead Tice to conclude that "exposure by inhalation induces about 8 times more bone marrow damage than an oral exposure." He assumed that 400 mg/kg by gavage for 5 days/week for 120 days is approximately equal to 300 ppm benzene for 6 hours/day, 5 days/week by inhalation.

During hearing testimony, there was discussion of Tice's conclusions regarding the comparative toxicity of inhalation versus gavage exposure (Tr. 89–90, 3/26/86). In response to these comments, Dr. Tice provided data (Ex. No. 252A–15) from a recently completed experiment, designed specifically to compare the two routes of exposure, and to avoid potential confounding by differences in laboratory protocols. Using the same dose of benzene (400 mg/kg) and strain of mice (male B6C3F1) used in the NTP bioassay, the results confirmed the earlier conclusions: the frequency of micronucleated polychromatic erythrocytes (MN–PCE) induced by 400 mg/kg benzene by gavage remained constant at a frequency of 23.4 per 1000 cells throughout the duration of the exposure period and was 5 times lower than the level of MN–PCE (approximately 100 per 1000 cells scored) observed in male B6C3F1 mice exposed by inhalation to 300 ppm benzene over the same duration of exposure.

Toft et al. (1982, Ex. No. 252A–17–81) exposed male NMRI mice to benzene in air at concentrations between one and 200 ppm. They examined the bone marrow to determine the number of nucleated cells, the number of colony forming granulopoietic stem cells (CFU–C) and the frequency of micronuclei in polychromatic erythrocytes at various exposure levels. Highly significant effects on all three parameters were observed with continuous exposure (24 hours/day) to benzene concentrations of 21 ppm, 50 ppm, and 95 ppm for 4 to 10 days. Toxicity was dose-dependent. At 14 ppm, the frequency of micronuclei was significantly elevated over control values. Exposures at 21 ppm, 50 ppm, 95 ppm, and 107 ppm for 8 hrs/day, 5 days/week, for 2 weeks resulted in significant toxicity as indicated by CFU–C and the fequency of micronuclei. Dose-response relationships were linear for both of these parameters. Cellularity was significantly decreased with 8 hrs/day exposures of 50, 95 and 107 ppm. Short peak exposures increased the proliferation rate of the bone marrow. The three parameters measured in this study reflect different functions of the bone marrow. Measurement of CFU–C examines the ability of the granulopoietic stem cells to undergo cell division. The authors observed that this parameter appeared more sensitive to prolonged exposure to low levels of benzene than did the majority of bone marrow cells, as measured by the cellularity or the number of nucleated cells. At high exposures of short duration, the situation was reversed. Exposure to 95 or 201 ppm for 2 hours/day suppressed cellularity but not CFU–C, indicating that short exposures caused rapid injury to the bone marrow. The proliferation rate of the bone marrow responded to the exposures by an increase, so the number of granulopoietic cells (CFU–U) was higher than in controls.

The frequency of micronuclei in PCE is a sensitive measure of genetic toxicity due to low background rates and ease of observation. The production of micronuclei is thought to be dependent on the actions of toxic chemicals on the DNA, DNA-associated proteins, or the spindle apparatus (Ex. No. 252A–17–81). Toft et al. pointed out that "since it is assumed that somatic mutations precede most chemically induced cancers, it is worth noticing that exposures to low benzene concentrations gave rise to increased frequency of micronuclei." (p. 301).

Recent work at New York University Medical Center (Ex. Nos. 146–1, 159–86, 146–2) has demonstrated that exposure of C57B1 mice to 10 ppm benzene for 6 days reduced the mitogen-induced blastogenesis of femoral B-cells to 30%

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of control values. Moreover, 6 days exposure to 10 ppm was just as effective at reducing blastogenesis as 6 days exposure to higher benzene concentrations. In addition, splenic T-cell mitogen-induced blastogenesis was reduced to about 40% of control values after 6 days of exposure to concentrations of 31 ppm benzene. These results indicated to the authors that exposures to benzene at or near the current occupational exposure limit may affect certain immune functions and may be hematotoxic.

In the study by Baarson et al. (1983, Ex. No. 146–2), C57B1 mice were exposed 6 hours a day, 5 days a week to 10 ppm of benzene for 32, 66, and 178 days. Benzene was found to cause a progressive depression in the *in vitro* colony forming ability of one of the erythroid progenitor cells, the colony forming unit-erythroid (CFU–E). Colony growth of cells from exposed mice was only 5% of control colony growth after 178 days of exposure. Burst forming cell growth was depressed to 55% of control growth after 66 days but returned to control growth values at 178 days. The benzene exposed mice also exhibited depressions in the number of splenic nucleated red cells and in the numbers of circulating red cells and lymphocytes. The authors suggest that these results demonstrate that low level exposure to benzene may be hematotoxic. In the second study, short term exposure (6 hours/day for 6 days) to 10 ppm benzene in air significantly depressed mitogen-induced blastogenesis of both B- and T-lymphocytes in mice (Rozen et al., 1984, Ex. Nos. 146–1, 159–66). Moreover, 6 days exposure to 10 ppm benzene was just as effective at reducing blastogenesis as 6 days exposure to higher benzene concentrations. The authors concluded that benzene exposure at or near the current occupational limit may affect certain immune functions. OSHA interprets these studies in animals as indicating that less than one week of exposure to the current permissible exposure limit for benzene may be associated with consequential damage to human health, i.e., significant depression of the bone marrow and disturbances of immune system function, all of which represent a potential significant hazard to human health.

Gad-El-Karim et al. (1983, Ex. No. 159–32) also reported a dose response and a 2-fold increase in micronuclei in CD–1 mice administered two oral doses of benzene at concentrations as low as 8.8 mg/kg body weight. Assuming that the CD–1 mice weighed 25 grams and their minute volume of air intake is 24 ml, this dosage would be equivalent to two eight-hour atmospheric exposures of approximately 6 ppm.

Dr. Andrew Kligerman reported findings at the International Symposium on Sister Chromatid Exchange held at Brookhaven National Laboratory (Kligerman et al. 1983, Ex. No. 159–47). Male DBA/2 mice exposed to 10 ppm benzene by inhalation for only 6 hours demonstrated a significant increase in SCE and in micronuclei.

Erexson et al. (1986, Ex. No. 252A–17–25) published the results of that study, showing the induction of cytogenetic damage in rodents after short-term inhalation exposure to benzene. Inhalation of benzene for 6 hours also induced statistically significant, concentration-related, increases in the frequency of sister chromatid exchanges (SCE) in peripheral blood lymphocytes of male DBA/2 mice at 10, 100, or 1000 ppm, and of male Sprague-Dawley rates at 1, 3, 10, or 30 ppm, as compared to air-exposed controls. Inhalation of benzene for 6 hours also induced statistically significant, concentration-related increases in micronuclei (MN) in bone marrow polychromatic erythrocytes of mice of 10, 100, or 1000 ppm, and of rats exposed to 1, 3, 10, or 30 ppm, when compared to air-exposed controls. These data, showing parallel induction of SCE and MN in both mice and rats, suggest that a common benzene metabolite or metabolites may be involved. Erexson et al. point out that, since the formation of micronuclei "is indicative of either spindle disruption or chromosome breakage leading to lagging acentric fragments or entire chromosomes at anaphase" (part of the cell division cycle), the "formation of MN in bone marrow might be a result of either the accumulation of phenol, hydroquinone, and catechol" or the minor metabolism of benzene and its metabolites in the bone marrow, "leading to disruption of the spindle and aneuploidy." The idea that chromosome loss is involved in micronuclei induction by benzene is supported by the work of Irons. Several other studies showing benzene induction of chromosomal aberrations in rodent bone marrow cells support the idea that micronuclei are the result of chromosome breakage.

Barale et al. (1985, Ex. No. 252A–17–6) examined the induction of micronucleated circulating erythrocytes in the peripheral blood of CD–1 Swiss mice being chronically treated with benzene by oral intubation at daily doses ranging between 0.03 to 0.5 ml/kg body weight, for 5 days per week for 42 days (about 6 weeks) for chronic treatment; and in a single dose of 0.250 ml/kg body weight in acute treatments for bone marrow analysis. Chronic treatment with benzene for up to 42 days resulted in decreased body weight and decreases in the ratio of polychromatic erythrocytes (PCE) to normochromatic erythrocytes (NCE) (an indicator of toxicity) in the males treated with the highest dose (0.50 ml/kg body weight). Dose-related significant increases in micronucleated NCE were observed after 21 days of treatment. The frequency of micronucleated PCE in bone marrow cells after a single dose of benzene (0.25 ml/kg body weight) was of the same order of magnitude as that obtained in circulating NCE after chronic treatment. Females were observed to be less sensitive than males to these effects, a finding consistent with those of other investigators. A decline in micronuclei after longer periods of treatment was thought by these investigators to be possibly due to a decreased ability to metabolize benzene to genotoxic metabolites or due to an increased capability to detoxify benzene metabolites.

Choy et al. (1985, Ex. No. 252A–17–10) analyzed peripheral blood smears from the National Toxicology Program (NTP) carcinogenesis bioassay of benzene in B6C3F1 mice for the induction of micronuclei. They demonstrated that the frequency of micronuclei in circulating normochromatic erythrocytes reflects the clastogenic effect and sex-related sensitivity reported previously in acute cytogenetic studies. Blood smears from both subchronic (120 days) and chronic studies (54 weeks and 103 weeks) were analyzed, at benzene doses delivered 5 days per week by gavage of 25, 50, 100, 200, 400, or 600 mg/kg for the subchronic studies, and 25, 50, or 100 mg/kg for the chronic studies. In benzene treated mice, a statistically significant, dose-dependent increase in the frequency of micronucleated normochromatic erythrocytes was found at all sampling times as compared with control mice. At each dose and time, the frequency was higher in males than in females, consistent with other reports of greater male sensitivity to benzene-induced chromosomal damage.

Erexson et al. (1985, Ex. No. 252A–17–26) have demonstrated the induction of sister chromatid exchanges (SCE) in human peripheral blood T-lymphocytes exposed to benzene and its metabolites *in vitro*.

In summary, the above studies show chromosomal damage from benzene exposures equivalent to 2.8 ppm for only 4 hours (Tice, 1983) (Ex. No. 159–87), 1 ppm for 6 hours (Erexson et al., 1986, Ex. No. 252A–17–25), 6 ppm for two 8-hour

exposures (Gad-el-Karim, 1983, Ex. No. 159–32), or 10 ppm for 6 hours/day for 9 days (Tice, 1983, Ex. No. 159–87). The Dow cytogenetic study demonstrates significant chromosomal breakage among workers exposed to TWA benzene concentrations below 10 ppm.

Until recently, the data available from short-term tests on the mutagenic potential of benzene indicated that benzene induces chromosomal damage but not mutations. These data have been the subject of several reviews (IARC, 1982, Ex. No. 128–8; Von Halle, 1983, Ex. No. 159–94; Dean, 1978, Ex. No. 128–50, 1985, Ex. No. 252A–17–20). *In vivo* and *in vitro*, benzene has been shown to cause chromosome breaks, aberrations, and sister chromatid exchanges. Benzene has been found to be negative in the Salmonella/microsome assay and in other prokaryotes. No evidence could be found in the published literature reviewed by Von Halle for the induction of point mutations in lower organisms and in mammalian cell culture systems (1983, Ex. No. 159–94). Kale and Baum (1983, Ex. No. 159–44) found that benzene did not induce significant increases in sex-linked recessive lethal mutations or translocations in Drosophila or crossovers in Drosophila spermatocytes when compared with unexposed controls. However, induction of crossing-over in spermatogonia was several times more than that in controls. The authors concluded from these findings that benzene may be a stage-specific chemical and that if mutations can also be induced in spermatogonial cells, then replication may be required for mutation induction by benzene.

Snyder and Laskin (1986, Ex. No. 248), in comments prepared for the Motor Vehicle Manufacturers Association, pointed out that the equivocal results sometimes seen in the *in vitro* mutagenicity studies may be "due to technical difficulties with the test systems. For example, benzene may produce negative results in *in vitro* systems since it is extremely volatile and may evaporate before sufficient time has elapsed for the test to be completed. In addition, in some of the test systems, benzene may exert cytotoxic effects on the bacteria or mammalian cell culture which may mask its mutagenic effects" (p. 9). Furthermore, Dr. Marvin Legator, in testimony presented at the hearings (Tr. 4/2/86, p. 18) pointed out that the complex metabolic patterns seen with benzene may not be mimicked well by the *in vitro* microbial and cell culture tests since the latter tests are not carried out in intact animals.

Crespi and Penman (1984, Ex. No. 159–19A) reported at the 15th Annual Meeting of the Environmental Mutagen Society that benzene was found to be mutagenic in human cells in a recently developed gene-locus mutation assay utilizing a metabolically competent human lymphoblastoid cell line. This assay measures the induction of mutations at the hypoxanthine guanine phosphoribosyl transferase locus via resistance to the purine analog 6-thioguanine (6TG). The mutant frequency in the benzene treated cultures was statistically greater than both the concurrent negative controls (p less than 0.005) and the historical negative control data base for this cell line and locus (p less than 0.0001).

Dr. Carroll Snyder reported the results of a study (Ex. No. 201–42, Attachment 5) demonstrating adverse effects on the hematopoietic system of mice exposed *in utero* to 5, 10, and 20 ppm benzene. Dramatic effects were observed in the growth of erythrocytic and granulocytic/macrophage precursor cell populations. Long-term effects of *in utero* benzene hematotoxicity were demonstrated by reduction in neonatal weight gain and by increased sensitivity to the hematopoietic stress caused by low-level (10 ppm), short-term re-exposure to benzene when the pups became adults. For this study, pregnant Swiss-Webster mice were exposed to either 0, 5, 10, or 20 ppm benzene by inhalation for 6 hours per day, for 10 consecutive days, from day 6 through day 18 of gestation. Parallel air-exposed fetuses were maintained and examined as controls throughout the study. Dr. Snyder concluded:

> Our results demonstrate that *in utero* exposures to all concentrations of benzene studied induce marked changes in the fetal hematopoietic system. Although changes were observed in granulopoietic populations, the erythron was particularly affected by the exposures. Moreover, the hematopoietic system was still responding to the exposures in the 2-day neonates (8 days after exposure) and in the 6 week old adults (7 weeks after exposure). Moreover, we acquired evidence that the *in utero* benzene exposures induced persistent changes in the hematopoietic reserve for at least 11 weeks after exposure (Ex. No. 201–42, Attachment 5).

G. Absorption of Benzene through the Skin

Several recent studies, both in animals and in humans, conclusively demonstrate that benzene is absorbed through the skin. OSHA concludes that the best estimate is that approximately 1% of the benzene in a solution would be absorbed through the intact skin and about 5% through cracked and calloused skin.

Two of the earliest studies on skin absorption of benzene in humans were carried out in Italy in 1946 and 1955. Cesaro (1946, Ex. No. 2–47) exposed human volunteers for 20–30 minutes in an airtight box saturated with benzene. The subjects' heads were outside the box. Benzene was not detected in the breath of these subjects. The ratio of inorganic sulfate to total sulfate excreted in urine remained unchanged. Thus, benzene absorption was not detected in the study.

Conca and Maltagliati (1955, Ex. No. 2–46) carried out measurements of benzene in breath and urinary sulfate ratio of three human volunteers. Subjects were fitted with fume masks to prevent inhalation of benzene, and their hands and forearms were immersed in benzene for 25–35 minutes. Skin irritation with burning and painful sensations occurred after 5–10 minutes. No benzene was detected in the breath and no change in urinary sulfate ratio was found.

Both studies used limited analytical methodology. The determination of breath benzene level used a colorimetric method that could not detect trace or very low levels of benzene. The urinary sulfate ratio measurements are not sensitive enough to detect benzene absorption unless considerable amounts of benzene are absorbed.

Maibach reported in 1979 the results of studies of skin absorption in the rhesus monkey using carbon ^{14} labeled benzene (Ex. No. 143–2a,b). The studies addressed single and multiple exposures of intact skin of the forearm to full strength (100%) benzene and a benzene containing (0.35%) rubber solvent used in passenger tire manufacturing. One study protocol addressed a single exposure to stripped skin with 100% benzene. A single exposure to the palmar surface of the hand with the tire rubber solvent (0.35% benzene) was also evaluated. (This study was published in 1981. In the latter report, some of the values for the percentage of benzene absorbed through the skin changed. OSHA will use the values from the 1981 report in its discussion of the study). A single application of full strength benzene to intact skin of the forearm resulted in 0.172% of the benzene being absorbed while multiple exposures resulted in 0.848% being absorbed. A single exposure of full strength benzene to stripped skin of the forearm resulted in 0.909% absorption. A single exposure to 0.35% benzene in a rubber solvent to the palmar surface of the hand resulted in 0.651% benzene absorption, whereas a single exposure to the same solvent on intact skin of the forearm resulted in

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0.080% absorption. Multiple exposure to the solvent on the forearm resulted in 0.431% benzene absorption. These studies suggest that multiple exposures to rubber solvent containing 0.35% benzene on the skin of the forearm result in about 5-times as much benzene being absorbed as compared to a single exposure (0.43% vs. 0.08%). They also indicate about 8-times greater skin penetration for the palm as compared to forearm skin following single applications of rubber solvent (0.651% vs. 0.080%). A single application of undiluted benzene to stripped skin resulted in a 5-times greater penetration of benzene as compared to absorption through intact forearm skin (0.909% vs. 0.172%).

On the basis of these results, Rodricks and Brett (Ex. No. 204-7, III-B) estimated that about 3.4% of benzene applied as a 0.35% benzene containing solvent to the palm of the monkey would be absorbed. See Table A. For example, the Maibach and Anjo (1981) reports indicates that a multiple application of 0.35% benzene in petroleum naphtha to the monkey forearm resulted in 0.431% of the benzene being absorbed. Since 8-times as much benzene was absorbed through the palm as compared to the forearm of the monkey, the amount absorbed through the palm is 3.4% (0.431% × 8.08 adjustment factor = 3.448%).

In September 1983, OSHA requested that NIOSH undertake a study of the amount of benzene absorbed through the skin as a result of skin contact with petroleum naphtha, a solvent commonly used in tire building operations. The results of the study by Susten et al. were submitted to OSHA in April 1984 (Ex. No. 156A) and published in 1985 (Ex. No. 252A-17-78).

TABLE A.—DERMAL ABSORPTION IN MONKEYS

Percent Absorption		Site	
		Single application	Multiple application
Diluted	Palm	0.651	* (3.448)
Benzene (0.35%)	Arm	0.0805	0.431
Undiluted	Palm	* (1.376)	* (6.784)
Benzene	Arm	0.172	0.848

Source: Rodricks and Brett (Ex. No. 204-7, III-B)

* Assuming the same relationship as found after single application of diluted benzene.

The NIOSH study was conducted on hairless mice using dermal application of petroleum naphtha containing 0.5 percent benzene radiolabeled with carbon 14. Under the conditions of the experiment, approximately 1 percent of the applied benzene was absorbed through the skin. On the basis of these results, NIOSH calculated that a worker building 150 tires per day using a rubber solvent containing 0.5% benzene could absorb approximately 6 mg of benzene daily through intact skin; the upper and lower 95 percent confidence limits are 8.4 and 3.7 mg/day. The 6 mg of benzene absorbed through the skin may be compared to an estimated 14 mg of benzene that would result from inhalation of 1 ppm over an 8-hour day. According to the NIOSH investigators these quantitative findings are consistent with those of Maibach who studied benzene absorption through the intact skin of rhesus monkeys.

Workers building tires are known to have cracked and fissured skin on their hands as a result of daily contact with tire building solvents. Thus, evaluation of benzene absorption through skin that is not intact may have a bearing on the actual benzene skin penetration of workers building tires. In this regard, the study by Maibach (Ex. No. 143-2b) indicated that benzene exposure to stripped skin in the rhesus monkey results in 5.3 times the absorption as compared to exposure to intact skin. If this factor is applied to the study results of NIOSH, approximately 32 mg (6 mg × 5.3) of benzene could be absorbed daily through the skin as a result of exposure to petroleum naphtha in tire building operations.

Several studies have also evaluated dermal absorption of benzene to human skin. In one study Maibach (Ex. No. 231-6) reported the results from a single application of C-14 labled benzene to a 2x2 inch surface area of the forearm of four human volunteers. Urine was collected for six days following benzene application. C-14-CO_2 was captured and counted in a scintillation counter. Penetration values were corrected for incomplete urinary excretion using the values obtained from the experiments on the rhesus monkey. (In the latter experiment it was determined that 41% of absorbed benzene would be excreted in the urine). Thus, benzene urinary excretion values were adjusted by a factor of 2.4 (1/0.41). The results indicated that 0.065% of the applied benzene dose was absorbed through the forearm of humans. In a similar experiment (Ex. No. 231-7), Maibach estimated that 0.128% of the applied benzene dose was absorbed through the palm of humans. Thus, twice as much benzene was absorbed through the palm as compared to the forearm. The author noted that many of the scintillation counts of radioactivity in the urine were close to background levels and that the experiments approached the detection limits of the methodology.

Hanke et al. (1961, Ex. No. 144-175) estimated the rate of undilated benzene absorption through the forearm skin of human volunteers following 1.25-2.0 hours of continuous contact with 8-45 cm^2 of skin surface area. Using two different analytical methodologies, the absorption rates of benzene ranged from 0.24-0.4 mg/cm^2/hr. The authors preferred the absorption rate of 0.4 mg/cm^2/hr as it was based on a direct method of measurement which they felt was quantitatively more definitive. If one were to apply the assumptions of Susten et al to these findings as done by Rodricks and Brett (Ex. No. 204-7, III-B) and account for a 2-fold difference in skin absorption between the forearm and the palm of the human hand, about 4.8 mg of benzene [0.4 mg/cm^2/hr. × 0.005 (benzene % in solvent) × 150 cm^2 (surface area of hands exposed) × 8 hrs/day × 2 (adjustment for palms) would be absorbed per day.

Franz (1982) published an evaluation of dermal absorption following a single application of undiluted C-14 benzene to the forearm of four human volunteers and six monkeys (Ex. No. 159-30). The amount of benzene absorbed was 0.05% for humans and 0.14% for monkeys. Franz noted by direct observation that

liquid benzene was undetectable within 30 seconds of its application. He concluded that the high volatility of benzene made the contact time with the skin a critical factor for controlling percutaneous absorption.

Franz also conducted *in vitro* experiments with human and monkey skin. The amount of benzene absorbed was 0.10% for human skin and 0.19% for monkey skin. He concluded that the *in vitro* results correlated well with the above mentioned *in vivo* results. Franz observed that the diffusion of benzene through the skin is very rapid with the peak absorption occurring at 15–20 minutes. From Figure 4 of his data, one can calculate an absorption rate of 0.2–0.3 mg/cm² hr. Using the assumptions of Susten et al. and adjusting for benzene penetration of the palms versus the forearm of humans from the Maibach study (2-fold adjustment factor) would result in 2.4–3.6 mg of benzene absorbed per day through tirebuilding.

In 1985, Blank and McAuliffe (Ex. No. 204–7, III-B) reported the results of dermal absorption of undiluted benzene through human abdominal skin *in vitro*. From Figure 1 of their data, the benzene absorption rate can be calculated to be 0.56 mg/cm²/hr [0.64 ul/cm² × 0.88 g/ul (density of benzene) = 0.56]. [Note: the authors incorrectly stated that the absorption rate was 2.11 ul/cm²/hr rather than 0.64 ul/cm²/hr]. Using the assumptions of Susten et al. and the correct benzene absorption rate as done by Rodricks and Brett (Ex. No. 204–7, III–B) results in an estimated daily benzene absorption of 6.7 mg per day through tire building with a 0.5% benzene containing solvent.

Since the 1977 OSHA benzene rulemaking, at least nine studies have become available which demonstrate the dermal absorption of benzene in both experimental animals and humans. These studies are difficult to conduct and some of them are limited because of the methodology employed and the volatile nature of the benzene or rubber solvents used in the study. These limitations for the most part would bias the results toward an underestimate of the amount of benzene absorbed through the skin when extrapolating to working conditions. For example, the studies in which benzene was applied as a single application would suffer from benzene being evaporated from the skin so that it would remain in skin contact for a very short period of time. Franz noted that liquid benzene was undetectable within 30 seconds of its application. In a working situation, evaporation does not take place as rapidly when clothing becomes soaked with a solvent containing benzene in comparison to bare skin being splashed with a solvent, or when the solvents are splashed inside of impermeable gloves, etc. In the Maibach studies, the doses of radioactivity chosen for cutaneous application were in general too low to provide scintillation count rates sufficiently over background for reliable calculations and conclusions. For accuracy, count rates should be at least twice the background levels in the urine. for the most part, they were less than twice background levels.

The NIOSH study of dermal absorption of benzene in hairless mice is considered the most thorough of the reports available for evaluation. The methodology was more detailed; the radioactive dose administered to the animals was much greater than that used in other studies resulting in more accuracy and better sensitivity; the direct method used for summing the levels of radioactivity in the carcass, expired breath and excreta did not require the use of adjustment factors.

Nevertheless, the results from studies of dermal benzene absorption are remarkably similar. NIOSH estimated 6.19 mg of benzene would be absorbed per day through tire building operations using a 0.5% solvent based on the hairless mouse. Studies of the monkey result in an estimated 21.3 mg [6.19 mg (for 1% absorption) × 3.4% (percent absorption for palm of monkey)] of benzene being absorbed per day. The Rubber Manufacturers Association were of the opinion that the Rhesus monkeys as used in the Maibach studies provide "a reasonable model for percutaneous absorption where relevance to man is sought." (Ex. No. 201–27, p. 10).

Studies of benzene absorption through human skin even in light of the methodologic problems mentioned above still result in estimates ranging from 3.6–6.7 mg of benzene absorbed per day using the assumptions for tire builders as reported by Susten et al. of NIOSH. Thus, the NIOSH study seems to provide a mid-range estimate of the studies evaluated based on mice, monkeys and humans. Therefore, the estimate of 1% of benzene being absorbed through intact skin seems well supported. However, OSHA acknowledges that the corresponding resultant daily dose of 6.19 mg may be underestimated by as much as 5-fold for individuals who have cracked and fissured skin. An additional daily amount of benzene absorption can also be absorbed through splashing of solvents containing benzene on clothing. This results in large amounts of additional surface area of skin being exposed and at the same time slower evaporation of benzene from the skin due to overlying clothing.

Thus, OSHA is of the opinion that benzene absorption through the skin as a result of benzene contamination in rubber solvents is a major route of exposure in tire building operations. This problem, however, can be dealt with adequately through use of low level benzene containing solvents (less than 0.1%) and proper training, education work practices and appropriate protective clothing.

H. Metabolism and Body Burden

The metabolism of benzene in humans and animals follows many similar pathways (Rusch et al., 1977, Ex. No. 159–68). Benzene is metabolised in the liver and its primary oxidative products include phenol, catechol and quinol. Further oxidation may produce hydroxyquinol and muconic acid. Subsequently, these oxidative products are transformed to phenylsulfuric and phenylgluconic acids, which are excreted as their alkaline salts.

The primary oxidation of benzene occurs via the cytochrome p–450–dependent monooxygenase system, resulting in biologically reactive intermediates, such as benzene oxide which spontaneously forms phenol (Irons and Pfieffer, 1982 Ex. No. 159–41). Evidence indicates that benzene per se dose not represent the principal structural moiety causing the identified toxic effects on the bone marrow or lymphoid system (Irons and Pfeiffer, 1982, Ex. No. 159–41).

The metabolism and elimination of benzene in humans appear to be similar to those in rats and mice; the amounts of various metabolites, the extent of metabolism, and the nature of the phenol conjugates depend on the species, strain, and route of administration (Rusch et al., 1977, Ex. No. 159–68). The similarities in the metabolism of benzene and similar effects on bone marrow toxicity in both animals and humans would tend to support the use of rats and mice for bioassay studies on the carcinogenicity of benzene.

Irons (1983, Ex. No. 159–41A), has shown that hydroquinone, a benzene metabolite, does cause bone marrow suppression in the mouse and under an appropriate experimental regimen will produce symptomatology that is consistent with aplastic anemia. Irons (1983, Ex. No. 159–41A) also reported that intermittent exposure appears to be much more potent at producing bone marrow aplasia than continuous exposure to a relatively greater amount

of benzene and suggested that protection of workers in an occupational setting requires prevention of peak exposures rather than the progressive lowering of the TWA in the absence of regulating or limiting transient exposure situations.

NIOSH (Ex. 250) pointed out that, "cumulative dose is an important consideration in benzene induced cancer." The studies by NIOSH of rubber hydrochloride workers and Wong of chemical workers both demonstrate that cumulative benzene dose is significantly associated with mortality from cancers of the lymphoid and hemopoietic systems. "Thus, the ability of benzene to accumulate in the body and manifest adverse biologic effects should be carefully examined." From its analysis of current data on the absorption, distribution, and metabolic fate of benzene and its metabolites in the body, NIOSH concluded that:

- Regardless of the exposure regimen, as long as it is routine, benzene and its metabolites will accumulate in the body;
- Benzene is lipophilic, thus it is not surprising to find three times more benzene in the bone marrow than in the blood;
- Bone marrow can metabolize benzene to phenol and quinone at a rate four times that found in liver. Therefore, production of toxic metabolites in the liver and their subsequent transport to bone marrow does not appear to be a necessary step in the mechanism of benzene induced bone marrow toxicity
- Benzene metabolites are toxic to bone marrow *stromal* cells, they bind to bone marrow DNA and inhibit synthesis of both mtRNA and mRNA and may interfere with DNA replication. Benzene metabolites also form adducts with d-adenosine and d-guanosine.
- Single exposures to benzene at low doses produced increases in the numbers of micronuclei and SCEs in rats.
- Benzene metabolites produce an increased frequency of SCEs in cultured human lymphocytes.

Furthermore, based on these data, NIOSH concluded that a:

plausible mechanism for benzene induced toxicity following exposures at either low concentrations or perhaps intermittent peak concentrations would involve inhalation, preferential deposition in the bone marrow, metabolism to phenol and other metabolites, inhibition of MRNA synthesis, inhibition of DNA replication and formation of DNA adducts; possibly resulting to transformation of normal cells to cancer cells. The fact that an increased frequency of SCEs is found apparently among only those exposed at relatively high concentrations is not inconsistent with this proposed mechanism. At higher exposures DNA alkylation may be so wide spread that even under conditions of diminished repair and replication, exchanges are still occurring at a detectable rate.

NIOSH concluded that, "The need for a limit on high exposures over short periods of time (i.e., peak exposures) is clear" (Ex. No. 250).

The preamble discusses in considerable detail the various biological effects of benzene. For regulatory purposes, though, the studies which are most important are the major epidemiological studies which demonstrate the association between benzene exposure and human leukemia. Those studies are sufficient by themselves to justify the regulation.

VI. Quantitative Risk Assessment for Benzene

As discussed in the following section, OSHA's best estimate of risk is that 95 excess leukemia deaths per 1000 workers are associated with an average of 10 ppm for 45 years (occupational lifetime) and 10 excess leukemia deaths per 1000 workers are associated with exposure to 1 ppm benzene. These estimates are based on high quality epidemiologic studies, and represents the mid-range of estimates presented to the Agency. They are also based on a risk assessment model that is well supported for cancer risk assessment.

A. Introduction

The scientific literature has documented hundreds of cases of leukemia, aplastic anemia, and other blood abnormalities which have been associated with benzene exposure. Epidemiologic studies of workers exposed to benzene have demonstrated significant excesses of leukemia, multiple myeloma, and lymphatic cancers as well as chromosomal aberrations. Several of these studies have provided a reasonable basis for quantitative cancer risk assessment. More recently, experimental animal studies have demonstrated the induction of cancer, chromosomal damage and bone marrow toxicity in relation to specific benzene exposure levels. All of this information has been used to the extent feasible in OSHA's evaluation of risk associated with benzene exposure levels. In its proposal OSHA requested comments on various risk assessments based on epidemiologic and experimental studies for purposes of determining quantitative estimates of disease associated with benzene exposure.

Although benzene exposure has been associated with leukemia, aplastic anemia, multiple myeloma, various forms of lymphoma, myelofibrosis, pancytopenia, and depression of singular blood cell lines. OSHA presented risk assessments based preferentially on epidemiologic study results of leukemia only and upon experimental studies involving the induction of solid tumors in mice and rats. OSHA did not include in its quantitative risk assessments the other above mentioned conditions because they were for the most part identified in case reports and relative risks could not be quantified. As a result, the total disease risk associated with benzene exposure may be underestimated. OSHA requested opinion on the methodology for inclusion of mortality from disease other than leukemia in its assessment of quantitative disease associated with benzene exposure. It also requested opinion on whether experimental results of cancer in animals should be used in risk assessment calculations.

A succinct explanation of the rationale and basis for quantitative risk assessment in general had been presented in the benzene proposal and in previous OSHA proceedings and is reiterated here. (See the benzene proposal, 50 FR 50512, 12/10/85; Arsenic 48 FR 1864, 1/14/83; ethylene dibromide, 48 FR 45956, 10/7/83; ethylene oxide, 49 FR 25734, 6/22/84; asbestos, 51 FR 22612 6/20/86).

Several approaches have been used to estimate cancer risk from exposure to toxic agents. A standard approach uses mathematical models that were developed for cancer risk assessment in an attempt to fit curves to data points that represent relative risks observed at different exposure levels and from these curves to predict the risk at other, usually lower, exposures. These curves range from linear extrapolations to zero exposure and zero risk to curves which are non-linear and may have an effective threshold. The use of a particular model or curve can be justified in part by statistical measures of "fit" to available data points. These considerations have been reviewed from the statistical standpoint (Krewski and Van Ryzin, 1981) (Ex. No. 159-48).

It is theorized that the mathematical curves are reflective of biological processes that control the biological fate and action of the toxic compound. The models preferred do have a basis for cancer risk assessment. However, the underlying science has not advanced far enough to fully confirm the models biologically and it is unlikely to advance that far in the near future.

Studies can contribute useful information in the development of a quantitative risk assessment if they provide reasonable estimates of excess risk and dose. Such assessments might be improved by incorporating additional biological factors, though these are not necessary to obtain an estimate of disease risk. Information on several

biological factors which, if available, might possibly have a bearing on the risk assessment include: (1) dose of the material at the sensitive tissue(s); (2) rates and sites of biotransformation; (3) toxicity of metabolites; etc.

With present knowledge, few of these factors can be determined easily or incorporated into a single mathematical model. Even if they could be identified, it would be difficult to determine the weight that should be given to each factor. In the specific case of benzene and leukemia, while the basic mechanism whereby benzene affects the bone marrow cells is still unclear, evidence in the record as reviewed in the health effects section indicates that cytogenetic changes may be involved. The influence of some of the above factors on the cytogenetic changes, however, is not known.

Quantitative cancer risk estimates based on epidemiologic data require assumptions about the shape of the dose-response relationship and the duration of exposure. Epidemiologists have frequently assumed a linear model for dose-response (IARC, 1982). Although it is recognized to be a rather simplified model which may vary with the biological factors mentioned above, the linear model has scientific plausibility (Crump *et al.*, 1976 (Ex. No. 217-32-H7); Acheson and Gardner, 1980 (Ex. No. 159-1); Committee on the Biological Effects of Ionizing Radiation, 1980) (Ex. No. 159-55).

In developing its criteria for arsenic, the Arsenic Working Group (WHO, 1981; Ex. No. 159-104) of the World Health Organization stated:

> The use of the linear non-threshold model is recommended for extrapolation of risks from relatively high dose levels, where cancer responses can be measured, to relatively low dose levels, which are of concern in environmental protection where such risks are too small to be measured directly either through animal or human epidemiological studies.
>
> The linear non-threshold model has been generally accepted among regulatory bodies in the USA for chemical carcinogens (IRLG) and for ionizing radiation on an international basis (ICRP). The linear non-threshold philosophy was accepted by a Task Group on Air Pollution and Cancer in Stockholm in 1977 (Task Group on Air Pollution and Cancer, 1978). The scientific justification for the use of a linear non-threshold extrapolation model stems from several sources: the similarity between carcinogenesis and mutagenesis as processes which both have DNA as target molecules, the strong evidence of the linearity of dose-response relationships for mutagenesis, the evidence for the linearity of the DNA binding of chemical carcinogens in the liver and skin, the evidence for the linearity in the dose-response relationship in the initiation stage of the mouse 2-stage tumorigenesis model, and the rough consistency with the linearity of the dose-response relationships for several epidemiological studies; for example, aflatoxin and liver cancer, leukemia and radiation.

While the multistage model also seems plausible, the linear model is a reasonable approximation of the multistage model at the response rates of concern. The linear model seems biologically sensible since it assumes risk is linearly proportional to dose.

The issue of the effects of cessation of exposure and subsequent follow-up on risk is also a problem in modeling dose response relationships from epidemiologic studies. As stated by IARC (1982) (Ex. No. 159-38):

> If on the one hand, the exposure acts as an early-stage initiator, then the risks remain somewhat the same after cessation. If, on the other hand, the chemical is a promoter, then the risk decreases after elimination of the exposure . . . The typical occupational study involves continued follow-up of workers after they have left the workplace. The resulting risk ratios may thereby misrepresent the true risks for a continued exposure.

The "misrepresentation" referred to would be an underestimate of the risk from continuous exposure. Since most of the epidemiologic studies used for risk estimation are based on working populations exposed for relatively short periods of time and the dose calculated for those studies is spread over an entire occupational lifetime, the risk of death from leukemia for those continuously exposed may be underestimated if benzene is a promoter as well as an initiator.

In order to estimate the potential quantitative risk of cancer for workers exposed to benzene, OSHA requested comments on several quantitative risk assessments and other epidemiological and toxicological studies in its proposal of December 1985 (50 FR 50512, December 10, 1985). In response, OSHA received various comments on the risk assessment for benzene. Additional risk assessments were also introduced into the hearing record. The following discussion gives a description of each of the major risk assessments, evaluates the comments on these assessments and presents OSHA's determination of the cancer risk posed by occupational exposure to benzene.

B. Terminology and Definitions

Several statistical/technical terms are defined here for reference in reading this section.

(1) *Mathematical model:* A well-defined mathematical equation describing the relationship between dose (e.g. parts per million of benzene) and response (e.g. number of cancer deaths among workers or number of tumor-bearing animals). The biological data are used to define the relationship; that is, a curve is "fit" to the data.

(2) *Mathematical fit:* A term used to describe how close a predicted dose-response curve is to the actual observed points. Fit is often measured by a Chi-squared goodness-of-fit statistic and its corresponding p value. Using the Chi-squared test, the closer the p value is to one, the better the fit.

(3) *Types of Models:* Several different mathematical models have been developed for high dose to low dose extrapolation. Most of the models are based on theories of cancer development, such as the one-hit, the linear, the multistage, and the gamma multihit model.

a. Linear model: This model assumes that the expected number of chemical-cell interactions is directly proportional to dose. This is a very common biologic presumption. However, this model does not account for repair, detoxification reactions and metabolic activation as well as the multi-stage model.

b. Multistage model: This model assumes that the toxic response is the result of an ordered series of biological events and that the occurrence of each event is linearly related to the dose. (Note: At doses relevant to occupational exposure, the linear or one-hit model is a reasonable approximation of the multistage model.)

c. Probit model: Use of this model results in a typical sigmoid-shaped curve; strongest in the 5% to 95% response area. Zero responses are approached very rapidly as the dose decreases.

d. Logit model: Use of this model also results in a sigmoid-shaped curve symmetric about the 50% response point. It approaches zero response more slowly than the probit model.

3. Weibull model: This quadratic model is a generalization of the one-hit model which allows for non-linear responses in the low dose region. The response may be concave or convex depending on estimates from the observed data sets.

f. Gamma Multihit model: This also assumes that an expected number of chemical-cell interactions is related to dose, but it further assumes that a number of responses is needed to produce the cellular response. Thus, the model may fit data observed at higher doses better than the one-hit model.

(4) *Extrapolation/interpolation:* Once a mathematical model is fit to a set of data points, one may wish to predict the risk at other points along the curve.

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Extrapolation is the prediction of risk outside the range of the observed data; interpolation is the prediction of risk within the range of the observed data. The term interspecies extrapolation refers to the prediction of risk in one species (e.g. humans) based on observations in other species (e.g. rodents).

C. Summary of Risk Assessments

1. Risk Assessments Based on Experimental Bioassays

Experimental bioassays have served as a basis for the majority of quantitative cancer risk assessments. While risk estimates based on single compound exposures to experimental animals can readily determine dose and response, they pose some difficulty in extrapolation to humans for a number of reasons including factors associated with interspecies variability in metabolism, and human insult by a host of other chemicals in the environment which may interact to potentiate the carcinogenic response.

The Carcinogen Assessment Group (CAG) of the EPA conducted a quantitative cancer risk assessment for benzene based on the results of experimental bioassays (CAG 1983, Ex. No. 159–15). The preliminary results of its analyses were based upon the report of benzene exposure by oral gavage to Spraque-Dawley rats by Maltoni in 1982 (Ex. No. 128–75) and the report of benzene induced hematopoietic neoplasms in male C57BL mice following inhalation exposure by Snyder *et al.* in 1980 (Ex. No. 128–77). See the lengthier discussion in the proposal at 50 FR 50535.

With the multistage or one-hit models which are linear at low responses rates, CAG calculated the maximum likelihood estimate resulting from lifetime exposure to 1 μg/cubic meter of benzene to be 6.52×10^{-6} which is equivalent to 0.0212 for lifetime exposure to one ppm. Using the probit model, the MLE gave virtually the same result as the multistage and one-hit models. The Weibull model gave a higher MLE. The MLE of risk from the multistage was approximately 0.030 or 30 excess leukemia deaths per 1,000 workers exposed for an occupational lifetime to 10 ppm benzene. The risk at 1 ppm would be one-tenth or 3 per 1,000.

Dr. Kim Hooper presented risk assessments based on results of the NTP Cancer Bioassay (Ex. No. 236). He used the linearized multistage model. He adjusted the dose administered to the experimental animals to an equivalent dose to humans using a scaling factor that corrects for differences in surface area between rodents and humans. [Some researchers like Crump and Allen use a dose correction factor based on a μg of toxic substance per unit of body weight basis, while others such as the Carcinogen Assessment Group of EPA use a correction factor based on μg per surface area. There has been justification for use of either method in the literature and OSHA does not have a preference for one scaling factor over the other.]

The MLEs associated with lifetime occupational exposure to 10 ppm benzene ranged from 26 excess cancer deaths per 1,000 workers based on Zymbal gland carcinomas in male mice to 170 excess cancer deaths per 1,000 workers based on preputial gland cancers in male mice. Cancer risks associated with lifetime occupational exposure to 1 ppm ranged from 1.3 to 13 excess cancer deaths per 1,000 workers depending upon the tumor selected for risk assessment from the bioassay. Some of these results along with those calculated by CAG and Crump and Allen are shown in Table A.

TABLE A.—MAXIMUM LIKELIHOOD ESTIMATES OF OCCUPATIONAL LIFETIME EXCESS CANCER RISK PER 1000 WORKERS BASED ON EXPERIMENTAL STUDY RESULTS BY EXPOSURE LEVELS AND AUTHOR

Author	Exposure Level	
	10 ppm	1 ppm
CAG (1983): Zymbal Gland Carcinoma in female rat	30	3
Crump & Allen (1984): All SqCC in male mice	20	2
All SqCC in male rats	8	1
Hooper (1986): Preputial Gland in male mice	170	13
Mammary Carcinoma in female mice	57	5.4

SqCC = squamous cell carcinoma.

OSHA requested Dr. Kenny Crump, an expert in the field of quantitative cancer risk assessment, to perform a quantitative risk assessment based on the NTP data. Crump and Allen (Ex. No. 152) estimated excess risk of dying from leukemia and other cancers based on experimental data. Estimates of excess risk from 40 years of occupational exposure to 10 ppm benzene derived from application of the linearized multistage model to animal data on leukemia ranged from 0.4 to 1.5 per 1000. (It should be noted, however, that a good animal model for benzene and leukemia has not yet been developed.) When data from the NTP bioassay on all squamous cell carcinomas were used, the corresponding estimates of MLE ranged from 8.6 per 1000 in male rats to 20.0 per 1000 in male mice as shown in Table A. The estimates by Crump and Allen are somewhat lower than those based on epidemiologic data.

In discussing the results of their analyses, Crump and Allen stated that the estimates made from human data should take precedence over those from animal data in the case of benzene, because the former estimates are derived from reasonably good studies involving both the species (man) and the route of exposure (air) of interest. The National Research Council of the NAS Committee on the Institutional Means for Assessment of Risks to Public Health has stated recently that "well-conducted epidemiologic studies that show a positive association between an agent and a disease are accepted as the most convincing evidence about human risk" (NAS. 1983. Ex. No. 159–57).

Both CMA (Ex. No. 201—33) and API (Ex. No. 260) concluded that the experimental bioassays have demonstrated the ability of benzene to cause cancer in both mice and rats. Both groups also stated that it is not appropriate to use the animal data for purposes of quantitatively estimating the risk of cancer (leukemia) to workers exposed to benzene given the availability of reasonably good epidemiologic data for risk assessment purposes (Ex. No. 247–F, p. 16). In post hearing comments, API stated that whatever degree of reliance is placed on the animal bioassay results is essentially immaterial "since the results of quantitative analyses of these studies reveal that they do not produce carcinogenic potency estimates substantially different from those derived from human data" (Ex. No. 260, p. 21a).

OSHA agrees with Crump and Allen, API and CMA that the quantitative risk assessment for benzene and leukemia should be based on epidemiologic data, given the good quality of the data. Virtually, all parties who commented on the experimental cancer data were of the opinion that the studies were of good quality, or that they confirmed the carcinogenicity of benzene as demonstrated in the epidemiologic studies. As stated by Dr. Huff, who was the project officer of the National Toxicology Program's animal cancer study on benzene, if there was no epidemiological evidence on benzene related to carcinogenesis, the results of the animal studies would firmly

establish benzene as a potential human carcinogen since the results from the animal groups tested were so overwhelmingly positive. The fact that no leukemias were seen should not be grounds for diminishing the importance of the animal toxicity test results. Both Dr. Hooper and Dr. Huff were of the opinion that it is not unusual for carcinogenic agents to produce different tumor types in animals and humans (Tr. 3/18/86, pp. 189–190; Tr., 4/3/86, p. 40, 63). In past rulemaking, OSHA has relied upon similar experimental cancer data to estimate cancer risks to humans If such good quality epidemiologic data were not available to the Agency, OSHA would then rely upon the experimental cancer data to estimate cancer risk of benzene to humans.

2. Risk Assessments Based on Epidemiologic Data

In order for an epidemiologic study to contribute useful information to the development of a quantitative risk assessment, it must meet two minimum requirements. First, the study must provide an estimate of the excess risk in a population which was exposed to the substance in question, based on the experience of an appropriate control population. Second, industrial hygiene and employment data must be available to permit a reasonable characterization of previous exposure conditions for the cohorts of workers being studied.

From epidemiologic studies, relative risk values and corresponding exposure estimates are used with a mathematical model to predict cancer risk. In studies of occupationally exposed persons, the relative risk (RR) of a given cause of death can be approximated by a standardized mortality ratio (SMR) in a cohort study. In a case-control study, the relative odds ratio (OR) of developing the disease for those exposed versus those not exposed can be estimated. For practical purposes, the OR and RR will be considered equivalent measures of risk. An SMR divided by 100 will be considered equal to the RR or OR. For example, a SMR of 250 will be similar to an RR or OR of 2.5 (250/100). If the number of workers who die from a particular cause of death in a population is small, the confidence interval surrounding the SMR or OR may be quite large. In other words, the actual risk may be much higher or much lower than the estimated risk. However, the maximum likelihood estimates would still be the best estimate.

Exposure levels for the time periods of interest must also be determined. These are not always available and estimates of exposure quite often have to be made on the basis of the best available data. Since epidemiologic mortality studies of occupationally exposed workers are usually historically prospective in nature, exposure information for specific individuals comprising the study groups, or exposure data for the agency as a whole, usually have to be estimated. From a combination of data based on personal samples and area samples related to some members of the cohorts being studied during specific time periods, and knowledge of process changes or industrial hygiene practices that may have taken place over time, exposure to individual workers or to groups of individuals can be estimated. These estimates are also used to characterize exposure for those individuals involved in the same types of jobs over the same periods of time, but for whom actual exposure data are not available. This process of exposure estimation usually involves interpolation to time periods between exposure measurements and extrapolation to earlier or later time periods for which exposure data are not available. Such a process may result in either overestimation or underestimation of dose. However, reasonable or approximate estimates are sufficient for risk assessment purposes; precise estimates are not necessary and never will be available.

Risk assessments based on epidemiologic studies must apply observations made under one set of conditions to other and sometimes different sets of conditions. As a result certain assumptions have to be made for several unknown variables. The use of these assumptions may result in a degree of uncertainty. The uncertainty of several of these assumptions has been discussed by White *et al.* (1982). This is an inherent situation with risk assessments based upon epidemiologic studies. Some of these limitations can be minimized in the case of benzene by deriving data for risk assessment from cohorts of workers who have experienced exposure in different types of occupations or by including data from different studies.

Confidence in the dose estimates from epidemiologic studies can be strengthened when separate estimates of exposure data by different investigators result in similar findings. Confidence in dose response determinations are strengthened if the results can be reproduced. If the analyses of different investigators result in similar dose response relationships, in this case dose of benzene in relation to the risk of developing leukemia, or cancer, such reproducibility lends confidence to the predicted dose response relationship.

The strength of epidemiologic study lies in its ability to evaluate and determine dose response in humans. Hence, any concerns with scientific issues related to inter-species extrapolation are eliminated.

IARC (1982) (Ex. No. 159–38) conducted a quantitative risk assessment of workers exposed to benzene based on four studies. The first study chosen was that of Rinsky *et al.* (1981) (Ex. No. 128–32) who completed the follow-up begun by Infante *et al.* (1977) (Ex. No. 128–17). IARC also selected the study of benzene exposed workers by Ott *et al.* (1978, Ex. No. 128–33), (Vigliani (1976, Ex. No. 128–5) and Aksoy (1971, Ex. No. 144–160) to determine an estimate of leukemia risk.

A detailed discussion of the IARC study was presented in the benzene proposal at 50 FR 50531. A summary of the IARC benzene risk assessment data along with a range of OSHA estimated excess risks based on IARC methodology for exposure levels of 10 ppm and 1 ppm using linear extrapolation is shown in Table B. Dropping the two extreme values on both the upper and lower ends of the estimates, the excess risk per 1000 workers from lifetime occupational benzene exposure to 10 ppm ranges from 17–140, while the risk from exposure to 1 ppm ranges from 1.7–14. Of the four studies used for risk estimation, estimates of relative risk and exposure level were considered more exact for the studies by Ott *et al.* (1978) (Ex. No. 128–33) and Infante-Rinsky (1977, 1981) Ex. Nos. 128–7, 32). However, the upper range of the excess leukemia risk based on Ott *et al.* using IARC methodology as published in the proposal seems too high. When one considers that the Ott *et al.* total cohort was exposed for an average of 9.9 years to an average of about 5.5 ppm, the excess leukemia risk associated with lifetime occupational exposure to 10 ppm and 1 ppm would be 122 ($3.75-1\times45/9.2\times5/10\cdot0\times10/5.5$) and 12 per 1000, respectively.

TABLE B.—ANALYSIS OF RELATIVE RISK AND EXCESS LEUKEMIA RISK PER 1,000 WORKERS EXPOSED TO BENZENE FOR AN OCCUPATIONAL LIFETIME BY STUDY, BASED ON IARC METHODOLOGY (1982)

Authors	RR	Estimated exposure to cohort	Occupational lifetime excess risk per 1,000	Excess risk per 1,000 exposed to—	
				10 ppm	1 ppm
Ott *et al.* (1978)	3.75	1–30 ppm for 8–9 yrs	[1] 72	24–720	2.4–72
		5.5 ppm for 9.2 yrs	[2] 67	[2] 122	[2] 12
Infante *et al.* (1977)	5.6	10–100 ppm 8.5 yrs average exposure for cases [3]	170	17–170	1.7–17
Rinsky *et al.* (1981)	21	5 yrs average exposure	140	14–140	1.4–14
Vigliani (1976)	20	200–500 ppm 9 yrs average exposure for cases	475	9.5–23.8	1.0–2.4
Aksoy (1977)	25	150–210 ppm [4] 9.7 yrs average exposure for cases	534	25.4–35.6	2.5–3.6

[1] Based on exposure of 8.5 yrs.
[2] Based on actual average length of employment (9.2 yrs) and average cohort exposure (5.5 ppm).
[3] IARC extrapolated average exposure of cases (8.5 yrs.) to average exposure for cohort.
[4] Based on testimony of Aksoy at 1977 OSHA Hearing.

Note: IARC did not perform all calculations in last three columns. These were performed by OSHA using IARC methodology for the Infante-Rinsky study and IARC opinion that "risk calculations . . . reflect the degree of uncertainty in the estimates of dose rate . . . by citing upper and lower bounds of such estimates (IARC, 1982).

Little substantive comment was received in relation to the IARC risk assessment. CMA (Ex. No. 201–33, pp. 59–65) felt the brief IARC risk assessment was less reliable than the "lengthy careful and detailed analysis presented by Crump and Allen." It also contended that IARC's basing its estimates on group exposure data rather than on estimates of exposure to individual workers was a limitation.

The MVMA (Ex. No. 248) discussed the IARC risk assessment stating that the quantitative estimates for benzene are relatively crude and reflect the present early stage of development of the field or risk estimation and that the aim was to demonstrate how risk assessment could be written and to promote working sessions on risk assessment. MVMA then used the IARC portion of the risk assessment based on the NIOSH study to conclude that an extrapolation of the estimated risk 170/1000 excess leukemia deaths for lifetime occupational exposure to levels between 10–100 ppm results in a greater than 5-fold overestimate of risk as compared to a rate (31/1000 workers) it calculated from a summary of case-reports of leukemia deaths from the published literature by Goldstein in 1977 (Ex. No. 128–59).

OSHA is of the opinion that the above comparison is invalid for the following reasons. The 170 excess leukemia deaths per 1000 workers calculated by IARC based on the NIOSH study referred to an occupational lifetime (45 years) length of exposure, while the rate of 31 per 1000 by MVMA was not based on a working lifetime of exposure. Hence, any difference in the excess risk between the two groups could be due to a difference in length of exposure.

Second, the authors of the MVMA report acknowledged that "many individual case reports were not published once benzene toxicity was recognized as being fairly common in the 1920's and 1930's. Thus, accuracy of total reporting presents a problem." The "accuracy" referred to by the authors would represent an underascertainment of cases and result in a lower leukemia mortality rate based on the literature review calculation. Thus, the leukemia rate calculated from the literature review suffers from exclusion of leukemia deaths in the numerator and too short a follow up to determine leukemia mortality among individuals comprising the groups over an occupational lifetime.

MVMA also questioned the IARC procedure for risk assessment, which assumed that the risk of developing leukemia in relation to benzene exposure was linear down to 1–10 ppm. This opinion was based on part on the comparison referred to above and in part on MVMA's opinion that there are likely to be levels of benzene exposure below which benzene cannot be metabolized to a toxic or carcinogenic metabolite (Ex. No. 248).

However, MVMA provided no substantial evidence to demonstrate the existence of a threshold, or on what the shape of the dose-response curve would be at these levels, nor on what the implied threshold level for benzene toxicity might be. Moreover, evidence in the record demonstrates many biologic effects below 10 ppm including a significant excess in chromosomal damage to bone marrow cells as a result of 1 ppm benzene exposure for only six hours and the Ott study showing excess risk of leukemia in humans at average exposures of 5 ppm.

OSHA is of the opinion that the excess leukemia risks calculated by IARC based on the NIOSH study and the Ott *et al.* study are preferred to those based on the Vigliani (1976) report or the Aksoy (1977) report.

The latter two reports are limited for quantitiative risk assessment because of the inability to reasonably define the numerator (actual number of leukemia deaths that may have occurred in the population), the denominator (the actual number of people exposed to benzene in the populations studied) and the average exposure levels to which the workers in the occupations studied actually experienced. White *et al.* (1982), Crump and Allen (1984) and API (Ex. No. 260) all expressed an opinion that the Aksoy and Vigliani reports were less suitable for quantitative risk assessment. OSHA agrees. It is noteworthy, however, that the excess risks in relation to benzene dose calculated from each of the four studies are similar. The mid-point of the range of estimates is about 8 excess leukemia deaths per 1000 workers exposed to 1 ppm for an occupational lifetime.

It is OSHA's opinion that IARC made reasonable assumptions and methodology for the data available at the time its analysis was conducted. More confidence, however, should be placed in the estimates derived from the NIOSH (Infante, 1977; Rinsky, 1981) and DOW studies (Ott, 1978) because of the methodology used to determine estimates of relative risk and dose in those studies. It is noted that the estimates of leukemia risk derived from all of the studies are of similar

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magnitude. The findings of four separate studies providing similar estimates of risk provide confidence in the estimates. Even though risk assessments conducted subsequent to the IARC evaluation are more detailed and are used for OSHA's best estimate, the results of those best estimates are similar to the ones derived by IARC.

OSHA also requested comments on the risk assessment performed by the Carcinogen Assessment Group (CAG) of the Environmental Protection Agency. CAG estimated leukemia risk associated with ambient benzene exposure using a linear non-threshold model (Albert *et al.* 1979, Ex. No. 128–6). This assessment was based on the occupational studies by Infante *et al.* (1977) (Ex. No. 128–17), several studies by Aksoy reported between 1974–77 and the study by Ott *et al.* (1978) (Ex. Nos. 128–7, 33, 43; 144–5, 160). These estimates were presented in detail in the proposal at 50 FR 50534. Converting the CAG risk estimate into an estimate for lifetime occupational exposure (45 years, 240 work days per year, 8 hours per day) would result in 33.8 excess leukemia deaths per 1000 workers exposed to 10 ppm benzene, or 3.38 per 1000 exposed to 1 ppm for an occupational lifetime.

A number of scientists believe the CAG assumptions on dose and relative risk are reasonable and well supported. The CAG risk assessment establishes an estimate of leukemia risk among benzene exposed individuals that is similar to the estimates made by IARC (1982) (Ex. No. 159–38) and White *et al.* (1982) (Ex. No. 127).

After reviewing comments on this risk assessment, OSHA is of the opinion that CAG conducted a reasonably good risk assessment for the data available at the time (1979). However, more data have become available for the NIOSH (Infante, 1977/Rinsky, 1986) and Dow (Ott, 1978/Bond, 1986) studies pertaining to estimates of individual cohort members' benzene exposure. In addition, the Wong study was not available to EPA in 1979 as it was not completed until 1984. Thus, OSHA prefers risk estimates based on the latter studies and particularly those calculated by Crump and Allen who used data from all three epidemiologic studies combined. Nevertheless, OSHA notes that the risk calculated by CAG of EPA based on epidemiologic data are not substantially different from these calculated by Crump and Allen.

The EPA-CAG risk assessment can best be summed up by Dr. Goldstein, testifying for API, who stated:

> I think it's a pretty good risk assessment and I think the fact that there are so many different risk assessments out there which all seem to come up with roughly the same number is very reassuring for those of us who were involved in trying to develop risk assessment tools which would be of value (Tr., 3/26/86, p. 140).

Dr. Goldstein supported this opinion in a post-hearing correspondence with API in which he attached a paper he published in 1985. Based upon three epidemiologic studies, the results were characterized as showing "reasonably good agreement" in estimating excess leukemia risk associated with 1 ppm benzene exposure. There was a 3-fold difference in results. The average cancer risk projected from 1 ppm exposure to experimental animals was virtually the same as the average cancer risk calculated from the three epidemiologic studies used in the EPA risk assessment. Thus, Dr. Goldstein also concluded that there was excellent agreement between the assessments based upon epidemiologic data and experimental animal data (Ex. No. 247E–C).

White *et al.* (1982, Ex. No. 128–37) reported a quantitative estimate of leukemia mortality associated with occupational benzene exposure. They selected the NIOSH (Infante *et al.* 1977; Rinsky *et al.* 1981) and DOW (Ott *et al.* 1978) (Ex. Nos. 128–7, 32, 33) studies for their risk assessment as they felt these studies more adequately met their requirements of providing both an estimate of relative risk and a reasonable characterization of previous exposure conditions.

For the NIOSH study, White *et al.* (1982) (Ex. No. 128–37) based the risk assessment on the experience of workers who had 5 or more years of employment, because the elevated risk was statistically significant only for this group. The standardized mortality ratio (SMR) was 2100 (5 observed leukemia deaths versus 0.23 expected). Workers who had been employed for less than 5 years were not included in the assessment. For these individuals the SMR was 200 (2 leukemia deaths observed versus 1.02 expected). The range of duration of exposure for those workers with more than 5 years of employment was estimated to be 5 to 30 years. The authors calculated that workers could have been exposed for 5 years to an average of 83 ppm benzene or 415 ppm-years, or they could have been exposed for 30 years to an average of 50 ppm, or 1500 ppm-years. The estimates of levels of exposure were based on industrial hygiene information from the report by Rinsky *et al.* (1981) (Ex. No. 128–32) for the period 1941–1975. Since some workers had been exposed to benzene as early as 1937, White *et al.* assumed exposures from 1937–1941 to have been 150 ppm benzene, which is 50% above the maximum allowable concentration or peak exposure level recommended in 1941.

For the Ott *et al.* study (1978) (Ex. No. 128–32), White *et al.* based their risk assessment on the 3 observed cases of leukemia as compared to 0.8 expected (SIR is 375, p less than 0.05). Based on data in the Ott *et al.* study, the average benzene dose for the entire cohort was estimated to have ranged from 500 to 1500 ppm-months, or 42–125 ppm-years. White *et al.* (1982) (Ex. No. 127) noted that the cumulative dose of benzene for the three leukemia cases ranged between 1.6 ppm-year and 45 ppm-years.

To describe the relationship between benzene dose and the probability of developing leukemia, White *et al.* selected a linear model as they felt the epidemiologic evidence available for benzene exposure and leukemia did not include the detail needed to test the appropriateness of more complex models.

To determine the excess probability of developing leukemia for a given dose of benzene over a defined period of time, White *et al.* (1982) determined the lifetime adult white male (ages 20–84 years) probability of death from leukemia (0.0070 for all cell types and 0.0050 for myelogenous leukemia) and the rate at which the excess probability of leukemia increased with each increment in dose. Separate risk estimates were then calculated for both studies using the above mentioned values.

As shown in Table C, based on the NIOSH study, the excess leukemia risk was estimated to be 44 to 152 per 1,000 workers exposed for an occupational lifetime (45 years) to an average of 10 ppm benzene. The excess risk of death from leukemia associated with exposure to 1 ppm for 45 years ranged from 5 to 16 per 1000 workers.

TABLE C.—ESTIMATE OF EXCESS LEUKEMIA DEATHS PER 1,000 WORKERS EXPOSED TO BENZENE BY NUMBER OF YEARS EXPOSED AND EXPOSURE LEVEL

Years exposed	Exposure levels			
	10 ppm		1 ppm	
	NIOSH study	DOW study	NIOSH study	DOW study
45	44–152	48–136	5–16	5–15
30	30–104	32–93	3–11	3–10
15	15–54	16–48	1.5–5	2–15
5	5–18	5–16	0.5–2	0.5–2

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TABLE C.—ESTIMATE OF EXCESS LEUKEMIA DEATHS PER 1,000 WORKERS EXPOSED TO BENZENE BY NUMBER OF YEARS EXPOSED AND EXPOSURE LEVEL—Continued

Years exposed	Exposure levels			
	10 ppm		1 ppm	
	NIOSH study	DOW study	NIOSH study	DOW study
1	1-4	1-3	0.1-0.4	0.1-0.3

Source: White *et al.* 1982 (Ex. No. 128-37).

Based on the study by Ott *et al.* (1978) (Ex. No. 128-33), the excess risk of death from leukemia was estimated to be 48 to 136 per 1000 workers exposed for an occupational lifetime to 10 ppm, while the excess risk was 5 to 15 per 1000 for those exposed to 1 ppm for 45 years. In discussing their results, White *et al.* (1982) (Ex. No. 127) noted that the range of excess risk was based on the uncertainty in the benzene exposure levels from the NIOSH and DOW studies, but that the projected risk did not reflect uncertainty associated with the relative risks for death from leukemia observed in the studies. For instance, they stated,

> the upper 95% confidence interval for the SMR of 2100 from the Rinsky *et al.* report is 5073. The use of this value would have resulted in much higher risk estimates. Thus, even though these risk estimates are expressed as ranges, the upper range of the risk estimates actually would have been greater if the uncertainty of the SMRs had been included in the analysis.

OSHA solicited opinion on the risk assessment by White *et al.* 1982 from a number of recognized experts in the field of occupational health, or risk assessment, representing government, academia, or industry (Ex. No. 137). Opinions of the assessment varied. Dr. Brian MacMahon (Ex. No. 137-5) and Dr. Bruce Karrh (Ex. No. 137-1) felt that the underlying studies upon which the assessment was based were too limited for purposes of conducting a quantitative cancer risk assessment. Dr. Philip Cole, stated "it is only an opinion that epidemiologic evidence regarding the leukemogenicity of benzene is 'conclusive.' " (Ex. No. 137-3) Dr. Cole's statement was based on his view that most of the epidemiologic studies of benzene and leukemia have methodological limitations and that the case reports of leukemia among benzene workers "are of limited scientific value." However, several consensus groups including IARC and the National Toxicology Program have concluded that there is sufficient evidence that benzene is carcinogenic to humans. No party to the hearing challenged the conclusion that benzene is a known human leukemogen.

Dr. Irving Kessler (Ex. No. 137-2) was of the opinion that the underlying studies represented the best available information. Dr. Kessler and Dr. David Gaylor (Ex. No. 137-9) stated that the results of the assessment seemed plausible and were well documented. Dr. Karrh criticized the NIOSH study on the basis of the critique of Tabershaw and Lamm (1977) (Ex. No. 159-81) and Van Raalte and Grasso (1982) (Ex. No. 159-91). Comments on these critiques have been addressed in the section on epidemiologic study results.

Dr. Norman Breslow, Dr. Cole, Dr. Charles Brown and Dr. Gaylor all thought the linear model used by White *et al.* (1982) was acceptable and that other more complex models were not justified (Ex. Nos. 137-3, 4, 7, 9). However, Dr. William Rowe felt other models should be evaluated in addition to the linear model while Dr. Karrh (Ex. No. 137-1) felt the linear model was unverifiable. The issue of model selection was also addressed by Dr. Charles Brown (Ex. No. 137-7) who stated:

> The "correct" model is unknown, and will remain so until we know the mechanistic relationship between benzene exposure and leukemia; however, I do not believe that the data warrant more sophistication than the simple linear model (to which the one-hit model is a very close approximation at low response rates); in addition, since the range over which the dose extrapolation is performed appears to be relatively small (one order of magnitude?), the dose-response model should have a small effect on the risk assessment results.

Dr. Cole and Dr. Brown (Ex. Nos. 137-3, 7) felt that the exclusion from the risk assessment of individuals in the NIOSH study who had less than 5 years of benzene exposure and a relative risk of 2 for death from leukemia resulted in a bias toward an overestimate of the quantitative risk based on the NIOSH study. In the benzene proposal OSHA was of the opinion that the latter data should have been included in the assessment, but that inclusion of these data would not change the dose response. For example, individuals with less than 5 years of exposure had a median duration of exposure of about 0.5 years (Rinsky, 1983, Ex. No. 159-65A). If one assumed that these individuals were exposed to a TWA of 100 ppm benzene (an estimate related to their time of employment), their cumulative dose of benzene would have been 50 ppm-years associated with a relative risk of 2, or 7 per 1000 excess leukemia deaths. This estimate would fit comfortably within the estimate of 5 to 16 excess leukemia deaths per thousand workers exposed for an occupational lifetime to 1 ppm., e.g., 45 ppm-years of exposure.

Three reviewers raised the issue of the cumulative dose concept of exposure used by White *et al.* (1982) (Ex. No. 127). Dr. Bruce Karrh was of the opinion that short-term, high intensity exposure was the mode of exposure to benzene (Ex. No. 137-1). Dr. Brown was of the opinion that the cumulative dose model may not be a valid measure but that the epidemiologic data would not provide the proper measure of exposure. He suggested the use of animal studies to resolve the issue of dose rates and duration of exposure. (Ex. No. 137-7). In contrast, Dr. Norman Breslow stated that dose additivity and low dose linearity should be adopted as biologically reasonable and scientifically prudent assumptions in the absence of specific evidence to the contrary (Ex. No. 137-4).

In response to questioning at the hearing, Dr. White stated that the 2-fold risk observed for those who were exposed for less than 5 years is about what you would expect to be associated with a 102 ppm years dose of benzene exposure that she had estimated for this group of individuals (Tr., 3/18/86, pp 178-183). In response to a hypothetical question raised by Mr. King of CMA, Dr. White also stated that had the average benzene exposure for these individuals been 5 times higher, the 2-fold risk of death from leukemia for those exposed for less than 5 years might not fit as comfortably within the estimate based upon the group of workers exposed for 5 or more years. Rather than speculating on what the dose was for individuals from the NIOSH cohort who were exposed for less than 5 years, White suggested that currently available NIOSH data for these workers, that was not available to her, be used to answer the question on their dose in relation to leukemia response.

In evaluating the White *et al.* risk assessment, API (Ex. No. 260, p. 27) and CMA (Ex. No. 201-33) were of the opinion that risk assessments based upon individual exposure data are preferable to those based on group exposure data as done by White *et al.* In response to questioning from Mr. King, who inquired whether risk assessment performed later on, on the basis of more comprehensive data, by Crump and Allen would perhaps be a more reliable reflection of what the actual risk was in the total cohort. Dr. White stated

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"no * * *. Because we did a group estimate of exposure, there may be a wider range of confidence in terms of what the exposure was for the * * *. Crump * * * may have a narrow confidence interval around his estimates of exposure * * *. Our estimates may have been less precise. They may not have been necessarily less accurate "(Tr., 3/20/86, p. 172). March 20 at 172). Dr. White is speaking in technical terms. She is pointing out that her estimates of exposure could be as accurate as those derived by Crump, that is as close to reality, but that they are not as precise meaning that the confidence intervals surrounding her estimates of exposure are wider.

In response to the same questioning, Dr. Savitz stated that individual exposure data would be better than group exposure data, if indeed the individual exposure measures were more accurately reflective of what the individuals had received "(Tr., 3/24/86, p. 65). On this same issue, Dr. Crump responded that individual profiles give you more latitude in defining dose groups and searching for a dose response pattern although frequently it turns out that you'll get about the same risk estimate in an overall average (Tr., 3/24/86, p. 131).

Because of differences of opinion about the individual exposure data in the NIOSH cohort, quantitative risk assessment based on the individual exposure data in this study may or may not be more precise than those estimated from group exposure data. OSHA is of the opinion, however, that it is better to attempt quantitative risk assessment using as much data as available to determine dose response. Hence, the Crump and Allen risk assessment using individual exposure data for the entire cohort to define dose group may be given preference over the risk assessment performed by White *et al.* OSHA notes, however, that the results obtained by Crump and Allen are similar to those derived by White *et al.*

Under OSHA contract, Crump and Allen (1984) (Ex. No. 152) estimated excess leukemia deaths among workers exposed to benzene based on three epidemiologic studies that they considered most suitable for developing quantitative estimates of risks, the Rinsky *et al.* 1981 (NIOSH) study, the Ott, *et al.* 1978 (Dow) study and the Wong, 1984 study. A summary of their risk assessment follows.

Using the relative risk model and cumulative dose, the maximum likelihood estamate (MLE) based on data solely from the NIOSH study indicated that occupational exposure to 10 ppm benzene for 40 years would result in 63 excess leukemia deaths per 1000 workers. See Table D. Using the MLE and the weighted cumulative dose and relative risk model and based solely on data from the Rinksy and Ott studies combined, Crump and Allen estimated that the excess leukemia risk per 1000 workers exposed to benzene for 40 years would range from 29 associated with 10 ppm (400 ppm-yrs) and 3 associated with 1 ppm (40 ppm-yrs). The excess risk based on data from the Wong study resulted in an MLE of 121 excess leukemia deaths per 1000 workers exposed to 10 ppm for 40 years. With data for all three studies combined, Crump and Allen estimated a maximum likelihood of 88 excess leukemia deaths per 1000 workers exposed to 10 ppm for 40 years. The MLE associated with 40 years of exposure to 1 ppm was 6.6 per 1000 based on the NIOSH study, 13 per 1000 based on the Wong study and 9.5 per 1000 based on data for all three studies combined. For all studies combined the risk associated with 45 years of exposure (Occupational lifetime) to 10 ppm would be 95 per 1000 and to 1 ppm would be 10 per 1000. The risk associated with 0.5 ppm for 45 years is 5 excess leukemia deaths per 1000 workers.

TABLE D.—ESTIMATED EXCESS LEUKEMIA DEATHS PER 1000 WORKERS EXPOSED TO BENZENE FOR 40–45 YEARS (1 PPM OR 10 PPM) USING RELATIVE RISK AND CUMULATIVE EXPOSURE MODEL CRUMP AND ALLEN, 1984

Study	40 ppm-yrs		400 ppm-yrs	
	MLE	(95% CI)	MLE	(95% CI)
Rinsky (NIOSH)	6.6	(2.1–15)	63	(21–129)
Wong (CMA)	13	(0.1–31)	121	(1–243)
Rinsky, Wong and Ott	10	*(4–22)	95	*(37–186)

Source: Ex. No. 152.
*Indicates 45 ppm-yrs and 450 ppm-yrs, respectively.

A detailed analysis of the Crump and Allans study follows. In brief, OSHA concludes it is a high quality risk assessment. It utilizes the most data, utilizes the most appropriate model, utilizes sophisticated and appropriate statistical techniques and makes reasonable assumptions. The various criticisms made are responded to and do not call into question these conclusions.

Crump and Allen calculated dose for each individual cohort member in the NIOSH study. To do this, they used the NIOSH study data tape containing follow-up information on the cohort through 1978, plus various industrial hygiene reports and a NIOSH report detailing areas of work for each operation code listed on the computer tape (Ex. No. 152). The estimated concentrations in each area were then assigned to operation codes for each area. This procedure allowed them to construct a complete exposure profile for each worker.

Crump and Allen's estimates showed that the standards applicable to a given period were not in general exceeded, and thus corroborated the conclusion reached by Rinsky *et al.* Crump and Allen mentioned several aspects of their exposure estimation methods which influenced the dose estimates, but for which the direction of the bias was unknown: (1) use of data from two locations to arrive at one set of estimates; (2) averaging over years rather than interpolating values for each year; and (3) use of recommended standard concentrations to estimate concentrations when no data were available in a time period. They concluded:

> Given the variability in the measurements, in personal safety measures (e.g. use of respirators), in concentrations of benzene over time (within a day, perhaps), the estimates provided should not be considered to be precise. By the same reasoning, it seems that little could be done to refine the estimates given the information available.

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Using their new estimates of individual benzene exposure and the NIOSH data tape, Crump and Allen evaluated the dose response relationship between benzene exposure and leukemia in the NIOSH study. Eight deaths from leukemia observed in the study were included in the risk assessment calculations. Four leukemia deaths were excluded from the analysis. One case was a leukemia coded as aplastic anemia on the death certificate to enhance the widow's chances of receiving compensation, a second decedant had a clinical diagnosis of leukemia and two cases died from leukemia but did not satisfy requirements for membership in the cohort.

In the Ott *et al.* study, jobs histories were combined with estimated average exposure levels in various work areas by company personnel to construct a complete exposure profile for each cohort member. Cohort members were categorized according to whether they were exposed to arsenicals, asbestos, or vinyl chloride as well as benzene. (Numerous epidemiologic studies of workers exposed to these latter substances have failed to demonstrate an increased risk of leukemia. Thus, OSHA does not consider exposure of the Ott *et al.* cohort members to these substances to be confounding the relationship between benzene exposure and leukemia.) The data tape from the Ott *et al.* study was furnished to Crump and Allen for their analysis. This data set, containing only two leukemia deaths, was not used independently to assess risk, but rather, as used only in conjunction with data from the other epidemiologic studies. A third case of leukemia among Ott *et al.* cohort members was not included in the Crump and Allen analysis as this leukemia was listed under "other significant conditions" on the death certificate.

For the Wong study, the Crump and Allen risk assessment used data for the cohort members categorized as continuously exposed to benzene and a comparison group of chemical workers not exposed to benzene from the same plants. A cumulative benzene exposure index was calculated for each cohort member. Data from the three epidemiologic studies, Rinsky *et al.* Ott *et al.* and Wong *et al.* were then used to estimate the relationship between benzene exposure and leukemia.

Two alternative linear models were used. A relative risk model and an absolute risk model. Crump and Allen stated:

> Although many other dose response forms could be posited, it was felt that the number of leukemias is too few (there are only 16 leukemias in Rinsky *et al.*, Ott *et al.*, and Wong *et al.* cohorts combined) to permit discrimination among alternative dose response models. A linear model provides an acceptable fit to all the data sets examined. There are scientific grounds for believing that the dose response for carcinogens such as benzene is likely to be linear and particularly that the risk is not apt to be much larger than that predicted by a linear model (cf., e.g. Crump, 1984). Consequently linear dose-response models provide what have been described as "plausible upper limits for the risk at very low exposure levels" (Ex. No. 152, p. 16).

It should be noted, however, that OSHA relied on Crump's maximum likelihood estimates (MLE) of risk and not on his upper 95% confidence limits. In addition, OSHA is not extrapolating leukemia risk to very low exposure levels when it estimates risk for workers exposed to 1 ppm. Consequently, OSHA concludes Crump's MLE estimates are best estimates, not upper bounds.

The relative risk models assumes that the age-specific mortality rate for leukemia among benzene exposed workers is proportional to the age-specific mortality rate for leukemia among the general population. The absolute risk model assumes that additional mortality due to benzene exposure is the same for all ages given equal doses.

Crump and Allen also used four measures of benzene exposure in their analyses. One measure was the simple cumulative exposure in ppm-years. Another measure was a weighted cumulative exposure in ppm-years. Here, Crump and Allen assigned zero weight to exposures occurring within 2½ years prior to the five-year age interval of interest; exposures in the next earlier five years are given full weight. Exposures occurring more than 7½ years before the age interval of interest were assigned progressively less weight depending on when they occurred. A third measure was a "window" exposure in ppm-years. For this measure, only exposures occurring between 2½ and 12½ years prior to the age interval of interest were counted. The last measure of exposure considered by Crump and Allen was peak exposure which they defined as cumulative exposure in ppm-years of all exposures greater than 100 ppm.

Crump and Allen (Ex. No. 152) indicated a slight preference for estimates based on the relative risk model over the absolute risk model because it seemed more plausible to them that the effect of benzene exposure should be larger when the background occurrences of leukemia are larger. They preferred estimates of risk based on the cumulative or weighted cumulative measure of dose over those based on the "window" dose because the "window" dose allowed the risk to disappear completely after 15 years. This was not consistent with the data on leukemia among Japanese atomic bomb survivors. They also had a slight preference for the weighted cumulative measure of dose over the cumulative measure of dose because the model using this measure of dose fit the data somewhat better than those with cumulative dose and it seemed somewhat implausible to them, based on the Japanese A-bomb data, that a brief exposure early in life would entail the same risk 50 years hence as 15 years hence.

OSHA does not agree with a preference for the weighted cumulative dose. In its proposal, OSHA noted that the mode of industrial benzene exposure is different than A-bomb exposure. Workers are exposed to low levels or intermittent bursts of benzene over many years, whereas, A-bomb survivors experienced a single burst of radiation exposure.

Furthermore, the epidemiologic studies of workers exposed to benzene indicate relative risks for myeloid and monocytic leukemias (the most predominant cell types associated with benzene exposure) to range from 3.75 to 8.7 for cohorts of predominantly active or terminated employees as compared to 4.0 for cohorts of predominately retired employees (Ex. No. 142–13A—Shell study). OSHA also notes that 2 of 4 leukemia deaths in the Ott Bond study occurred after retirement. Therefore, the relative risk of death from leukemia may remain high following cessation of exposure. API (Ex. No. 204–7, P. 56) stated "In our judgment, application of the relative risk model and cumulative dose measurements to the Rinsky *et al.* data, provides the risk estimates which are most plausible in the Crump and Allen assessment." Furthermore, Crump and Allen considered "the estimate based upon cumulative or weighted exposure to be the most reliable" (Ex. No. 152, p. 33). Thus, OSHA viewed the relative risk model with cumulative dose as being the most representative of the models used by Crump and Allen to determine dose response. OSHA also prefers the Crump and Allen cumulative dose model over their weighted cumulative dose model because the latter model was not able to accommodate all data available from the three major studies of benzene exposed workers. It could only accommodate from the Rinsky and Ott studies.

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Some issues were raised about the Crump and Allen risk assessment regarding their exposure assessment based on the NIOSH study, their use of a linear model and their use of three epidemiologic studies to determine dose-response. These issues are discussed in sequence below.

Virtually all of those who commented on the Crump and Allen exposure assessment (Ex. No. 152) felt they did a good job of estimating dose for individuals in the cohort studied by Rinsky *et al.* (Ex. 259A). For example, API stated that "the record establishes overwhelmingly that Crump's exposure estimates for the Pliofilm cohort are superior" to those estimated by NIOSH (Ex. No. 260, p. 10) and that the Crump Assessment employed a more rational extrapolation procedure (Ex. No. 260, p. 36a).

Rodricks & Brett evaluated the exposure assessments of Rinsky *et al.* and Crump and Allen for API and concluded that "in the absence of additional monitoring data it is not possible to render a judgment as to which methodology best estimates the absolute exposure experienced by the cohort" because the differences between the estimates of the two groups were related to methodologies for estimating exposures when no industrial hygiene data were available (Ex. No. 204-7, p. 67). Dr. Goldstein, who testified for API also stated:

> We must remember through the efforts of Dr. Infante, Rinsky and their colleagues at NIOSH, the group of workers which we presented surveillance data on, is not only the most thoroughly studied of any group of benzene exposed individuals but perhaps the most thoroughly studied of any American workforce in terms of this retrospective exposure assessment. People really worked hard to try to figure out what the exposure was to these individuals (Tr., 3/26/87, pp. 119-120).

In response to a question by Dr. Miller, Dr. Rodricks stated:

> In our review of the available epidemiology data, we saw what Rinsky had done in 1981 with his very, very careful analysis of exposures in Pliofilm operation, being vastly superior to anything else available—not that the others do not suggest an effect. . . . So we relied very much on what Dr. Rinsky had done with those exposure data. They were as good as I have ever seen for epidemiologic data. Dr. Crump seemed to reach the same conclusion and also used the data, but made what were thought were some refinements in the way exposures were treated (Tr., 3/21/86, pp. 90-91).

Thus, Rodricks & Brett preferred Crump and Allen's methodology and felt an analysis by Kipen *et al.* on correlations of hematology data with pliofilm benzene exposure data added support for their preference.

OSHA is of the opinion that both Rinsky, and Crump and Allen made reasonable assumptions regarding individual exposures. The Crump and Allen assessment results in higher estimated benzene exposures particularly during the earliest years of the cohort's employment. This may result in lower estimates of risk. In determining its best estimate of leukemia risk, OSHA will use the exposure estimates by Crump and Allen.

Several commenters discussed the use of the Rinsky *et al.*, Ott *et al.* and the Wong studies by Crump and Allen for estimating the relationship between leukemia and benzene exposure. All commenters agreed on the appropriateness of using the Rinsky *et al.* study for risk assessment and most agreed on using the Ott study. Some commenters agreed on the appropriateness of using the Wong study for risk assessment and others did not.

API (Ex. No. 260, p 12a) contended that the NIOSH cohort studied by Rinsky *et al.* was superior to the other cohorts for risk assessment. First, API stated that the NIOSH cohort produced relatively more precise estimates of risk because it contained more leukemia deaths than either the Ott or Wong cohorts and hence less statistical uncertainty in its estimates of risk. It also noted that all three studies contained relatively small absolute numbers of leukemia deaths. There were 9 leukemia deaths in the NIOSH study, 7 in the Wong study and 4 in the update of the Ott study published by Bond *et al.* OSHA concludes that combining studies is a good way of responding to the fact that the studies do not have large numbers of deaths. The consistency of results as exists here further strengthens this conclusion.

Second, API argued that a dose response relationship, which is a favorable factor to have in a study selected for risk assessment, was observed in the NIOSH study, was not observed in the Ott study, and was observed in the Wong study but only because of a substantial decrease in leukemia rates for the control groups of workers. API also argued that the Ott and Wong studies both involved workers who had greater opportunity for exposure to other chemicals than did the NIOSH cohort members (Ex. No. 260, pp. 14-16). As mentioned earlier, none of the additional chemicals to which these workers were exposed have been demonstrated to cause leukemia.

Dr. Savitz testified (Ex. No. 222) that all three studies used by Crump and Allen are of sufficiently high quality and consistency to provide valid and credible estimates of the relationship between benzene and leukemia. He stated that the major limitation of the Ott/Bond study was the small number of expected leukemia deaths because this would result in wide confidence limits for the observed excess leukemia risk. He concluded "Nonetheless, the risk estimates for leukemia are comparable to those generated in the other studies of benzene and leukemia." With regard to the Wong study, Savitz testified that concerns about the exposed and unexposed workers and the low mortality rates in the unexposed workers have been raised, "but do not negate the value of the dose-response gradient which was seen" for those exposed to benzene. He felt the favorable mortality for lymphohematopoietic cancers in the workers unexposed to benzene may reflect the healthy worker effect or a chance finding. He stated that the "usual uncertainties about the accuracy of exposure data and the small number of cases upon which the dose-response function is based could be expected to mask rather than exaggerate the pattern, rendering the observed dose-response relationship an underestimate of the true effects of benzene" (Ex. No. 222).

In response to questioning about possible errors made in assigning dose, Dr. Savitz stated that "saying something is high when it's not, saying something is low when it's not, * * * will bias the risk ratio toward the value of 1.0. There is no way that that will bias it upwards [Note: a risk ratio of 1.0 would indicate no elevated risk] (Tr., 3/24/86, p. 92). In other words, misclassification of dose results in a bias toward finding no dose response. In response to a question about which epidemiologic study he would use for benzene risk assessment, Dr. Savitz stated that he would accept no single study as sufficiently definitive and that the more confident one is in the overall pattern of the results (Tr., 3/24/86, p. 99).

Bond *et al.* (Ex. No. 201-28) updated the Ott study and concluded that their study provided support for an association between benzene exposure and leukemia but that the study should not be used for risk assessment because of competing exposures to other substances and the small number of leukemia deaths observed. In 1977, however, Dow lowered its benzene ceiling concentration to 10 ppm in all its plants worldwide on the basis of the identification of the third leukemia case in this study (Ex. No. 82). API (Ex. No.

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247–F) conducted an analysis on the DOW data and were not able to demonstrate a dose response from these data. Dr. MacMahon (Ex. No. 201–33 at Appendix B), in a comment submitted by CMA, stated that these data provided the most convincing evidence for benzene being leukemogenic at concentrations of 10 ppm and below.

OSHA concludes that the Bond/Ott study is not large enough to attempt to establish several data points in the evaluation of dose/response. Either its data should be combined with other studies or a point estimate used. These approaches were followed by Crump and White. Crump and Allen combined data for the entire Ott cohort (characterized by individual exposure) with data from the Rinsky and Wong studies. White *et al.* as well as IARC and EPA used a point estimate of 3.75 for the relative risk of leukemia in relation to an estimated average dose for the entire Ott cohort. OSHA concludes that either of these approaches represent reasonable use of this data set and are consistent with approaches used by OSHA in its asbestos risk assessment (29 CFR 1910 and 1926, June 20, 1986).

CMA stated "that while the Rinsky and Ott studies may provide appropriate data for quantitative risk assessment, the Wong study should not be used for that purpose" (Ex. No. 258 p. 58). Citing Rinsky's critique of Wong's exposure assessment methodology, CMA stated that exposure assessment was not uniform because personnel from each plant were responsible for assembling their own data (Ex. No. 247, Attach 1).

Rinsky stated that Wong's results were not inconsistent with previous reports showing a relationship between benzene exposure and leukemia. In a letter to CMA from the Director of NIOSH transmitting NIOSH's review of the Wong study, Dr. Millar stated that the Wong study "adds information to our understanding of a possible dose-response relationship between cumulative exposure to benzene (ppm-months) and development of leukemia" (Ex. No. 247, Attach 1).

In both his written testimony and in his written report, Dr. Wong stated several times that his data were subject to thorough audits and no major errors were found (Ex. No. 235). "Our data audits indicated that the cohort was 99.2% complete, and the accuracy of coding was 97.4%. As such, we did not feel that the data had any major obvious problems." Dr. Wong also commented (Ex. No. 235) that he disagreed with a contention that data collection in his study was unsupervised. He stated that many of the individuals at the companies responsible for data collection are professional epidemiologists and that the uniform task approach used in his study "provided a procedure for the industrial hygienists to consider carefully the exposure level associated with each particular task" (Ex. No. 151–A, p. 19).

OSHA concludes that the exposure data in the Wong study is quite good. It was gathered by expert industrial hygienists based on exposure data and evaluation. The protocol was approved by CMA.

At the hearing, Dr. Wong stated that his study should not be used for risk assessment because he did not believe it was precise enough to give exact results. OSHA concludes that the data are reasonable and sufficient for risk assessment purposes. Crump and Allen Crump believed that the data were appropriate for risk assessment purposes. The results are consistent with assessments from other studies. The dose-response relationship in the study is an additional reason to support its use for risk assessment purposes. The preciseness that Dr. Wong believes necessary would seldom if ever be available for human studies.

All of the major risk assessments based on epidemiologic data done prior to the OSHA hearing had made use of the NIOSH (Infante/Rinsky) or DOW studies. The Wong study was not available at the time these risk assessments were performed. The Crump and assessment was done later and they chose to include it. Only the risk assessment conducted for API by Chinchilli and Rodricks limited itself to using the NIOSH study.

There was some discussion during the rulemaking that Crump and Allen's risk assessment did not include data from the most recent updates of the NIOSH and Ott cohorts. API (Ex. No. 260, p. 9) in its post-hearing submission argued that the Rinsky and Ott studies have been updated and all risk assessments completed prior to the hearing such as the White, *et al.*, Crump and Allen and the EPA's Carcinogen Assessment Group's (CAG) assessments are in practical effect superseded. While the CAG risk assessment published in 1979 used data from the initial NIOSH benzene study by Infante published in 1977, both White *et al.* and Crump and Allen used more updated data from the NIOSH study. However, the updates did not change the results substantially, so OSHA concludes assessments based or the earlier results are not superseded.

The Bond update of the Ott study included 134 additional workers first exposed after 1973 and 228 who were first exposed after 1965. The results of the update indicated a 4-fold risk of myelogenous leukemia (based on 4 deaths) for a group exposed to average benzene concentrations of about 5 ppm. The earlier Ott study demonstrated a 3.75-fold increase in myelogenous leukemia (based on 3 cases) for a group exposed to an average benzene concentration of about 5 ppm. Thus, risk assessments based on this cohort at the two different periods of follow-up would not be substantially different regardless of whether a point estimate of the relative risk was used as done by White *et al.*, IARC or CAG or whether leukemia deaths were combined with the data of other studies as done by Crump and Allen.

The Rinsky 1986 update (Ex. No. 250 A) of the Rinsky 1981 report added 165 workers first exposed between 1960–65 and followed the entire cohort through 1981. He observed 9 leukemia deaths during the follow-up period. Crump and Allen used data for the cohort followed through 1978 and based their risk assessment on the inclusion of eight leukemia deaths. Thus, the slight difference in the observations over the two follow-up periods (1950–1978 by Crump and Allen versus 1950–1981 by Rinsky *et al.*) would not change the conclusions of the risk assessment based on follow-up of the entire cohort through 1978 as conducted by Crump and Allen.

OSHA prefers the Crump and Allen estimates based on the three studies as its best estimate of risk. See the discussion in the Summary of Risk Assessment and conclusions below.

Rinsky *et al.* (Ex. No. 250A) performed a risk assessment based on the data in their study. It was based on a matched case control analysis on a subset of the Pliofilm cohort. They matched 10 controls to each of the nine leukemia deaths that occurred through 1981 by year of birth and year first employed. This analysis was performed in order to evaluate the effects of various measures of benzene exposure and other potential confounders and effect modifiers on the relationship between benzene and leukemia. They performed a conditional logistic regression to examine the relationships between leukemia and benzene xposure, duration of exposure and average exposure rate.

This model gives an odds ratio of the form: $OR = \exp(B_1X_1 + B_2 + \ldots B_nXn)$ where the X_i's are exposure variables, potential confounders, and/or effect modifiers, and the B_i's are parameters to be estimated from the data. In other words, we assume there is a linear relationship between the log odds and

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the independent variable as expressed by the equation:

$\log (OR) = B_0X_0 + B_1X_1 \ldots + B_nX_n$.

Cumulative exposure expressed in ppm-years was reported to be the strongest predictor of death from leukemia with B=0.0126; 95% CI=0.0028-0.0244; (X^2=6.4; P=0.011). The P value indicates that the slope of the line, beta or B, was significantly different from zero. The results for duration of benzene exposure and average exposure in relation to relative odds of leukemia death were not provided in the report.

The equation established by Rinsky *et al.*, OR=exp [0.0126 ppm x years of benzene dose), predicted an odds ratio of 1.7 (C.I.=1.1 to 2.5) associated with 40 ppm-years of benzene exposure, i.e., 1 ppm for 40 years, and an odds ratio of 154 (CI=3.1 to 7785) associated with 400 ppm-years of exposure. The odds ratio associated with 1 ppm or 10 ppm exposure for 45 years (occupational lifetime) would be 1.76 and 290, respectively.

Based on these odds ratios, the relative risk of leukemia associated with 450 ppm-years of benzene exposure would be 290 times that of the general population. The relative risk of death from leukemia associated with 45 ppm-years of benzene exposure would be 1.7 times the general population. Rinsky *et al.* noted the large confidence interval surrounding their estimate of risk associated with the 450 ppm dose level and the narrower confidence interval surrounding the odds ratio at the 45 ppm dose level.

OSHA is of the opinion that NIOSH conducted a high quality epidemiologic study which has been used by numerous groups for quantitative risk assessment. To our knowledge, there has not been a quantitative risk assessment on benzene and leukemia which has not used the NIOSH study (Infante *et al.* 1977; Rinsky *et al.* 1981; Rinsky *et al.* 1986). Use of log-linear model which relates benzene dose to an exponential increase in the relative risk of death from leukemia also seems appropriate for testing hypotheses regarding associations between various explanatory variables and disease. In applying this method, Rinsky *et al.* found a highly significant relationship between cumulative benzene exposure and leukemia.

Chinchilli (Ex. No. 226-II) performed several additional risk assessments from the Rinsky *et al.* data set using the log-linear model. Chinchilli selected 10 controls for each of the nine leukemia deaths identified by Rinsky using three separate criteria for selection, resulting in three separate control sets. He also used the controls selected by Rinsky for comparative purposes (control set #1). Control set #2 was selected using Rinsky *et al.* criteria; control set #3 added criteria for inclusion of plant location in addition to date of birth and date of first employment; control set #4 used the criterion for date of last employment in addition to the three criteria used in control set #3. Chinchilli then used three separate exposure matrices. Exposure matrix #1 involved a slight modification to the Rinsky exposure estimation; exposure matrix #2 was similar to the Crump and Allen exposure matrix; exposure matrix #3 involved the revised Crump and Allen exposure matrix in which some exposure estimates were downgraded. In 11 of 12 analyses, the beta coefficient was significant, indicating a positive, non-zero dose response "relationship between benzene exposure and the odds of dying from leukemia." Chinchilli noted that the beta parameter did not change very much with changes of exposure matrices [Ex. No. 226-II, p. 13).

The Chinchilli approach was to take the data supplied by NIOSH and make various alternative assumptions. This led to a wide range of estimates from higher than OSHA's preferred estimate to lower. The higher estimates were from 137-819 per 1000 at 10 ppm to 2-7 per 1000 at 1 ppm. The lower were 5-11 per 1000 at 10 ppm at 0.4-0.7 per 1000 at 1 ppm. The higher range estimates were similar to those preferred by NIOSH. Chinchilli, Rodricks, and Brett, and API preferred the lower range estimates. Chinchilli preferred results based on control sets #3 and #4. See Table E. Rodricks and Brett [Ex. No. 204-7) preferred the use of control set #3 as they felt that control set #4, which matched on date of last employment, was not most appropriate since it is an indicator of exposure. API preferred the Chinchilli analysis based on Control set #3 and Crump and Allen's exposure estimates (exposure matrix #2).

TABLE E.—SUMMARY OF CHINCHILLI ANALYSIS OF RINSKY ET AL. (1986) USING CONDITIONAL LOGISTIC REGRESSION AND ALTERNATE EXPOSURE ASSUMPTIONS AND CONTROL SETS

Exposure matrix	Control set	Excess leukemia deaths per 1,000 workers exposed to benzene	
		45 ppm-years	450 ppm-years
1	1	5.1 (0.8-11.7)	634 (16-986)
1	2	8.4 (1.2-14.7)	819 (26-991)
1	3	4.2 (1.0-8.7)	449 (21-953)
1	4	2.6 (0.6-5.1)	137 (8-638)
2	1	0.5 (0.1-1.0)	8 (1-20)

TABLE E.—SUMMARY OF CHINCHILLI ANALYSIS OF RINSKY ET AL. (1986) USING CONDITIONAL LOGISTIC REGRESSION AND ALTERNATE EXPOSURE ASSUMPTIONS AND CONTROL SETS—Continued

Exposure matrix	Control set	Excess leukemia deaths per 1,000 workers exposed to benzene	
		45 ppm-years	450 ppm-years
2	2	0.7 (0.1-1.3)	11 (1-31)
2	3	0.6 (0.1-1.0)	8 (1-20)
2	4	0.4 (0.0-0.8)	5 (0-15)
3	1	1.9 (0.3-2.3)	30 (4-106)
3	2	1.6 (0.3-3.1)	47 (4-218)
3	3	1.2 (0.3-2.3)	28 (3-103)
3	4	0.9 (0.1-1.7)	16 (1-56)

Source: Ex. No. 226-II, Table 2A.
Numbers in parenthesis are 95% confidence intervals.

API submitted a report after the hearing record closed dated January 16, 1987 related to additional benzene exposure among cohort members in the Rinsky study. It urged OSHA not to delay issuance of a final standard while API was continuing to evaluate the NIOSH cohort benzene exposures. Furthermore, the issue of additional benzene exposure to the NIOSH cohort has been dealt with at length above. After reviewing the API recent submission (Ex. No. 261), OSHA is of the opinion that it does not contribute sufficient additional data that would justify reopening the record or change the Agency's conclusion on leukemia risk related to benzene exposure. OSHA agrees with API that the final benzene standard should not be delayed.

3. Choice of Model

Both the NIOSH and Chinchilli risk assessment used a conditional logistic regression analysis (log linear model). EPA-CAG, IARC, White, *et al.* and Crump utilized a linear mode. OSHA believes the linear model is preferable for benzene. (See also the discussion in the introduction).

A conditional logistic regression analysis has several limitations when used to predict lifetime risk from given exposure patterns. The exponential form of the dose response relationship was originally selected as a mathematical convenience by Cox (1972) and others who developed the method of analysis. It was not developed as a dose response model for cancer risk assessment. When used for testing hypotheses, the exact form of the model is generally not critical. However, in risk assessment.

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the form of the dose response model is of greater importance. Also, there were no comments presented during the rulemaking that would support a biological basis for assumption of a log-linear relationship.

The assumption of a log-linear relationship between dose and relative odds of developing leukemia will cause any variation in the estimate of dose to result in an exponential change in the associated risk. This has just been shown in the NIOSH and Chinchilli assessments where there is a broad range in the estimates of risk from the different assumptions Chinchilli made.

More importantly, there is more of a biological basis for using a linear model. In the experimental setting where dose can be controlled, several cancer sites from the NTP study and Maltoni study demonstrate a linear relationship between dose of benzene and incidence of tumors such as malignant lymphomas and mammary gland carcinomas. Several cytogenetic studies also demonstrated a linear relationship between dose of benzene and chromosomal effects. Toft *et al.* 1982 (Ex. No. 252 A–17–31), Tice *et al.* 1982 (Ex. No. 159–88) and one epidemiologic study (Picciano, 1980, Ex. No. 128–60) have demonstrated a linear dose-response between benzene exposure and increased frequencies of sister chromatid exchanges (SCE's), micronuclei in bone marrow erythroblasts, chromosomal breakage in circulating lymphocytes and inhibition of cellular proliferation and suggest that a linear model may have the most reasonable biological basis. In contrast, an exponential increase in chromosomal changes or in site-specific cancers with an increase in benzene dose does not seem to be supported in experimental animal studies.

A linear model has also given the best fit in occupational carcinogen risk assessments based on epidemiologic data presented to OSHA in other proceedings where more studies and data were available to evaluate the form of the dose response relationship. The use of linear models with epidemiologic data have best represented the dose response for arsenic and lung cancer and for asbestos and lung cancer. A linear model also demonstrates an adequate fit to the data as shown by Crump and Allen. Thus, for the reasons mentioned above, OSHA is of the opinion that the relationship between cumulative benzene exposure and leukemia is more apt to be linear than log-linear and hence prefers estimates based on a linear model.

4. Other Issues on Benzene Dose Response for Cancer

Rodricks and Brett (Ex. No. 204–7) also argued that the risks projected by the Rinsky *et al.* study may be overestimated because the exposure estimations for the study cohort members did not include any atmospheric or skin exposure to benzene that may have occurred during times of employment in non-Pliofilm jobs. This would be the case for those employed at location 2 more so than for those employed at location 1, since the former location had more opportunity for non-Pliofilm benzene exposure. For example, three of the individuals who died from leukemia at location 2 had jobs in either tire building operations or jobs with potential exposure to solvents outside of the Pliofilm operations. However, it is not known which types of solvents were being used by which of these workers at the time of their employment in these jobs, nor is it known what percent volume benzene may have been in those solvents that contained benzene.

Dr. Harris, who has conducted numerous studies in the rubber industry testified that he would be reluctant to compute airborne concentrations based upon solvent composition and that it is not possible to generalize the experience from pure benzene to solvents containing benzene (Tr., 3/19/86 pp. 128–31). He indicated a number of atmospheric conditions and properties of specific solvents which would need to be evaluated in order to determine whether such an estimate of airborne benzene concentrations could be considered. Such data have not been provided to the hearing record.

Mr. Wright, an industrial hygienist with the Steelworkers, argued that undocumented atmospheric and skin exposures to the Pliofilm cohort members that may have occurred prior to their employment in Pliofilm operations can only be considered speculation (Ex. No. 262). In response to a question by Mr. Sampson, Mr. Rinsky (Ex. No. 250) stated that he attempted to determine solvent exposures in non-Pliofilm jobs by interviewing people and searching Goodyear files and "found nothing reliable on which to base any estimates of exposure outside of Pliofilm."

OSHA is of the opinion that some members of the NIOSH Pliofilm cohort experienced some degree of benzene exposure through inhalation and dermal absorption, but that it is not possible to estimate in any reliable sense the amount of benzene to which these individuals may have been exposed. Furthermore, OSHA agrees with Dr. Crump (Tr., 3/18/86, pp. 130–131) who stated that an addition to the total cumulative benzene exposure of the cohort could result in either a greater or lesser carcinogenic potency even if mortality stayed the same. He further stated "it would depend on how the specific exposure is distributed in the population. I could see where it would go either way."

Rodricks and Brett (Ex. No. 247–F, p. 7) argued that if non-Pliofilm benzene exposure was randomly distributed in the cohort, the nature of the dose response relationship would change in that the absolute additional risk based on total benzene exposure (incorporating non-Pliofilm exposure) would decrease. They relied primarily on an additional analysis by Chinchilli as mentioned below for this opinion.

Chinchilli (Ex. No. 247–F) performed an additional analysis after the hearing in order to evaluate whether unaccounted for non-Pliofilm benzene exposure had any effect on the dose-response for benzene and leukemia if cases and controls received exactly the same amount of non-Pliofilm benzene exposure. Chinchilli used the case-control data set based on Rinsky matching criteria and exposure assessments (exposure matrix 1, control set 1 from Table 1 in Ex. No. 226–II). He then developed three new data sets by adding 100 ppm-years, 250 ppm-years and 500 ppm-years cumulative benzene exposure to the Rinsky data set. Chinchilli concluded that the slope parameter, beta, does not change when the additional exposure is added to the analysis, but that the background leukemia rate, Po, decreases with the net result being a decrease in additional leukemia risk from benzene exposure. In this analysis, Chinchilli used Po differently than he used it to estimate risk in his earlier submission (Ex. No. 226–II). In the earlier analysis, Po was the lifetime probability of leukemia mortality estimated independently of the Rinsky data by applying a lifetable analysis to current death rates from all causes and leukemia. If Chinchilli had been consistent and applied this approach in his latter analysis (Ex. No. 247–F), he would have applied the unchanged slope parameter to the unchanged Po, based on the U.S. general population, and concluded that the estimates of additional leukemia risk are unchanged as well by including the additional exposure. Furthermore, Chinchilli did not explain how the new estimates of Po in this supplemental submission (Ex. No. 247—F) were derived.

If the estimate was derived from the Rinsky study itself, it would generally be unstable and statistically uncertain. Second, and more important, we are interested in estimating risk to future worker populations, not the cohort studied by Rinsky and exposed in past years. Even if there was an estimated deficit in background leukemia deaths in the Rinsky study, there is no reason to expect a comparable deficit to occur in future exposed populations and consequently such a deficit (or excess) should not be used to estimate the leukemia risk to future populations. In OSHA's opinion, the best estimate of background leukemia risk (Po) of future workers is that derived from leukemia death rates in the general population as calculated by White *et al.* or Crump and Allen. Thus, contrary to Rodricks and Brett's opinion, the supplemental analysis by Chinchilli demonstrates that an increase in the same amount of non-Pliofilm benzene exposure to cases and controls in the Rinsky study does not change the estimates of additional leukemia risk.

Several arguments were made by industry consultants that non-Pliofilm benzene exposure to Rinsky cohort members was not accounted for and that the inclusion of such benzene exposures would result in a lower slope or beta coefficient to the dose response curve and result in a lower absolute risk of death from leukemia (Ex. N. 247–F. p. 9). However, an increase in the same moderate amount of benzene to each dose group will not change the estimates of additional risk because the slope of the dose response will remain the same.

Rodrick and Brett (Ex. No. 247–F, p. 9) conducted an analysis with the assumption that non-Pliofilm benzene exposure would add 100 ppm-years of benzene exposure to each of the four dose groups presented in Table 3 of the unrevised Rinsky *et al.* report dated August 9, 1985 (Ex. No. 176 A). In this report, Rinsky *et al.* presented data by four dose categories and corresponding SMR's: <40 ppm-yrs. SMR=105; 40–200 ppm-yrs, SMR=314; 200–400 ppm-yrs, SMR=1757 and greater than 400 ppm-yrs, SMR=4535. Rodricks and Brett then calculated excess risk of leukemia per 1000 workers for each of the four point estimates given above; they then added 100 ppm-years to each dose group and calculated new estimates of excess leukemia risk. The excess risk associated with 1 ppm for 45 years using the data reported by Rinsky *et al.* (Ex. No. 176 A) ranged from an equivalent of 0.8–28.4 per 1000 workers. After the addition of 100 ppm-years to each dose category listed above, the excess risk for 1 ppm exposure over 45 years ranges from 0.1–23.4 per 1000 workers. Therefore, the hypothetical addition of 100 ppm-years of benzene dose from non-Pliofilm jobs results in little change in the range of the absolute excess risk of leukemia as a result of 1 ppm exposure for a 45 year period.

A major problem with this analysis, however, is that the range of estimates was based on four separate data points independently and the use of each data point separately results in more uncertainty in the estimate of risk. Therefore, on the bases of the Chinchilli and Rodricks and Brett analyses, the random distribution of non-Pliofilm benzene exposure (or unaccounted for additional Pliofilm benzene exposure) to the cohort in the Rinsky *et al.* study would have relatively little effect on the estimate of risk.

Several witnesses at the hearing also expressed the view that additional benzene exposure to the cohort during non-Pliofilm operations was probably random and as such would have relatively little effect on the risk estimate.

NIOSH testified that it made all efforts reasonably possible to estimate the benzene exposure to the individuals comprising the Rinsky cohort. API has also made exhaustive efforts to modify the cohort's benzene exposure, requesting additional information on dermal exposure, engineering records, non-Pliofilm operation etc. from Goodyear Tire and Rubber Company where the NIOSH cohort members were employed. The Vice President of Goodyear responded that the records (30–40 years old) API requested do not exist and that the use of incomplete data based upon ancedotal information could lead to serious misinterpretation and would not significantly improve the various risk assessments already available (Ex. No. 247–D–35).

OSHA hired a contractor, Crump and Allen to independently estimate individual's benzene exposure in the Rinsky study. Most witnesses, including those from industry, thought Crump and Allen did a good job of estimating benzene exposure. Rodricks and Brett and Chinchilli relied on Crump and Allen's exposure estimates for their preferred analyses.

Whether the data indicate there were significant amounts of unreported exposures are not easily studied with the retrospective approach used by Chinchilli, because it relates to the estimate of the intercept, which a retrospective analysis does not directly provide. However, it can be studied using the prospective method of analysis employed by Crump and Allen. Additional unreported exposures that occurred more or less uniformly across the population would manifest themselves in estimates of the intercept from the risk analyses as being larger than 1, and/or in an excess (relative to the control population) of leukemias in the lower exposure groups. In fact, neither of these conditions occurred. Estimates of the intercept in the five analyses that used only the Rinsky data are 0.87, 0.82, 0.88 (Table 12, Ex. No. 152) 0.18 (Table 14) and 1.11 (Table 16). All but one of these estimates of intercept is less than one and the exception is from the analysis that was considered the least reliable, the "window" dose analysis (Ex. No. 152). Thus the Rinsky *et al.* data provide evidence against uniform exposures from other sources of a magnitude sufficient to affect leukemia rates in the study.

OSHA concludes that there was some additional exposure, but the data indicate that it did not make any substantial difference in the risk estimates. There was a clear dose response in the NIOSH study and internal analysis of the data show that any extra dose received by the cohort was not large enough to make a difference in the estimates.

API has stated that the assumptions used by OSHA and its contractor in developing quantitative cancer risk assessments for benzene overestimate the risk. OSHA disagrees. The risk assessment OSHA has relied upon for this final standard is derived from epidemiologic studies which relate relative risks for leukemia to cumulative dose of benzene exposure. The study cohorts were derived from a comparison of mortality among employed populations (except for the Wong study) to that of the general population which is comprised of less healthy individuals. Because the study results do not take into consideration this phenomenon known as the "healthy worker effect," the relative risks estimated in the epidemiologic studies probably underestimate the true risk of disease in the industrial cohorts. Likewise, the cohorts used for the quantitative risk assessments were comprised of workers who were employed for relatively short periods of time. If benzene acts as a promoter as well as an initiator of the carcinogenic process, the resulting risks would be underestimated.

The risk estimates OSHA relied upon calculated maximum likelihood estimates (MLE) as well as 95% confidence intervals on those estimates. OSHA did not select the upper 95% confidence interval as an estimate of

risk which would lead to higher estimates of risk. Furthermore, the risks from blood diseases other than leukemia were not counted in the quantitative risk assessment, deaths from multiple myeloma were not included despite epidemiologic evidence for an association with benzene exposure and "other diseases of the blood and blood-forming organs" were not included in OSHA's quantitative estimate of risk. These exclusions serve to underestimate the risk of disease related to benzene exposure.

Lastly, that OSHA used epidemiologic data instead of animal data to quantify the risk further supports the Agency's contention that risk assessment understates rather than overstates the risks. Studies of experimental animals exposed to benzene have demonstrated the induction of multiple solid tumors, yet OSHA did not use these data as part of its quantitative estimate of risks. OSHA used data for leukemia in humans only and did not include solid tumors in its estimate of cancer risk.

The API submitted a risk assessment performed by Chinchilli as a basis for its preferred estimate of cancer risk. Chinchilli used the NIOSH study only for estimating cancer risk. Rodricks and Brett preferred the exposure estimate of the NIOSH study by Crump and Allen to that done by Rinsky *et al.* but on the other hand, they preferred the log-linear model used by Rinsky of NIOSH to the linear model used by Crump. Thus, they picked and chose various aspects of a single study rather than selecting all of the best available data for risk assessment.

OSHA prefers the risk assessment methodology used by Crump and Allen for several reasons as discussed above. They combined data from three separate epidemiologic studies for their risk assessment and thus used all of the best available data to determine excess risk. They demonstrated that the data from all three studies fit a linear model well. Furthermore, the linear model projected excess leukemia risks that were more mid-point estimates as compared to the log-linear model when considering both the high and low ranges of cumulative dose. A linear relationship has been demonstrated between benzene and several site-specific tumors in animals and chromosomal alterations in animals. Thus, there appears to be biological plausibility for a linear relationship as well as a statistical plausibility.

5. Studies Showing Effects on DNA and Bone Marrow

Studies have demonstrated chromosomal abberrations in workers exposed to benzene levels that averaged below 10 ppm. Fredga *et al.* (1979, Ex. No. 128–57) have demonstrated a significant increase in chromosomal aberrations among industrial workers exposed for several hours a day to benzene levels ranging between 5 and 10 ppm as compared to expected values.

The results of the DOW Chemical Company study (Holder, 1978, Ex. No. 159–45) demonstrate a significant excess of chromosomal aberrations among the benzene exposed workers as compared to controls. Average benzene exposures of these workers were reported as being below 10 ppm. This study also demonstrates an exposure level-response for chromosomal breakage resulting from average bezene exposures below 10 ppm and perhaps below 1 ppm.

As mentioned earlier, there is expert scientific opinion that the induction of chromosomal aberrations serve to give an estimate of the magnitude of an exposure that could increase the risk of disease (Bloom *et al.* 1981). Thus, chromosomal aberrations have been demonstrated in experimental animals subjected to a single six-hour exposure of 1 ppm benzene. Chromosomal aberrations also have been demonstrated in workers exposed to average concentrations of benzene averaging between 1 ppm and 10 ppm. These toxic responses had previously been observed at higher experimental doses or among workers exposed to higher levels of benzene concentrations. There was little, if any, dispute to these findings during the proceeding. An issue was raised, however, regarding the meaning of chromosomal aberrations in relation to benzene induced leukemia.

The exact mechanistic interaction of benzene and/or its metabolite(s) with cellular DNA which eventually leads to human cancer is not known. Nor is it known for any carcinogen. However, there is a substantial body of evidence relating chromosomal aberrations (errors in chromosomal number or in breakage) to an increased risk of cancer. Some of this evidence was presented in the introduction of the reports that justified the chromosomal studies being conducted. In the past 10 years there has been a substantial amount of data that has identified very specific breaks in chromosomes that have been related to specific tumors and particularly to leukemia in humans. While OSHA is of the opinion that the exact mechanism by which benzene causes leukemia is not known, as with all carcinogens, it is highly likely that benzene's effect on the DNA that results in chromosomal aberrations is a part of the process related to the eventual development of cancer. Thus, the Agency views the observations of benzene induced chromosomal aberrations in experimental animals and humans as a significant finding in relation to the toxicity of benzene.

Thus, the risks estimated using quantitative risk assessment procedures are consistent with empirical evidence demonstrating the induction of chromosomal aberrations and leukemia as a result of benzene exposures below 10 ppm.

6. Summary of Risk Assessment and Conclusions

OSHA concludes that there are good studies available to be used for the basis of risk assessment. A number of reasonable risk assessments have been performed. OSHA prefers the Crump and Allen estimates based on the cumulative dose and relative risk model and the results from the three studies which provide a good basis for risk assessment because it makes use of the most data, uses the most biologically plausible model and is in the middle of other estimates.

This estimate for a working lifetime of exposure (45 years) to 10 ppm is 95 excess leukemia deaths per 1000 workers and to 1 ppm is 10 excess deaths per 1000 workers. OSHA has also used these estimates in quantifying the number of lives saved from leukemia.

The NIOSH study was carried out in a detailed and careful manner with virtually complete follow-up and excellent and extensive efforts were used to characterize dose. The clear dose response relationship further strengthens the results. The Ott study is smaller, but there are reasonably good exposure data and the study clearly demonstrates an excess risk at low dose with average exposures of approximately 5 ppm for the cohort.

The Wong study had very complete follow-up and careful ascertainment of death. OSHA believes the estimates of exposure are reasonable having been performed by knowledgeable plant industrial hygienists based on a protocol approved by CMA. There was also a clear dose response.

Most risk assessments used a linear model (IARC, EPA-CAG, Crump and Allen, White *et al.*) They made estimates sometimes using the studies together and other times using the studies independently. Various differing assumptions of exposure were made, but the range of estimates was narrow. From 50–150 excess leukemia deaths per 1000 exposed workers were estimated over a working lifetime at 10 ppm, and 5–15 excess deaths per 1000 were estimated at 1 ppm. This narrow range adds further confidence to OSHA's best

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estimate. OSHA prefers the linear model with epidemiologic data to the log-linear model.

In previous OSHA proceedings where the cancer being evaluated was more common (lung cancer) and there were more studies available for the substances of concern (arsenic and asbestos), the linear model best described the shape of the dose response curve. OSHA preferred the Crump and Allen risk assessment because it was based on data from all three major epidemiologic studies that were of the highest quality. They also used a linear relative risk model that has been widely used and accepted for cancer risk assessment with epidemiologic data. The estimated risk was also in the middle of the other estimates made.

All parties were of the opinion that the Rinsky study is a well conducted study that is appropriate for use in determining risk. API also agreed that it is appropriate for use in quantitative risk assessment. API also preferred the Crump and Allen exposure assessment. Therefore, the selection of the Crump and Allen quantitative risk assessment includes the Rinsky study and the Crump and Allen exposure assessment. Even if OSHA had relied only on the Rinsky study with the Crump and Allen quantitative risk assessment, as shown in Table D, the excess risk of leukemia per 1000 workers over an occupational lifetime is 64 per 1000 at 10 ppm and 6 per 1000 at 1 ppm. This risk is not appreciably different than the risks projected using data from all three studies and it is OSHA's opinion that it is better to use all of the available good quality data for estimating risks. More confidence in the projected risks can be gained by evaluating estimates of risk using all of the high quality studies.

Several questions were raised about additional dose from skin absorption and several different assumptions were made about dose. But as discussed above, the additional dose from skin absorption could have led to either higher or lower estimates of risk. The analyses performed indicate that in any event, such additional exposures would not substantially alter the estimates.

OSHA preferred to rely upon risks projected from epidemiologic data rather than upon those derived from animal cancer studies. However, the animal cancer studies were of high quality and if high quality epidemiologic studies had not been available, OSHA would have relied upon the animal studies to estimate quantitative cancer risk to workers exposed to benzene. As pointed out by one witness for the API, it was very reassuring that so many different risk assessments all seem to come up with roughly the same number. He went on to explain that the average risk projected by EPA from several animal studies was virtually identical to the average risk EPA estimated from three epidemiological studies. Therefore, cancer risks based upon either epidemiologic studies or animal cancer studies would have been similar.

Finally, it is unusual to have observational data demonstrating a significant increase in cancer so close to a new permissible exposure limit being promulgated by OSHA. The study conducted by Dow Chemical Company has been accepted as a well conducted study and has been relied upon (as well as the NIOSH study) by numerous prestigeous groups and individuals for conducting quantitative cancer risk assessment. This study demonstrates a significant 4-fold increase in myelogenous leukemia for workers who had been exposed to average benzene concentrations of about 5 ppm for an average of about nine years. Furthermore, two out of the four individuals in the study who died from leukemia were characterized as having been exposed to average benzene levels below 2 ppm. The major epidemiologist representing CMA during these proceedings also interpreted the Dow study as providing the most convincing direct evidence for benzene causing leukemia as a result of exposures below 10 ppm (Ex. No. 201–33, p. 22).

Likewise, cytogenetic studies have demonstrated chromosomal damage among workers exposed to benzene below 10 ppm and in animals exposed to 1 ppm for a single 6-hour period. Thus, OSHA concludes that a significant risk of cancer is associated with a 10 ppm exposure limit and that this risk can be significantly reduced through the promulgation of a 1 ppm average PEL and a 5 ppm short-term exposure limit along with other provisions of the standard.

VII. Significance of Risk

OSHA follows the direction of the Supreme Court in the Benzene decision (*Industrial Union Dept., AFL–CIO v. American Petroleum Inst.*, 448 U.S. (1980)) and its statute in deciding whether to issue a new or revised standard. In regulating toxic materials, OSHA must make a determination that a "significant" health risk exists and that the new or revised standard will substantially reduce or eliminate that risk.

In the Benzene decision, the Supreme Court indicated when a reasonable person might consider the risk significant and take steps to decrease it. The Court stated:

> It is the Agency's responsibility to determine in the first instance what it considers to be a "significant" risk. Some risks are plainly acceptable and others are plainly unacceptable. If, for example, the odds are one in a billion that a person will die from cancer by taking a drink of chlorinated water, the risk clearly could not be considered significant. On the other hand, if the odds are one in a thousand that regular inhalation of gasoline vapors that are 2% benzene will be fatal a reasonable person might well consider the risk significant and take the appropriate steps to decrease or eliminate it; (*I.U.D.* v. *A.P.I.*, 448 U.S. at 655).

The Court stated that "while the Agency must support its findings that a certain level of risk exists with substantial evidence, we recognize that its determination that a particular level of risk is 'significant' will be based largely on policy considerations." The Court added that the significant risk determination required by the OSH Act is "not a mathematical straightjacket," and that "OSHA is not required to support its findings with anything approaching scientific certainty." The Court ruled that "a reviewing court (is) to give OSHA some leeway where its findings must be made on the frontiers of scientific knowledge (and that * * * the Agency is free to use conservative assumptions in interpreting the data with respect to carcinogens, risking error on the side of overprotection rather than underprotection" (448 U.S. at 655, 656).

As part of the overall significant risk determination, OSHA considers a number of factors. These include the type of the risk presented, the quality of the underlying data, the reasonableness of the risk assessments, the statistical significance of the findings and the significance of risk (See, for example, Arsenic, 48 FR 1864, January 14, 1983).

Benzene exposure causes a number of serious health risks. As discussed in section V–A benzene exposure is a cause of leukemia. Adult leukemia has a poor, survival rate (unlike childhood leukemia), and a shorter latency period than many types of cancer. It clearly is a fatal disease. Findings also indicate that benzene is assocated with multiple myeloma (plasma cell cancer of the bone marrow) and lymphatic cancers.

Benzene exposure is also known to cause aplastic anemia. This disease of the bone marrow reduces the body's oxygen transportation abilities, resistance to infection and clotting abilities. It can lead to death and often cannot be effectively treated. Even in those instances where the condition is

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responsive to therapy and the patient survives, the individual cellular elements of the blood rarely return to normal levels.

Benzene exposure is also associated with other forms of toxicity to the bone marrow. These conditions are serious, but often treatable and reversible if caught in their early stages.

As discussed in the health effects section, benzene exposure is also clearly associated with chromosomal damage. While such findings do not provide direct evidence for a genetic or carcinogenic effect, they do constitute indirect evidence for cancer because cellular DNA is being adversely affected.

Clearly both cancer, predominantly leukemia, and aplastic anemia are risks of the most serious and often fatal kind. The other disease risks are also serious, though not usually fatal. Although this significant risk discussion concentrates on the leukemia risk, and concludes that that risk alone is significant, the other risks, though not as readily quantifiable, add to the significance of the risk presented.

The underlying epidemiologic studies which provide a basis for the quantification of risk are in general of reasonable to high quality, clearly demonstrate a relationship between benzene exposure and leukemia, and provide a basis for risk assessment. There is a reasonable basis for determining the exposed population and excluding other agents. In the Rinsky, Ott and Wong studies there is excellent follow up. Follow up is not as extensive in the Askoy and Vigliani studies, but the methodology would tend to underestimate disease incidence. The Wong and Ott studies provide a reasonable basis for estimating dose with some contemporaneous exposure measurements and expert evaluations. The estimates of dose in some of the studies approach the level which currently exposed workers would experience over an occupational lifetime.

Subsequent to the proposal, the Rinsky 1986 study was completed. This study including a detailed evalution of contemporaneous exposure data and an assignment of cumulative exposure for each worker. All or virtually all participants in the rulemaking including API agreed it was an excellent evaluation of dose while the workers were at Pliofilm, far better than most retrospective epidemiology studies.

In addition, 2 of the studies, Wong, 1983 and Rinsky, 1986 demonstrated a clear dose response relationship, that is, higher exposures lead to higher risks of cancer. This strengthens the already high degree of confidence in utilizing the studies for risk assessment. In addition they are direct evidence that lowering exposure leads to substantial reduction in risk.

The studies which OSHA principally relies were statistically significant. The dose response relationship in Rinsky, 1986, and Wong, 1983, is statistically significant.

The International Agency for Research on Cancer and the Carcinogen Assessment Group of the Environmental Protection Agency concluded that the data available prior to the completion of Wong study and Rinsky, 1986 update were sufficient to perform risk assessments on the relationship between benzene exposure and leukemia.

OSHA concludes that the underlying epidemiologic studies provide a strong basis for risk assessment. There are several high quality epidemiologic studies with excellent follow-up and good to excellent exposure data. Two studies provide direct evidence of clear dose response. As discussed above the estimates of risk from the studies separately and taken together provide relatively close and consistent estimates of risk. A number of experts such as Dr. Crump agree that they provide a sound basis for risk assessment. (See also the extended discussion in the risk assessment section).

Since 1978, three major studies of high quality in experimental animals have confirmed the carcinogenicity of benzene. As discussed above, the National Toxicology Program (NTP) has demonstrated statistically significant, dose-dependent increases in cancers of multiple sites for both sexes of two species using its standard protocol. A minimum of nine tumor types or sites have been induced in mice and rats by benzene in the NTP study. Maltoni also demonstrated the induction of cancer in rats exposed to benzene through both inhalation and oral gavage as discussed above.

The animal data by themselves would provide a good basis for risk assessment. A number of the tumor sites demonstration clear dose-response down to the lowest level test. There was excess cancer incidence down to an equivalent of 20 ppm inhalation, the lowest exposure level tested in the NTP study.

Section VI, immediately above, discusses at length the risk assessments performed for benzene, the basis for those assessments and criticism of those assessments.

As analyzed above, a number of authoritative organizations and distinguished scientists have performed risk assessments on benzene. For example the Environmental Protection Agency-Carcinogen Assessment Group estimated, adjusted to occupational exposures for a working lifetime, that benzene presents a risk of 34 excess leukemia deaths per 1000 workers exposed to 10 ppm and 3.4 per 1000 at 1 ppm. The International Agency for Research on Cancer's assessment, based on the Rinsky, 1981 study, converted to occupational lifetime exposure, shows an excess risk of 14–140 per 1000 at 10 ppm and 1.4 per 1000 at 1 ppm.

(The estimates presented are based on a working lifetime of exposure of 40 to 45 years during working hours. Many employees in the chemical, petrochemical and refinery industries do spend a substantial part of their working lifetime in the industry. Section 6[b][5] of the OSHA their act states that OSHA health standards, should create a situation such "that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life.")

The White, et al. risk assessment estimated excess leukemia risk of 44–156 per 1000 at 10 ppm and 5–16 per 1000 at 1 ppm. This study has been extensively reviewed and the comments responded to as discussed above.

Crump and Allen performed risk assessments using data from the three major epidemiologic studies that evaluated benzene and leukemia. In one analysis, they combined the results of the Ott, Wong and Rinsky studies. This analysis utilized the most detailed exposure data available for the Rinsky and Ott, studies. That assessment indicated an excess risk per 1000 exposed workers of 95 leukemia deaths at 10 ppm and 10 at 1 ppm. The confidence intervals were also computed and are quite narrow. There is 95% confidence that the risk is between 37 and 186 per 1000 at 10 ppm and between 4 and 22 per 1000 at 1 ppm.

NIOSH and the American Petroleum Institute presented assessments utilizing the log-linear model. This model is more commonly used for measuring the effects of various confounding variables on dose response then for cancer risk assessment. It has an exponential term that can result in very large changes in risk over small changes in exposure. The NIOSH estimate of risk converted to the method of presentation used here as 634 at 10 ppm and 5 at 1 ppm.

The API presented an assessment by Chinchilli as analyzed by Rodricks and Brett. Their preferred estimate based on the Rinsky study, the log-linear model,

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the initial Crump exposure assessment and various adjustments is 8 excess leukemia deaths per 1000 at 10 ppm and 0.6 at 1 ppm. However, they argued the risk will probably be lower because they believe exposures in the Rinsky study might have been higher then the estimates.

Several risk assessment based on animal data have been performed. EPA–CAG estimated 30 excess human deaths per 1000 exposed workers at 10 ppm and 3 at 1 ppm based on Zymbal gland carcinoma in female rats. This estimate is virtually identical to the risk CAG projected based upon epidemiologic data. Crump, estimated 20 and 2 based on all squamous cell carcinomas in male mice. Hooper estimated 79 and 8 based on mammary carcinoma in female rats. Hooper converted animal exposure to human exposure based on adjustment for surface area differences between animals and humans while Crump made the adjustment based on body weight differences. Both are accepted techniques.

OSHA concludes that it is more appropriate to utilize the human data for significant risk analysis since it avoids the need to convert animal results to human risk. Most participants in the proceeding recommended this approach. However, the animal data are strong and allow for better control of dose than epidemiologic studies. The animal estimates are consistent with the human estimates and would be a strong basis for risk assessment if good human data were not available.

OSHA concludes that the Crump and Allen estimates based on the three epidemiologic studies is its perferred maximum likelihood estimate. That estimate is based on the most data of any risk assessment. Because of possible unique factors at one location or mistakes in estimation of exposure or relative risk, consistent results from several good studies add to the confidence in the estimate of risk. Crump and Allen made use of the most extensive exposure data with an approach preferred by API. They also used a model for epidemiologic data which is widely accepted for cancer risk assessment purposes and the data fit the model acceptably. The model is also supported by biologic data which is discussed extensively above. A number of the chromosomal and blood element responses to benzene in both humans and animals are clearly linear. In addition, it is an estimated broadly in the middle range of other reasonable estimates presented.

The Crump and Allen assessment projects the risk as 95 excess leukemia death per 1000 exposed employees for a working lifetime of exposure to 10 ppm benzene and 10 excess deaths per 1000 at 1 ppm. The other reasonable estimates projected risks ranging from 8–634 per 1000 ppm and from 0.6 to 16 per 1000 at 1 ppm (The NIOSH estimate at 634 per 1000 is substantially higher than the next highest of 156 per 1000 at 10 ppm). These are maximum likelihood estimates not upper confidence bounds.

OSHA's best estimate of risk is approximately in the mid point of its best estimates at time of the proposal (44–152 per 1000 at 10 ppm). Subsequent to the proposal OSHA has had the benefit of additional data and time to analyze the Wong data and exposure analysis by Crump and Allen. The new best estimate takes all this evaluation into account. The Crump and Allen estimates incorporate modifications to the NIOSH exposure estimates which API recommended.

The American Petroleum Institute preferred the Chinchilli-Rodricks-Brett analysis of 8 at 10 ppm and 0.6 at 1 ppm. This is a reasonable estimate, but OSHA feels not as well supported. It uses a model that was not developed for cancer risk assessment. It does not make use of the data from several well conducted epidemiology studies which provide a reasonable basis for risk assessment. It is at the low range of a series of estimates made by experts and expert organizations.

OSHA has followed a consistent approach to significant risk analysis since 1982 when it first put into practice the directions of the Supreme Court in *IUD* v. *API*, the benzene decision. The approach has been used for the arsenic (48 FR 1669; Jan. 14, 1983) and ETO (49 FR 25734; 1984) final standards which have been upheld by 2 Courts of Appeal (ASARCO v. OSHA, 746 F.2d 483 (9th Cir. 1984)) and Public Citizen v. Tyson, 796 F.2d 1479 (D.C. Cir. 1986), the asbestos final (51 FR 22612; June 20, 1986) and the benzene, EDB and formaldahyde proposals.

OSHA pointed out that guidance for the Agency in evaluating significant risk is provided by an examination of occupational risk rates and legislative intent. For example, in the high risk occupations of fire fighting, and mining and quarrying the average risk of death from all causes of occupational injury or an acute occupationally related illness from a lifetime of employment (45 years) is 27.45 and 20.16 per 1,000 employees respectively. Typical occupational risk of death in occupations of average risk are 2.7 per 1,000 for all manufacturing and 1.62 per 1,000 for all service employment. Typical lifetime occupational risks of death in occupations of relatively low risk are 0.48 per 1,000 in electric equipment and 0.07 per 1,000 in retail clothing. These rates are derived from 1979 and 1980 Bureau of Labor Statistics data from employers with 11 or more employees adjusted to 45 years of employment for 46 weeks per year.

There are relatively few data on risk rates for occupational cancer as distinguished from occupational injury and acute illness. The estimated cancer fatality rate from the maximum permissible occupational exposure to ionizing radiation is 17 to 29 per 1,000 exposed employees. (47 years at 5 rems; Committee on the Biological Effects of Ionizing Radiation (BEIR) III predictions.) However most radiation standards require that exposure limits be reduced to the lowest level reasonably achievable below the exposure limit (the ALARA principle). Approximately 95% of radiation workers have exposures less than one-tenth the maximum permitted level. This risk at one-tenth the permitted level is 1.7 to 2.9 per 1,000 exposed employees.

OSHA pointed out in the benzene proposal that the fatality risk associated with 10 ppm benzene was similar to the risk OSHA found significant at the old exposure limit in arsenic of 148–425 per 1000 (48 FR 1864, 1896; Jan. 14, 1983), ETO of 69–109 per 1000 (49 FR 25734, June 22, 1984) and EDB of 70–110 per 1000 (48 FR 45975; Oct. 7, 1983). In addition in the recent asbestos final standard, OSHA found a risk of 64 per 1000 at the old exposure limit significant (Supra). OSHA stated in those standards and in the benzene proposal,

> Congress passed the Occupational Safety and Health Act of 1970 because of a determination that occupational safety and health risks were too high. Based on this it is clear that Congress gave OSHA authority to reduce risks of average or above average magnitude when feasible. Further the Supreme Court stated that "if the odds are one in a thousand that regular inhalation of gasoline vapors that are 2% benzene will be fatal a reasonable person might well take the appropriate steps to decrease or eliminate it (50 FR 50539).

Dr. Rodricks (testifying at the request of API) suggested that "lifetime risks (of death) in the range of 0.1, maybe even up to 3 per 1000, would likely be considered insignificant by most people." (Tr., 3/21/86, p. 29). As just stated OSHA believes Congress intended to reduce risks of average magnitude and the Supreme Court indicated a reasonable person might well take steps to reduce a risk of 1 per 1000. In addition, the benzene risk is an additive risk: it is in addition to the other risks from accidents, etc. that

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benzene exposed workers face. The national risk figures are totals of all risks. OSHA continues to conclude that it's analysis is the better policy.

Within this context OSHA's final conclusion (as was the preliminary conclusion) is that significant risk exists at the 10 ppm level. Based on the best supported estimates of 95 excess deaths per 1000, the risk is clearly greater than the risks in riskiest occupations or the risk of one in 1000 the Supreme Court found a reasonable person might find significant.

The lowest estimate presented was 8 per 1000 at 10 ppm. That is greater than the risks of average occupations and greater than the risk the Supreme Court indicates a reasonable person might choose to reduce. Therefore even based on this estimate, OSHA would, as it also stated in its proposal, determine that the risk was significant. No major party challenged OSHA's decision to reduce exposures from 10 ppm.

OSHA also concludes that the new benzene standard will result in a substantial reduction in significant risk. All the risk assessments indicate that the reduction of risk will be at least 90 percent. In addition several of the human (Rinsky, Wong) and animal (NTP) studies conclusively demonstrate that lowering exposures substantially lowers risk. A 90 percent reduction of risk is clearly substantial.

Based on OSHA's preferred estimates of risk, the final standard would result in 85 fewer leukemia deaths per 1000 workers exposed at the current 10 ppm level for a working lifetime. Based on OSHA's current estimate of exposures, the final standard would save a minimum of 230 leukemia deaths over a working lifetime (45 year period). Using the API preferred estimate, the lowest estimate of risk reduction, the standard would result in 7.4 fewer leukemia deaths per 1000.

OSHA would find a substantial reduction in significant risk at 1 ppm based on the reduction in leukemia rates alone. However, OSHA concludes that there will also be substantial additional benefits. OSHA's best estimate is that there will be a reduction in 92 deaths from aplastic anemia and other diseases of the blood and blood-forming organs over the period and perhaps more as they may be eliminated as an occupational disease. There will also be a reduction in multiple myeloma. Similarly there will be reductions in pancytopenias and other blood diseases and in damage to the genetic material. These may be possibly eliminated as occupationally caused diseases in conjunction with the medical surveillance provisions. Medical surveillance will detect early some of the blood changes which are indicative of bone marrow toxicity. Treatment or removal may prevent those diseases from developing further or lead to their cure. Aplastic anemia and most other blood diseases related to benzene exposure (except acute adult leukemia) are treatable.

The remaining risk predicted by the Crump and Allen assessment at 1 ppm is 10 per 1000. This estimate does not take into account the benefits of medical surveillance and the industrial hygiene provisions of the standard or that the employers will lower exposures below a long term averages of 1 ppm; or where feasible below the action level, to have confidence they are not going above the PEL or where feasible above the action level.

As stated in the proposal, the Crump and Allen predicted level of risk at 1 is such that "OSHA would, if it were feasible, seek to reduce the level of risk estimated at 1 ppm by the risk assessment. "(Benzene proposal, 50 FR 50539). OSHA reached similar conclusions in the Arsenic, ETO and Asbestos final standards. It is above average levels of risk in industry and above the level of risk the Supreme Court indicated a reasonable person might decide to reduce. OSHA concludes that the final standard is carrying out congressional intent within the limits of feasibility and does not attempt to reduce insignificant risks.

However, as just stated the real reduction in risk is greater than the risk assessment estimates demonstrate and the remaining risk will be less than the risk assessment number indicates. They do not take into account the benefits of medical surveillance and the industrial hygiene provisions. Many employers where feasible will reduce exposures below the action level to avoid the expense of the monitoring and medical provisions. Employees exposed between the action level and PEL will have the benefits of those provisions. In both cases employers will achieve average exposures below the action level or PEL in order to take into account a normal degree of variability and have a reasonable degree of confidence they are achieving the level consistently.

Therefore, OSHA concludes that the final standard is protective of workers and as stated in the proposal "that employers who fulfill the provisions of the standard will be taking reasonable steps to protect their employees from the hazards of benzene. Indeed many employers have already reduced exposure of employees to below those of the proposed standard." (50 FR 50539)

The API (and several employers) though not dissenting from a 1 ppm level, have contended that OSHA must adopt the Rodricks and Brett analysis of the Chinchilli risk assessment (RBC analysis). They contend that OSHA must then find that 1 ppm has eliminated all significant risk.

API stated:

> It would not oppose a reduction in the PEL to a level as low as 1 ppm so long as two crucial conditions are met. "First, * * * a finding that workplaces in compliance with a 1 ppm PEL, and with appropriate ancillary requirements, will fully protect workers from significant risk * * *.
>
> *Second*, the ancillary requirements of the new standard must be practical and justified by a clear hygiene necessity. Although most of the provisions OSHA proposed meet the test, several do not. (Ex. No. 260, pp. 2-3).

As discussed in the risk assessment section, OSHA agrees the RBC analysis is reasonable. However, OSHA's best estimate is the Crump and Allen analysis for the reasons stated. Even the RBC 0.6 per 1000 estimate at 1 ppm is not very much lower than the level the Supreme Court stated a reasonable person might take action to reduce.

However, as a comparison between the API quotes and the OSHA conclusion demonstrate, the disagreement is not dramatically broad. All agree that the standard is more than an exposure limit. It also is a carefully worked out set of medical and industrial hygiene provisions. All agree that these provisions will reduce risk to a greater degree than the risk assessments predict: In addition, virtually all employers keep long term average exposures under the PEL by a margin and where feasible under the action level with a margin.

Those factors assure OSHA that there will be a substantially greater reduction in risk than the risk assessments estimate and will provide protection to benzene exposed workers. Employers who carry out the provisions of the standard conscientiously may have confidence they are protecting their employees and employees working for such employers can feel confident that they are receiving substantial protection.

VIII. Summary of the Regulatory Impact and Regulatory Flexibility Analysis, Feasibility Analysis, and Environmental Impact Assessment

A. Introduction

Executive Order 12291 (46 FR 13197, Feb. 19, 1981) requires that a regulatory analysis be conducted for any rule having major economic consequences on the national economy, individual

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industries, geographical regions, or levels of government. Similarly, the Regulatory Flexibility Act [5 U.S.C. Subsection 601 et seq.] requires the Occupational Safety and Health Administration [OSHA] to consider the impact of the regulation on small entities.

Consistent with these requirements, OSHA has prepared a Regulatory Impact and Regulatory Flexibility Analysis for the benzene standard. This analysis describes the industries affected by the standard, some of the potential benefits that will accrue to employees exposed to benzene at their places of work and the costs of compliance with the standard.

The OSHA Act requires OSHA to demonstrate the technological and economic feasibility of the provision. This Section demonstrates that the final standard is feasible.

B. Industry and Exposure Profiles

Benzene is produced primarily by the petrochemical and petroleum refining industries by a process called catalytic reformation, which converts certain lower octane aliphatic hydrocarbons into higher octane aromatic hydrocarbons. These two industries are responsible for 98 percent of the total U.S. production of benzene. Recovery through catalytic reformation, including the benzene formed from the dealkylation of toluene, accounts for approximately 75 percent of the total quantity of benzene produced. Recovery through coal-derived benzene, primarily as a by-product of the coking process in steel mills was once a major source of benzene. Now it accounts for only 2 percent of the total United States production.

Industries Covered in the Preliminary Analysis

OSHA estimates that approximately 240,000 workers are exposed to benzene in seven major industry sectors that are under the Agency's jurisdiction. These sectors include the benzene producers (i.e., petrochemicals, petroleum refining, and coke and coal chemical manufacturing), the rubber tire manufacturing industry, and firms engaged in the bulk storage and transportation of benzene and petroleum products containing benzene.

In three industry sectors—petrochemicals, petroleum refineries, and coke and coal chemicals—the manufacturing processes likely to contribute to benzene exposures are either highly automated or are performed infrequently. Exposed employees are generally the unit operators, tankcar loaders and unloaders, laboratory technicians, and maintenance personnel.

In the manufacture of rubber tires, benzene exposures occur as a result of the use of benzene-contaminated solvents. Exposed employees include process operators, workers responsible for the storing, mixing, loading, and unloading of solvents, as well as laboratory technicians and maintenance personnel. Supervisory personnel may also be exposed to solvents containing benzene.

In three other industry sectors—bulk terminals (large wholesale storage facilities supplied by pipelines or barges), bulk plants (small wholesale storage facilities supplied by truck), and transportation—the exposed employee population consists primarily of those who load and unload benzene and material containing benzene. Employee exposures reach peak levels while these materials are being transferred; however, transfer operations may not occur daily.

OSHA believes that the exposure profile presented in Table A is representative of the industries analyzed. The data sources used to estimate the population at risk for each of these industry sectors are discussed in Chapter II of the Regulatory Impact Analysis.

TABLE A.—NUMBER OF EMPLOYEES EXPOSED TO BENZENE AND CURRENT EXPOSURE LEVELS (BY INDUSTRY DIVISIONS)

Industry sector	Percent of observations in each exposure category 8-hour time weighted average (TWA) benzene concentrations (ppm)						Total number of employees
	0.0–0.1	0.11–0.5	0.51–1.0	1.1–5.0	5.1–10	10+	
Petrochemical plants [a]		74.6		23.0	2.4	0.0	4,300
Petroleum refineries [b, c]	64.6	26.1	4.6	3.8	0.5	0.4	47,547
Coke and coal chemicals [d]	0.0	39.3	27.8	27.5	4.4	1.3	[e] 947
Tire manufacturers [f]	53.4	37.5	6.3	2.8	0.0	0.0	65,000
Bulk terminals [b]	57.8	32.8	5.3	3.7	0.3	0.1	27,095
Bulk plants [b]	57.8	32.8	5.3	3.7	0.3	0.1	45,323
Transportation via tank truck [b]	68.4	23.1	5.3	2.9	0.1	0.2	47,600
Total							237,812

Source: U.S. Department of Labor, OSHA, Office of Regulatory Analysis.
[a] Percentages represent the portion of workers whose average exposures are in each category. Data obtained from Ex. No. 242.
[b] Percentages represent the portion of sampling results in each exposure category. Data obtained from Ex. No. 159–67.
[c] Data do not reflect respirator use and sampling biases. (See Ex. No. 204–7).
[d] Percentages represent the portion of workers whose average exposures are in each category. Data obtained from Ex. No. 153.
[e] Excludes workers employed at the coke ovens.
[f] Percentages represent the portion of sampling results in each exposure category. Data obtained from Ex. No. 153.

Table A does not include workers employed by firms that are either covered by the exclusions (see the discussion of the exclusions under the scope section) or that are under the jurisdiction of other regulatory agencies. Additionally, the profile does not include workers employed in the miscellaneous industries that use products containing small quantities of benzene and tank maintenance firms because exposure data for these industries were not available.

OSHA believes that the firms that use solvents contaminated with benzene will be able to switch to solvents with very low concentrations of benzene. As these solvents are excluded from the scope of the proposed standard, this approach will provide the most cost-effective means of complying with the proposed standard. Tank maintenance firms have the problems of flammability and asphyxiation to contend with, which are general to most petroleum products in confined spaces. This standard does not specifically address

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these problems. Those firms have not made comments in the rulemaking. OSHA believes the efforts to control flammability and asphyxiation will handle benzene inhalation problems.

Industries Not Covered in the Preliminary Study

OSHA based much of its preliminary analysis on a study conducted by JRB Associates in 1984 [Ex No. 153]. JRB identified seven major industry sectors in which employees have significant benzene exposures. The 1985 OSHA proposal, therefore, also focused on these industries. In response to the proposal, two additional sectors were identified as a source of significant benzene exposures, namely indoor dispensing of motor fuels and the cleaning and repairing of barges. These sectors are discussed in the following paragraphs.

Indoor Dispensing of Motor Fuel

OSHA proposed to exempt the retail sale of motor fuels based upon data that indicate exposures are well below the proposed level of 0.5 ppm (Ex. No. 200, p 50548; H–059, Ex. No. 93A). Dr. Franklin Mirer of the United Auto Workers (UAW) pointed out that indoor dispensing of gas could lead to higher exposures (Tr., 3/25/86, pp. 10–11).

OSHA agrees with the UAW that samples taken for outdoor operations should not be used to exclude indoor operations, since the possibility of higher exposures exists during indoor operations. See the discussion under Scope and Application. Thus, the indoor dispensing of gasoline is not excluded from the scope of the final benzene standard.

The Agency believes that the revision will have an insignificant impact on indoor gasoline dispensing operations. Most sites already provide adequate ventilation in order to avoid hazards such as carbon monoxide poisoning. Thus, in most cases initial monitoring will only be required in order to show that exposures are below the 0.5 ppm action level. According to JRB [Ex. No. 153], the cost of this monitoring is $62.40 per sample. So the cost of monitoring will be under $200 even for a site that runs three shifts. Where the present level of ventilation is not sufficient, employers will have at least two options to lower exposures. First, they may choose to increase the ventilation. [This is clearly feasible as is demonstrated in JRB analysis of the tire industry [Ex. No. 153, chapter 4]. Second, employers may choose to contain the benzene emissions by installing Stage II vapor recovery systems. This equipment is readily available and is currently required in many air quality control regions in order to meet the requirements of the Clean Air Act.

Shipyard Barge Cleaning and Repairing

Although OSHA did not specifically study ship or barge repair for the proposal, the Agency did request comments on this issue.

The repair of tankers may lead to high levels of benzene exposure often in confined spaces. Control is possible through tank flushing or via the use of supplied air respirators. Consequently, it is proposed to cover ship repairing. In other types of ship repair, there will be little impact, as compliance can be achieved through utilizing solvents with low benzene contamination. Comments are requested on this issue [Ex. No. 200, p. 50552].

In response to the request, OSHA received comments from two sources, the American Institute of Marine Shipping (AIMS) and the American Waterways Shipyard Conference (AWSC).

According to Joseph Cox of the AIMS,

With respect to inclusion of this proposal into part 1915, ship repairing, I suggest this be separated from this proposal and given more study for a number of reasons. In the preamble, OSHA states that control is possible through tank flushing or use of air supplied respirators and this is presumably the rationale for evaluating the standard as feasible in the ship repairing industry. In response to questioning on Monday, OSHA stated these control techniques are in use on shoreside tanks and this led to the determination that the same techniques could be or are presently applied to ships and barges. I respectfully disagree with this determination of feasibility in ship repairing and believe such determination is flawed since the experience with these control techniques is not transferrable to vessels. Ships and barges have complex internal structures. Shore tanks are relatively smooth compared with a vessels which has longitudinal and transverse internals necessary for strength. These separations within a vessel can be I-beam structural members or steel bulkheads that form complete separations from tank top to overhead. The suction points within tanks can be situated to discharge as much cargo or wash water as possible although substantial amounts can remain, or the trim of the vessel can leave substantial amounts of residue in a tank. Also for strength purposes, access to spaces aboard ship may be limited. Many access holes to spaces are just large enough to admit a person.

Tank washing aboard ship is performed for cleaning purposes to allow for carriage of the next cargo with acceptable contamination levels. It is not designed to clean a tank for personnel entry without extensive testing and continued monitoring by a trained professional [Ex. No. 219, pp. 2–3].

Neal Platzer of the AWSC also contended that it may not be feasible to clean to levels below 1 ppm benzene.

One extreme difficulty for cleaning facilities in complying with the proposal is the amount of benzene located in the rust of the steel tank barge. This residual benzene can regenerate as the heat from the day increases causing the concentration of benzene inside the tank to fluctuate wildly. Some 90 percent of the barge cleaning facilities are located in warm, humid areas [Tr., 3/21/86, pp. 109–110].

For these and other reasons, the ASWC formally requested that OSHA conduct a feasibility and regulatory flexibility analysis of the barge cleaning and repair industry. OSHA has concluded that it is appropriate to further study this sector and has contracted with Meridian Research to collect the relevant information. OSHA, therefore, intends to cover the barge cleaning and repair industry in a separate proceeding as is discussed elsewhere in this preamble and in the interim is exempting them from several of the major provisions of this standard.

C. Benefits Analysis

Benzene exposure causes a number of serious health risks, including leukemia, the most extensively studied. Adult leukemia has a low survival rate (unlike childhood leukemia), and a shorter latency period than many types of cancer. It clearly is a very serious disease. Findings also suggest that benzene is associated with multiple myeloma (cancer of the bone marrow) and lymphatic cancers. Benzene exposure is also associated with several blood diseases including aplastic anemia (often fatal), pancytopenia and others.

OSHA's estimate of risk of death from leukemia resulting from a working lifetime exposure to benzene at 10 ppm is 95 cases per 1000 exposed employees. The new standard will result in a reduction of at least 85 excess leukemia deaths per 1000 employees exposed at the current 10 ppm level, a 90 percent reduction. This is a substantial reduction in significant risk as discussed in the significant risk section. The actual reduction is likely to be greater. As a result of the action level, many employers may be motivated to reduce exposure where feasible below 0.5 ppm to reduce their industrial hygiene costs and the industrial hygiene and medical surveillance provisions will also further reduce risk. In addition, the lowering of exposure is likely to reduce the incidence of, if not eliminate, other sometimes fatal diseases of the blood

and blood-forming organs, such as aplastic anemia.

Other benefits which are likely to occur but cannot be as well quantified include:

—Leukemia cases that may not occur as a result of progression from nonmalignant blood disorders because of medical removal.

—Reduction in the number of other hemolymphopoietic cancers in the exposed population.

—Reduction in the number of chromosomal changes in the exposed populations.

—Reduction in the number of benzene-induced cases of leukemia and malignant and non-malignant blood disorders caused by percutaneous absorption of benzene.

Based on the quantitative risk assessment, OSHA estimates that by reducing the PEL to 1.0 ppm, the number of excess leukemia deaths occurring in the seven industries studied will be reduced by 230 deaths over the 45-year period. (See OSHA's final Regulatory Impact Analysis [RIA] for the calculations.) OSHA's estimate of 230 excess leukemia deaths prevented is approximately 60 percent lower than the 571 deaths estimated for the proposal. The primary reason for the lower estimate is that some exposure estimates were revised downward (particularly in the bulk storage sectors) based on data submitted after the publication of the proposal. Also, revisions were made to the quantitative risk assessment.

OSHA also estimates that a number of deaths from diseases of the blood and blood-forming organs (e.g., aplastic anemia) will be eliminated by the new standard. In the proposal, the number of these aplastic anemia deaths avoided was estimated to be 42 percent of the leukemia deaths avoided. While some comments stated that the ratio of 0.42 was too high, as discussed at length in the health effects section, OSHA has concluded that 0.42 is reasonable for aplastic anemia and other diseases of the blood and blood-forming organs. Based on this ratio, OSHA estimates that approximately 96 deaths from diseases of the blood and blood-forming organs, (i.e., 230 × 0.42) will be prevented as a result of the revised standard.

Because of the linear nature of the preferred models, it should be noted that the estimates of lives saved based on the models used would be the same whether based on average exposures or frequency distribution. In addition, OSHA has concluded that there will be a substantial reduction of significant risk based on the reduction in excess risk leukemia alone.

OSHA believes that proper medical examinations can identify blood abnormalities in workers exposed to benzene prior to the onset of more serious symptoms. Worker exposures can then be controlled (e.g., possibly by removal from high-risk areas), and in some cases, the abnormalities will be reversed before the workers' condition progresses to fatal diseases such as aplastic anemia or leukemia [H–059, Ex. No. 217–34]. OSHA believes that the medical surveillance provision will result in additional lives saved, although the Agency has not attempted to quantify these benefits.

OSHA estimates that the benzene proposal will save at least 326 lives during a 45-year period (i.e., 230+96). See OSHA's final RIA for the calculations.

D. Technological Feasibility

OSHA concludes that the final standard is technologically feasible with a high degree of confidence in the sectors covered. Existing exposures are not high. The large majority of exposures are under the PEL. Those that are over are generally in the 1–3 ppm range so that large reductions are not needed. The methods that can be used to reduce employee exposure to benzene include conventional technologies such as air monitoring, double mechanical seals, exhaust ventilation, leak detection and repair, and respiratory protection for intermittent exposures. Such technologies are commonly known and currently used to some degree in the affected industries. These controls can be used in combination. So if one engineering control is not sufficient, additional ones can be utilized. Consequently, engineering controls are available to generally reduce exposures below the PEL in most locations in each industry.

Respirators are specifically permitted for maintenance and repair operations, intermittent, short term operations and in those few production or continual operations when feasible engineering controls are not available to achieve the limit.

The OSHA feasibility analysis is based on a 1983 study conducted by JRB Associates [Ex. No. 153] and the other evidence in the record. The JRB study is one of the most comprehensive reports developed for OSHA during the last several years. It is based on a large amount of high quality data that were obtained in cooperation with industry and labor. Several parties (including API, CMA, AISI and UAW) provided detailed exposure data. In addition, JRB conducted mail and telephone surveys, visited numerous plants throughout the country [Ex. No. 240], and consulted with several industry experts to further refine the data. Overall, the study took almost a year to complete and cost the Agency over one-half million dollars.

The JRB report identified emission sources in the affected industries that had the potential for causing occupational exposure to benzene. Much of Chapter 4 of the JRB analysis consisted of determining the feasibility of various types of controls for these emission sources and estimating the efficiency of these controls in maintaining exposures below 1 ppm.

Many of the potentially affected sectors, including petrochemicals and coke chemical plants, are similar in that they utilize large, automated, enclosed systems comprised of process vessels, pipes, valves, pumps, and compressors. Although these systems are enclosed primarily to reduce product loss and the probability of fire, worker exposures may occur as a result of small leaks and the opening of the equipment for operations such as tank gauging, process sampling and maintenance. The JRB feasibility assessment was based on controlling these sources of worker exposure.

Because workers in these industries tend to move about constantly, specific estimates of reductions in benzene exposures due to installing specific controls were not critical to the determination. If one type of control is somewhat less effective than expected, another may be more effective. Thus, it is the interaction of several controls and work practices that is predicted to result in an overall reduction in exposure. The feasibility of maintaining an 8-hour TWA worker exposures below 1 ppm, therefore, is based on reducing emissions from many sources by a combination of controls and practices, so that the highs and lows average less than 1 ppm.

Based on its analysis, OSHA reached the preliminary determination that it is technologically feasible to reduce 8-hour TWA worker exposures to less than 1.0 ppm in these sectors though the use of some combination of the following engineering controls and work practices:

—Limiting exposures during tank gauging through the use of proper work practices (i.e., requiring the employee to stand upwind of the hatch) or, in some cases, the use of automated gauging equipment.

—Installing double seals and containment systems on pumps servicing liquids containing more than 10 percent benzene.

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—Installing ventilated enclosures for process sampling.

—Enclosing wastewater collection systems, including open sumps and trenches.

Even if these controls were insufficient to reach 1.0 ppm, additional steps, such as the following, could be taken:

—Installing double seals and containment systems on all pumps.

—Installing closed hatch or automatic loading systems for the tank truck and railcar loading operations.

—Increasing the frequency of manual leak detection surveys and promptly repairing the leaks that are found.

—Installing automatic leak detection equipment to monitor problem areas.

Since current exposures are generally low (near the 1 ppm PEL), and since there is a great variety of controls available to reduce exposures, both OSHA and JRB conclude with a high degree of confidence that the 1 ppm PEL is feasible. JRB stated that it "has considerable confidence in its feasibility judgments of the controls necessary to achieve the proposed 1 ppm level" [Ex. No. 153, p 4–2].

OSHA's analysis was based on the professional "engineering judgment" of JRB and other expert consultants that some combination of engineering controls and work practices could be implemented to reduce the 8-hour TWA work exposure to below 1 ppm in most facilities of each sector. In order to illustrate how this might be accomplished, OSHA asked JRB to develop a scenario that a typical plant in each sector might implement in order to comply with the 1 ppm PEL. This scenario was presented in Chapter 4 of the JRB report [Ex. No. 153] and served as the basis for OSHA's preliminary compliance cost estimates. This scenario was not intended, however, to be a specific guide for each and every plant because OSHA's proposed and final standards did not require employers to institute the specific controls discussed by JRB.

On the contrary, OSHA intentionally drafted the rule in performance language in order to permit employers the latitude to develop a combination of engineering controls and work practices suited to particular facilities [Ex. No. 200, p. 50574]. Industry comments, noted in the preamble, to the proposal [Ex. No. 200, pp. 50559–60] supported this decision (See Ex. Nos. 142–1, 142–17, 142–609).

In addition, subsequent to the publication of the proposal, OSHA received several comments which supported the position that 1 ppm was the lowest feasible PEL. For example, Sohio stated:

> Sohio's experience with our benzene manufacturing facility indicates that we can achieve a TWA of 1 ppm with engineering controls * * *
>
> In 1984 Sohio constructed a benzene production facility at our petroleum refinery in Lima, Ohio. Best available control technology was used to minimize benzene emissions at all locations. This facility cannot consistently achieve 0.5 ppm 8-hour time weighted average exposures [Ex. No. 201–13, p. 2].

In response to the proposal, OSHA also received several negative comments regarding the Agency's preliminary feasibility analysis. In general, these comments can be divided into the following categories:

- OSHA's feasibility analysis failed to identify some benzene emission sources and overestimated the efficiency of controlling emissions at some of the sources that it did identify.
- OSHA's feasibility analysis failed to consider the use of the most efficient control technologies which could result in lower exposures.
- OSHA's feasibility analysis did not consider random exposure variability.

OSHA carefully considered these comments, before it reached its final feasibility conclusion. In the analysis that follows, OSHA explains why those points do not change the conclusion that the 8-hour time-weighted average (TWA) of 1 ppm PEL is technologically feasible with a high degree of confidence and is the lowest feasible level. In addition, OSHA makes the determination that compliance with a 5 ppm short-term exposure limit (STEL) is feasible.

In the final Regulatory Impact Analysis, OSHA discusses feasibility issues in greater depth. That discussion presents additional analysis demonstrating why the final standard is feasible.

The technological feasibility of the non-exposure level provisions (e.g., medical surveillance, exposure monitoring, respirators, protective clothing, training, etc.) was not disputed during the rulemaking.

Criticism that all of the Emission Sources were not Identified

CMA and AISI submitted comments contending that the JRB analysis was flawed and incomplete in a variety of respects. They argued that OSHA's feasibility conclusions were open to question.

For example, CMA listed seven operations (out of the scores of operations present in petrochemical plants) for which the association says that engineering controls are either infeasible or prohibitive from the standpoint of costs [Ex. No. 201–33, p. 95–100]. Thus, CMA faults JRB for failing to identify "benzene emission sources or tasks which, either regularly or from time-to-time, would require the use of respirators to achieve a PEL of 1 ppm or a short-term exposure limit (STEL) of 5 ppm averaged over 15 minutes."

JRB's primary task was to help OSHA determine the feasibility of meeting the proposal. The proposed standard (and the final rule) specified an 8-hour TWA PEL of 1 ppm. Meeting the PEL through the use of engineering controls and work practices is one way for an employer to comply, but is not the only way. Respirators are also permitted as a means of compliance in a number of circumstances. Specifically, paragraph (g)(1)(ii) permits the use of respirators for the following:

> In work operations for which the employer establishes that engineering and work practice controls are not feasible such as maintenance and repair activities, vessel cleaning, or operations where engineering and work practice controls are infeasible because exposures are intermittent in nature and limited in duration.

The JRB analysis did not address the feasibility of installing engineering controls for the seven activities cited by CMA, because these activities involved either maintenance or short-term intermittent operations where the use of respirators is specifically permitted. The confusion over this point apparently results from CMA's concern that use of respirators is not permitted by operating personnel. CMA stated that,

> JRB fails to recognize that, during some maintenance operations, operating personnel also may have to be provided with respirators to comply with a 1 ppm standard. While major maintenance typically is performed on a campaign basis when the unit is shut down, routine maintenance occurs on an on-going basis and is performed while the unit is running. This routine maintenance will increase background concentrations of benzene and may require respirator use by the operating personnel as well as by the maintenance workers themselves [Ex. No. 201–33, p. 100].

And examination of paragraph (g)(1)(ii), however, reveals that the use of respirators is tied to the type of activity or operation being performed and not the job title of the employee. Thus, in the situation cited by CMA, operating personnel would be permitted to use respirators.

CMA also criticizes the JRB conclusion that double mechanical seal pumps were an effective control, stating that "the use of double mechanical seals in pumps and compressors in petrochemical plants is not likely to

achieve a substantial reduction in emissions even on these pumps, that do lead" [Ex. No. 201–33, p. 107]. OSHA disagrees with CMA's conclusion. The Environmental Protection Agency (EPA), for example, reports that these seals have an efficiency of nearly 100 percent in controlling benzene emissions, although they are not the best available technology (BAT) [Ex. No. 240 B, Tables 6–2 and 7–4]. Thus, OSHA concludes that JRB was correct in asserting that the seals would be an effective control mechanism. Other examples of how controls developed for other chemicals or for other purposes can be used to control benzene exposures are provided in Chapter IV of the final RIA.

AISI also disagreed with several aspects of the JRB report. For example, AISI stated that "JRB's assessment of engineering controls used to reduce benzene exposures in light oil recovery units is based exclusively on information obtained during two site visits in 1983 [Ex. No. 201–44, p. 13]. This statement is inaccurate. While the two site visits were used in the JRB assessment, they were not the sole basis for JRB's statements. JRB used many other sources including materials submitted by AISI, analyses conducted by EPA [Ex. No. 153, p. 4–59], and the professional judgment of several consultants to arrive at its determination that 1 ppm was technologically feasible in this sector. Thus, the assessment was not "based exclusively on information obtained during two site visits."

AISI also stated that "JRB has not identified all of the major sources of benzene exposure in light oil recovery plants and has not properly evaluated the feasibility of controls on the sources it has identified" [Ex. No. 201–44]. AISI contended that these deficiencies "call into question OSHA's preliminary conclusion regarding the technological feasibility of complying with a 1 ppm standard" [Ex. No. 201–44, p. 14].

OSHA strongly disagrees with the AISI contention that these alleged inaccuracies in the JRB report mean that OSHA's conclusions are flawed. First, OSHA did not request JRB to identify all potential sources of benzene emissions, as would be required for an EPA study. Compliance with the OSHA standard does not require the control of all emission sources. Rather, OSHA asked JRB to identify sources of significant occupational exposure to benzene. It is only necessary to control emission sources where workers are routinely present. JRB did not discuss several emission sources, which they determined would not result in significant employee exposures.

In addition, even if some of these emission sources will result in exposures at some facilities, as AISI has claimed, it does not follow that compliance with 1 ppm PEL is infeasible. Controls are available to reduce emissions from the sources cited by AISI, so that the existence of these additional sources does not indicate that a PEL of 1 ppm is technologically infeasible in this sector.

Finally, JRB did not discuss all of the feasible methods to control emissions from the sources that it did identify in the report. Rather, JRB presented examples of the types of technologies that could be used to control the emissions. The fact that a specific set of circumstances may exist that would preclude the use of some of the controls discussed by JRB does not mean that compliance with the 1 ppm PEL is technologically infeasible under those circumstances. As discussed in Chapter IV of the RIA, other controls can be used under the circumstances of concern to AISI.

Failure to Identify the Most Efficient Controls

Although the AFL–CIO and USWA supported OSHA's preliminary determination that 1 ppm PEL was feasible in all sectors, they disagreed with the finding that a 0.5 ppm level was not feasible [Ex. No. 262, p. 23]. The basis for this position was their belief that (1) OSHA's preliminary analysis "adopted a far more stringent and conservative criteria for feasibility than OSHA has ever used in the past," and (2) little attempt was made to visit, evaluate, obtain sampling data from plants where 0.5 ppm is already being achieved. According to these parties, "A properly conducted feasibility analysis should examine the availability and effectiveness of state-of-the-art controls * * * [and] the authors of the JRB report did none of these things" [Ex. No. 262, pp. 31–32].

This section discusses these general comments made by the AFL–CIO and the USWA. (The industry-specific comments are covered in the final RIA.) JRB developed an exposure profile and a baseline of current practices by industry sector. Each was developed from different sources, for example, the industry profile primarily came from the Runion and Scott report [Ex. No. 159–167], and the baseline came from surveys and site visits [Ex. No. 240]. JRB relied on professional judgment, interviews with experts, consultants, equipment manufacturers, industry and union representatives and other sources including EPA documents [Ex. No. 240] to associate high exposure profiles with a lack of controls in developing the baselines estimates. JRB also used these sources to determine the additional steps that could be taken including engineering controls and work practices to lower exposures below those currently being achieved.

Based on this extensive study both JRB and OSHA concluded the 1 ppm was the lowest feasible level. It was the lowest achievable with confidence using current technology throughout the industry. Much more extensive use of existing technology could achieve 0.5 ppm in a substantial number of locations and attempting to force technology, if successful, might achieve 0.5 ppm in more locations. But neither OSHA nor JRB could be confident that 0.5 ppm could be achieved in a majority of locations where benzene or compounds with a high percentage of benzene are used.

OSHA concluded, as discussed extensively elsewhere in this preamble, that an action level would be a more effective approach to achieve 0.5 ppm with engineering controls where feasible rather than a technology-forcing approach. Quite extensive medical monitoring and other provisions take effect at 0.5 ppm and these create substantial expenses. Thus, there is a strong incentive for employers to reduce exposures to below the 0.5 ppm level either by more extensive and efficient use of current technology or by developing new technologies.

OSHA's conclusion that 1.0 ppm is the lowest feasible level is further reinforced by industry statements regarding the effectiveness of certain controls and the need for greater consideration of exposure variability. While OSHA does not believe these problems are as great as contended and variability is more controllable than has been argued (as is discussed below), these difficulties call into question the conclusion that the 0.5 ppm level is feasible without the use of technology-forcing techniques. Although OSHA does have the legal authority to force new technology, such an approach must be based upon predictions that have not always proved to be as accurate as hoped. In the case of the lead standard, for example, the approach resulted in the granting of variances and extensions, where appropriate. In addition, although the technology-forcing approach proved to be effective in the case of vinyl chloride, OSHA believes that such an approach would cause enforcement difficulties for the Agency in the case of benzene, because

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unlike vinyl chloride, benzene is used in a variety of sectors and processes. (OSHA's conclusion regarding benzene is substance specific; in other circumstances, technology-forcing may be appropriate). Thus, OSHA concludes that it has utilized the right criteria for making feasibility judgments in this case.

A second point made by the AFL–CIO and the USWA was that the JRB report, and thus OSHA's feasibility analysis, did not consider the use of "state-of-the-art" equipment. This is not true. According to JRB.

> Achieving exposure levels of 0.5 or 0.1 ppm (TWA[8]) in all facilities in each sector would require that many facilities use remote control technologies and automation to isolate workers from benzene-contaminated areas. Except in the most modern chemical facilities, this would require redesign and major restructuring of production plants [Ex. No. 153, p. 4-2].

Given the age of most facilities in the petrochemical, petroleum refining, and coke and coal chemical sectors, OSHA does not believe that typical plants can be retrofitted to use this technology (i.e., OSHA does not believe that it is feasible to use this equipment across all industries at this time.) This does not mean, however, that some specific plants cannot install automated equipment.

The AFL–CIO and the USWA have also alleged that the JRB study was flawed because JRB did not visit the most modern plants. Specifically, in the case of coke and coal chemical by-product operations, these parties contend that the LTV Corporation's plant in Chicago, should have been used to show that a 0.5 ppm PEL is feasible. As will always be the case with a regulation covering many industries, some modern plant in one of the sectors may not be visited. But it must be reemphasized that the JRB study was extensive and utilized visits, data, and expert judgment to determine what is achievable. This is a sound basis on which to make feasibility judgments.

In addition, as was stated by Peter Hernandez of AISI, the LTV Chicago plant, which was built in 1981, is not a typical coke by-product recovery plant. Most existing plants are significantly older than the LTV plant. In fact, as Mr. Hernandez understands the situation, there is only one plant less than 10 years old, three plants that are between 10 and 25 years years old, and 25 plants that are more than 25 years old. Paul Hitcho of the United Steelworkers confirmed this point, stating that by-product recovery plants range in age from 5 years to 70 years with most of the plants being older than 40 years [Ex. No. 251A pp. 11–12]. According to AISI,

> It would be extremely difficult to install many of the controls that are in use at the LTV Chicago plant at some of the older plants where the equipment tends to be in far worse condition. "As Dr. Robert L. Harris testified, there is a big difference between [s]atisfying needs for hazard control in the initial design and construction of a process or plant" and the postconstruction retrofitting of controls at an old plant * * * benzene exposures at the vast majority of coke oven by-product recovery plants are significantly higher than * * * [at this] new by product recovery plant upon which the United Steel workers' suggestion of feasibility rests. [Ex. No. 259 pp. 12–14].

Thus, OSHA concludes that while a PEL of 0.5 ppm may be achievable at the LTV Chicago plant, it is not generally achievable at other facilities in the industry.

Exposure Variability

Representatives of some of the industry sectors affected by OSHA's revisions to the benzene standard have contended that these sectors have greater than average random variability in exposures. Random variability is a term used to describe the fact that when exposures are controlled to a certain average level, individual observations will not always be identical to that level each day. Rather, exposures will fluctuate randomly about the average. On some days exposure will be higher than the average and on others exposures will be lower depending on changes in the weather, minor changes in process flow or employee work practices, filter efficiency, and other similar events, which can not be fully controlled by the employers. Exposure variability is usually characterized by the geometric standard deviation (GSD). A low GSD (i.e., below 2) means that variability is well controlled and a high GSD (i.e., above 5) means that variability is great.

Due to random variability, employers facing an exposure limit, will almost universally control to an average exposure level somewhat below the limit, in order to ensure that random variations above the average will not exceed the limit.

Some variability, however, is not truly random or outside of the employers' control. For example, some high exposures may be the result of inadequate or poorly maintained controls, improper work practices or the lack of review by qualified industrial hygienists. Thus, a relatively high initial GSD does not mean that employers can not meet an exposure limit. Steps can be taken to control exposure and thus reduce the GSD.

A representative of the API presented the following reasons for variability in the petroleum refining industry [these may also apply to some extent in some of the other sectors including petrochemicals, coke, and bulk storage]:

> The problem of day-to-day exposure variability is an especially great concern to API because of the realities of the working conditions in the petroleum industry. The overwhelming majority of work in our industry that involves potential exposures to benzene takes place outdoors. Accordingly, exposures can vary from day-to-day, and even hour-to-hour, depending on the workers; physical orientation to exposure sources, wind speed and direction, the presence or absence of precipitation, and other meteorological conditions.
>
> Moreover, as OSHA has recognized, encounters with benzene in the petroleum industry are by nature intermittent or sporadic. Unlike many other manufacturing sector workplaces involving routine process operations that produce exposures to essentially stationary workers in a fairly continuous basis, workers in our industry move about constantly and the exposure sources consist mainly of small leaks that occur unpredictably and go uncontrolled until detected by sophisticated monitoring equipment. These discrete and constantly changing exposure sources make each trip through the process vessels and equipment different in terms of the resulting 8-hour TWA [Ex. No. 204-7, p. 20].

API and others have stated that this variability has a significant impact on the feasibility of complying with the 1 ppm PEL. CMA, for example, stated that "JRB Associates did not perform an analysis of variability * * * [and] could not claim that the identified controls would have any effect on reducing random sources of variability" [Ex. No. 258, p. 105].

OSHA believes that the impact of variability on the feasibility of complying with the 1 ppm PEL was overstated by the commenters. As was noted by the API, some of this variability is the result of many small leaks in the process equipment that go undetected. [See, for example, Ex. No. 204-7, p. 20]. OSHA has determined that a good leak detection and repair program can reduce the number of leaks and thereby lower the variability. The comments of Dr. Harris, Dr. Spear, and others, all emphasize that non-random exposure variability, as well as average exposure levels, can be reduced by controlled peaks or high intermittent exposures. Such exposures can occur as employees move about a chemical plant or spend time in an area close to emission sources. Because an employee's duties may vary from day to

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day, he or she may come into contact with emission sources on different days, resulting in non-random day-to-day variability in his or her 8-hour TWA exposure levels. Non-random day-to-day exposure variability may also arise when emissions from a particular emission source increase because of a leak.

In assessing the feasibility of alternative PEL's for benzene, JRB staff took into account the effectiveness of various engineering and work practice controls for reducing both 8-hour average and peak exposures; some of the controls judged by JRB to be effective in reducing both average and peak exposures include dual pump seals, ventilated hoods on process sampling points, and leak detection programs.

During the course of the feasibility study, JRB engineers and industrial hygienists visited a number of facilities using these controls. During these site visits, plant personnel indicated that no special problems would be encountered in using these controls to achieve a 1 ppm 8-hour TWA PEL. Thus, the leak detection program, including employee training in hazard recognition and safety procedures, judged by JRB and Meridian to be necessary to achieve compliance with a 1 ppm 8-hour TWA benzene exposure limit will reduce both daily benzene exposure level and daily exposure variability [Ex. No. 252A–14, pp. 5, 6]. This position was supported by an EPA report [Ex. No. 240 B], which stated that a formalized leak detection program can significantly reduce benzene emissions.

There as some confusion in the questioning of Meridian. In the post hearing submission (Ex. No. 252A–14), Meridian clarified that they had considered variability when studying the effectiveness of controls. It was plant personnel who had not indicated in the visits that variability would create abnormal problems.

Furthermore, there are a number of methods that employers can take to minimize certain variability by controlling the peak or high level intermittent exposures. Dr. Harris, a professor of industrial hygiene, pointed out that there are methods to lowering the peak exposures that will reduce both the arithmetic mean exposure and the variability [Tr., 3/19/86, pp. 157–160]. Mr. Lynch, an industrial hygiene expert, testifying on behalf of CMA stated,

> the kinds of things—tasks, events episodes that are leading to the outliers, generally can be found.
>
> Two things happen if you can get rid of those events, identify and eliminate the high exposure events. One is that you reduce the variability and the other is you reduce the average [Tr., 3/26/86, p. 92].

This type of action, which will reduce the probability of a high benzene exposure, was not considered in the analysis conducted by API [Ex. Nos. 204–78; 218–B].

OSHA has carefully considered the impact of variability on feasibility (See also the discussions under methods of compliance and monitoring). There is much evidence that many sources of variability are detectable and controllable. In addition, OSHA's analysis of the API data indicates that the random variability problem is not as great in those sectors as API suggests. Consequently, OSHA concluded that variability which may remain outside of the employers' control does not make compliance with the 1 ppm PEL infeasible because control techniques are readily available to keep average exposures sufficiently below the 1 ppm PEL to ensure that the remaining variations will result in very few random exposures above the PEL.

Finally, as is discussed in the variability section under monitoring, there is no requirement to control exposures so far below the PEL so as to ensure that absolutely no random exposures exceed the PEL. OSHA's longstanding enforcement policy, in recognition of the existance of the "occasional outlier," is designed to prevent citations being issued under such circumstances.

Short-Term Exposure Limit

The final rule contains a 5 ppm 15-minute STEL. The health reasons for the STEL are explained above. OSHA concludes that it is technologically feasible.

An analysis of the record reveals that there are two important patterns of worker exposure in the industries discussed above. The first group moves about constantly and is exposed due to leaks that occur unpredictably [Ex. No. 204–7, p. 20]. For these workers, OSHA assumed that prudent employers will institute a leak detection program and install engineering controls in order to insure that the leaks will not cause a compliance problem for meeting the 8-hour TWA of a 1 ppm PEL. (This assumption is reflected in the cost chapter of the RIA.) As a result of these initiatives, it is extremely unlikely that random leaks will expose workers to ambient levels above the 5 ppm STEL.

The second group is exposed to high levels of benzene for relatively short periods of time during operations such as maintenance, product loading, process sampling, and tank gauging. For these workers, the 1 ppm PEL is ineffective in limiting short-term exposures because the peak exposures get lost in the average thus making the STEL an important requirement for controlling worker exposures. The method used to comply with the STEL is dependent on the specific type of operation involved. In some cases, it may be necessary to install engineering controls (e.g., for tank gauging, process sampling, and product loading), while in other cases, respirators are appropriate.

According to JRB,

> The engineering controls required to achieve a 5 ppm short-term exposure limit (STEL) are the same as those that can be used to achieve a 1 ppm 8-hour TWA exposure. The activities that can result in short-term exposures in the coke and coal chemicals, petroleum refinery, and petrochemical industry sectors are the following:
>
> • Process sampling
> • Loading railcars and tank trucks with benzene or benzene-containing liquids
> • Tank gauging
> • Laboratory work (quality control laboratories)
> • Maintenance.
>
> JRB has addressed the feasibility of controlling exposures for each of these activities in earlier sections * * *
>
> It is feasible to reduce short-term exposures during gasoline loading operations to below 5 ppm, measured as a 15-minute TWA. Data collected by Irving and Grumbles (1981) show that 20-minute exposures during tank truck loading of gasoline ranged from 1.1 ppm, for facilities that use bottom loading with vapor recovery, to 4.1 ppm, for those using top loading with vapor recovery * * *
>
> Short-term exposures are not typical in several operations in the rubber tire manufacturing industry sector; examples of these operations are tire building and tread cementing. Activities in which short-term exposures are likely include tire repair and the transfer of cements from the mixing area to the various areas where cements are used. Increasing local ventilation at tire repair stations can reduce benzene concentrations by approximately 95 percent, as stated in Section 4.2.4. Preventing spills and using closed containers should eliminate the sources of contamination that could lead to short-term exposures in these areas. JRB observed the use of closed containers during two site visits to tire manufacturing plants (JBR Site Visits, 1983) and considers their use to be current industry practice . . .
>
> Because of the intermittent, unpredictable, and varied nature of maintenance activities, JRB assumes that respirators would be the most appropriate control method to use for maintenance workers to achieve both the 1 ppm 8-hour TWA alternative PEL and 5 ppm 15-minute STEL [Ex. No. 153, p. 4–45].

Engineering controls are available to limit the short-term exposures of many workers, and the standard permits the use of respirators to control short-term

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exposures for maintenance and similar types of operations where engineering controls may not be feasible. OSHA, therefore, concludes that compliance with the 5.0 ppm 15-minute STEL is technologically feasible.

E. Cost of Compliance

This section presents OSHA's estimate of the compliance costs that would be incurred by employers in the seven industry sectors primarily affected by the proposed benzene standard. Because there are industry-specific differences in exposure characteristics and equipment usage, cost estimates for each sector were developed separately.

First, a baseline of current industry practice was identified for each sector. This baseline was derived from information on current production methods and hazard control methods obtained during the JRB information collection efforts and from other submissions to the record. The costs of the engineering controls to achieve each successively lower PEL were then estimated based on the assumption that new controls could be added to those controls already in place.

Table B summarizes OSHA's compliance cost estimates of the revised benzene standard with a 1.0 ppm PEL and 0.5 ppm action level. Note that the "nonengineering costs" are those costs associated with the other provisions of the standard, such as medical surveillance, exposure monitoring, training, etc. The annualized capital costs are the yearly interest and depreciation costs needed to pay for a capital investment over the useful life or the equipment. This also takes into account variations in the useful life of each type of equipment. The compliance costs attributed to the tire industry are for solvents with low benzene concentrations. Table C provides a sector-by-sector breakdown of the nonengineering costs of the standard.

TABLE B.—ESTIMATED TOTAL ANNUALIZED COSTS ASSOCIATED WITH THE REVISED BENZENE STANDARD

(Millions of 1983 dollars)

Sector	Total annualized engineering costs	Total annualized nonengineering costs	Total annualized costs
Petrochemical	5.1	0.5	5.6
Petroleum refining	2.1	1.9	4.0
Coke and coal chemical	*6.8	0.3	7.1*
Tire manufacturers	1.0	0.2	1.2
Bulk terminals	0.2	0.6	0.8
Bulk plants	N/A	4.9	4.9
Tank truck	N/A	0.5	0.5
Total all sectors	15.3	8.8	24.1

Source: U.S. Department of Labor, OSHA, Office of Regulatory Analysis.

N/A = Not Applicable (i.e., OSHA assumed that compliance with these provisions will not be required).

* The cost estimates for the coke and coal chemical sectors represent the upperbound because they were based on the assumption that industry would install the required engineering controls during the first year following the promulgation of the new benzene standard. However, coke and coal chemicals have been given a 5-year phase-in-period in order to lessen the potential impact. This provision will allow the industry to install the new equipment when old equipment wears out, reducing "upfront" compliance costs. Data were not available to estimate this reduction.

TABLE C.—SUMMARY OF ESTIMATED TOTAL ANNUALIZED NONENGINEERING COSTS ASSOCIATED WITH THE REVISED STANDARD

(1983 dollars)

Industry	Provision						
	Regulated area	Exposure monitoring	Compliance program	Respirator use	Training	Medical examination	Total annual costs
Petro chemicals	7,500	255,000	4,500	153,300	*0	117,700	538,200
Refining	11,800	279,400	7,100	414,000	*0	1,211,800	1,924,100
Coke and coal chemicals	2,100	62,900	1,200	130,500	*0	56,500	253,200
Bulk terminals	11,500	377,400	28,700	91,800	*0	52,100	561,500
Bulk plants	65,200	2,325,000	163,300	521,800	951,800	830,900	4,858,000
Trucks	N/R	51,600	7,800	N/R	281,300	122,200	462,900
Tire	N/R	N/R	N/R	N/R	N/R	209,900	209,900
Total	98,100	3,351,500	212,600	1,311,400	1,233,100	2,601,100	8,807,800

Source: U.S. Department of Labor, OSHA, Office of Regulatory Analysis.

*OSHA assumed to be in compliance.

N/R=OSHA assumes that these provisions are not required.

The total annualized cost to comply with the revised standard is estimated to be $24 million. An analysis of these costs on a provision-by-provision basis shows that the installation of engineering controls and work practice 65 percent of the compliance costs. modifications to comply with the 1.0 ppm PEL and 5.0 ppm STEL account for

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Exposure monitoring and medical surveillance are the two most expensive non-PEL-related provisions, each accounting for over 10 percent of the estimated compliance costs.

An analysis of the costs on a sector-by-sector basis reveals that the installation of engineering controls in the coke and coal chemical sector accounts for approximately 30 percent of the total annualized costs. This is probably due to the high current exposures in the industry (i.e., average exposure over 1.5 ppm) and the age of plants (i.e., average age from 20 years to 40 years).

F. Economic Feasibility Analysis

OSHA has determined that it is economically feasible for the seven industry sectors and solvent users (including tire manufacturers) to comply with the provisions of the revised benzene standard of a 1.0 ppm and a 0.5 ppm action level and that none of these sectors would experience a significant adverse economic impact because of the standard.

Typical Impacts

If none of the compliance costs were to be passed forward to consumers, an average firm would experience an after-tax profit decline of less than 2 percent in its product lines affected by the proposed benzene standard in all sectors except iron and steel which includes coke and coal chemicals. If all of the costs associated with the proposal were to be passed forward to the customers so that after-tax profits in these product lines were unchanged, then an average firm in each industry would require price increases of less than 0.1 percent (0.2 percent in iron and steel) to fully offset these costs (see Table D). OSHA believes that the economic impacts estimated under each of these scenarios represent extreme or bounding cases (it is likely that some of the costs will be passed on and some absorbed) and that these changes are clearly affordable to these industry sectors based on the small size of the costs in relation to both profits and sales. Consequently, no major impact are likely. The revised benzene standard is unlikely to have any significant impact on the long-term viability of otherwise productive facilities or to cause otherwise profitable firms to leave these industries. Thus, OSHA concludes that the revised benzene standard is economically feasible for typical firms in the industry sectors studied.

TABLE D.—ESTIMATED ECONOMIC IMPACTS OF THE BENZENE STANDARD ON AN AVERAGE FIRM IN EACH INDUSTRY SECTOR

Industry	After-tax profit decline of an average firm in each industry if revenues are unchanged (percent)	Increased revenues required to offset fully the compliance costs of an average firm in each industry (percent)
Petrochemical	1.64	0.07
Petroleum refining and bulk terminals	0.04	<0.01
Iron and steel	*0.24	0.02
Tire manufacturers	0.31	0.01
Bulk plants	0.61	<0.01
For-hire tank trucks	0.46	0.01

Source: U.S. Department of Labor, OSHA, Office of Regulatory Analysis.
*Since the iron and steel industry suffered a loss in 1983, this value represents an increase in the loss.

Solvent Users

Solvent users will probably comply with a revised benzene standard by using solvents that are excluded from the scope of the standard. There are processes available to reduce the benzene contamination in solvents to below 0.1 percent. The prices of the solvents with less than 0.1 percent benzene are only slightly higher than benzene-contaminated solvents. Consequently, OSHA concludes that the revised standard is economically feasible for solvent users.

Coke and Coal Chemicals

If the controls are installed during the first year following the promulgation of the new standard, OSHA estimates that the annualized compliance costs for this sector will be approximately $7.0 million, compared to gross revenues of approximately $40 billion. Consequently, the dollar amount of the costs are small in relation to the industry's size. According to the AISI, however, the iron and steel industry experienced a net after-tax loss of approximately $2.2 billion 1983 [Ex. No. 201–44, p. 39]. While much of this loss was due to one time write offs in the industry, the figures for 1984 still revealed a loss of almost $200 million. Thus, these data indicate that this sector is experiencing economic problems. In addition, AISI states:

> [The] imports constituted 25.2 percent of the U.S. apparent steel supply in 1985 (Second only to the 1984 record-high of 26.4 percent). With imports at such high levels, it is not likely that prices of steel products could be increased to cover regulatory costs that are applicable only to domestic producers [Ex. No. 201–44, p. 38].
>
> The domestic steel industry is facing a financial crisis. Industry debt and associated debt service costs continue to increase. The domestic steel industry can not afford additional regulation that are not flexible * * * [Ex. No. 201–44, p. 40].

On the other hand, imposition of various quotas on steel imports and a reduction in interest rates have offset these events. These two factors, as well as the closing of old and inefficient facilities, should reduce the losses experienced by the industry over the last several years.

Nevertheless, in view of the industry's current circumstances, both the USWA and AISI have recommended an extended phase-in period for the required engineering controls. Given this provision, both parties view compliance with the new standard to be economically feasible for the iron and steel industry. The USWA stated, for example.

> Despite these hard times in the industry, the AFL–CIO and USWA see no reason why any existing byproducts or BTX plant should have to close over the imposition of a new standard for benzene. While we would oppose a long phase-in period for the standard as a whole in this sector, certain expensive controls could be phased-in over time. For example the industry could be allowed to install double mechanically sealed or magnetically driven pumps as the current pumps wear out, so long as all such replacements were made within 5 years. Conversion sumps, gas blanketing systems, and the conversion of direct water final coolers where necessary [Ex. No. 262, pp. 35–36].

AISI stated:

> Allowing an extended compliance period for implementation of feasible engineering controls would enable the financially strapped steel industry to conserve scarce cash by installing engineering controls on a basis that corresponds more closely to a normal equipment replacement cycle. Such an implementation schedule (with use of respirators permitted in the interim) would represent a more feasible, practical and cost-effective course of action than OSHA has proposed. It also would lessen some of our concerns regarding the economic impact of the standard on the steel industry [Ex. No. 259, pp. 39–40].

For the reasons stated, therefore, OSHA has accepted these recommendations and has modified the method of compliance for the coke and coal chemical sector. Instead of

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requiring the implementation of feasible engineering controls to reduce worker exposure no later than 2 years after the effective date of the standard, as is required for other sectors, coke and coal chemical will be permitted to phase-in these controls over a 5-year period, and the use of respirators is permitted during the interim. Thus, OSHA concludes that compliance with the new benzene standard is economically feasible for the coke and coal chemical sector.

Conclusion

OSHA has also determined that the revised benzene standard is economically feasible in each of the industry sectors.

G. Regulatory Flexibility Analysis

Pursuant to the Regulatory Flexibility Act of 1980 (Pub. L. 96–353, 94 Stat. 1164 [5 U.S.C. 601 et seq.]), OSHA has studied and has given special consideration to the mitigation of the economic impacts of the proposed standard on small entities. OSHA carefully considered size factors such as number of employees, total assets, and gross revenues when identifying any adverse economic impact of the revised benzene standard.

In the four industries characterized by large firms (i.e., petrochemical, refining, coke and tire), OSHA does not anticipate any differential impact on smaller firms, because most of the major costs are roughly proportional to the size of the facilities. For example, the total cost of improving pump seals at a benzene production facility depends on the number of pumps seals at the facility, and the total cost of reducing exposures at a tire manufacturing plant depends on either the amount of ventilation that must be provided or the amount of low-benzene-content solvent used. These factors vary directly with firm production levels. In addition, due to economies of scale, the smaller firms in these sectors are of substantial size in terms of gross revenues and numbers of employees.

Two sectors are characterized by small firms. This section, therefore, concentrates on assessing the economic impacts of the benzene proposal on small firms in the bulk plant and tank truck for-hire sectors.

Bulk plants average 19 full-time employees, have average gross assets of $1.3 million, average gross revenues of $10 million, and average after-tax profits of $55,000. Although these firms are not large, on average, they have substantial revenues. The fuels stored at these facilities are primarily contained in closed systems. Most bulk plants will incur only minor costs of about $450 associated with monitoring, respirators, training, and medical surveillance. The small firms in this sector (i.e., those with less than $500,000 in assets) will incur an after-tax decline in profits (and in the salary of the chief executive) of less than 1 percent assuming none of the costs are passed forward to consumers. The larger firms will have less of a profit decline. Under the assumption that costs are passed forward, small firms will require a price increase of approximately 0.02 percent in order to maintain their current level of profits. OSHA believes that these firms will be able to pass forward the 0.02-percent price increase because most of these firms are located in sparsely populated areas with less competition, and because all firms in this sector will experience similar compliance costs. (In densely populated areas, the facilities usually have vapor controls and are in large part exempted from the standard.

In the tank truck for-hire sector, OSHA has not attributed any costs for engineering controls, because they have been considered in the discussion of other sectors (i.e., refining, petrochemical, and bulk storage). OSHA believes that this sector will incur costs of approximately $1,900 per firm for training, medical surveillance, and monitoring. Compliance with the revised benzene standard for "small firms" in this sector (i.e., those with less than $5 million in annual revenue) will result in an average decline in after-tax profits of about 2 percent if no costs are passed forward or will require price increases of approximately 0.07 percent to leave profits unchanged. Once again, since most firms will experience similar compliance costs, it is likely that these costs will be passed forward to consumers.

OSHA, therefore, believes the impact on small businesses in both of these sectors will be minor.

Small businesses currently using solvents contaminated with benzene are expected to purchase solvents that initially have less than 0.5 percent benzene and, after 2 years, have less than 0.1 percent benzene. They will then be excluded from the other provisions of the standard.

As discussed above, there are a number of processes available to reduce the benzene concentration in liquids (see Chapter 4 of JRB report [Ex. No. 153]. Some of these solvents are already on the market in the same price range as solvents contaminated with higher concentrations of benzene. One large oil company, for example, presently markets petroleum naphtha with less than 0.1 percent benzene at the same posted price as untreated naphtha. Although JRB reports that some of low-benzene-content solvents are currently more expensive than high-benzene-content solvents (approximately 10¢ per gallon), after the promulgation of a new standard, the competitive advantage of solvents with a low-benzene content will probably lead to expanded production of such compounds and lower prices. This was OSHA's experience with a similar provision in the vinyl chloride standard.

Solvents typically represent a small cost for most businesses, and a small increase in these costs will not appreciably affect employers, since all competitors will be equally affected. The substantial increase in the costs of solvents during the 1975–1982 period due to the large increase in petroleum costs were successfully passed forward by solvent users because these solvents are generally a small cost of business.

For these reasons, OSHA believes that compliance with the benzene standard is technically and economically feasible and will have no significant impact on small businesses currently using benzene-contaminated solvents.

H. Environmental Impact Assessment—Finding of No Significant Impact

The proposed revisions to the benzene standard have been reviewed in accordance with the requirements of the National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. 4321 et seq.), the Council on Environmental Quality (CEQ) NEPA regulations (40 CFR Part 1500), and OSHA's DOL NEPA Compliance Procedures (29 CFR Part 11).

As a result of this review, the Assistant Secretary has determined that the proposed rule will not have a significant impact on the external environment. Impacts on the workplace environment are discussed in other portions of this preamble.

Under the present revisions to the benzene standard, there have been some changes in the scope of the standard, the definitions of benzene and benzene mixture, and in the monitoring provisions as well as some language modifications throughout. The final standard includes provisions for an 8-hour TWA of 1 ppm and a ceiling of 5 ppm over a 15-minute period.

The changes in time period for employers to reformulate products or to find substitutes to meet the PEL, or for coke ovens to implement engineering controls, should not have a significant impact on the external environment. Consequently, the conclusions drawn in OSHA's earlier finding of no significant impact (50 FR 237: 5070–5071, December 10, 1985) remain valid.

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IX. Conclusion and Permissible Exposure Limit

OSHA had considered 4 exposure limits, to 5.0 ppm, 1.0 ppm, 0.5 ppm and 0.1 ppm prior to proposing a 1 ppm 8-hour time weighted average (TWA) and a 0.5 ppm action level. Two additional limits were proposed in comments, 2 ppm and 1 ppm with a different compliance strategy which would permit higher average exposures. In addition, OSHA requested comments on whether a short-term exposure limit (STEL), possibly 5 ppm over a 15 minute-period, should be included.

OSHA has carefully considered all the evidence and comments. Based on this review OSHA concludes that a 1 ppm 8-hour TWA and a 5 ppm STEL over a 15 minute period are the appropriate exposure limits. They will substantially reduce a significant risk of leukemia and other blood diseases and do not attempt to further reduce an insignificant risk. These levels are technically and economically feasible and are the lowest feasible level generally achievable.

As discussed in depth in the significant risk section, the risk of leukemia death from a working lifetime of exposure at 10 ppm is 95 excess deaths per 1000 exposed employees. This is clearly a significant risk. The 1 ppm 8-hour TWA will achieve a greater than 90 percent reduction in that risk, clearly a substantial reduction in risk. The new standard will substantially reduce risks from other disease of the blood and blood-forming organs such as aplastic anemia, multiple myeloma and pancytopenia.

As discussed above in the technical and economic feasibility section a, 1.0 ppm 8-hour TWA is clearly generally technically feasible with engineering and work practice controls for the large majority of production and more continual operations in the segments regulated. The standard permits the use of respirators for maintenance and repair activities, short intermittant operations, operations where benzene is present for 30 days or less, and other operations where the employer can demonstrate that engineering and work practice controls are not feasible to achieve the exposure limits.

OSHA also concludes that this standard is clearly economically feasible. It would result, if no costs were passed on to purchasers, of no greater than a 2 percent reduction in profits of the sectors where the effects are greatest. If all the costs were passed on to the purchasers, the maximum average price increase in a sector would be 0.2 percent.

As discussed in the Economic Impacts Section, the coke and coal chemical industry faces the greatest potential adverse impact resulting from the standard. Since compliance costs for coke by product operations would be approximately 0.2 percent of sales for the steel industry and this industry is operating at a net loss, OSHA has granted this sector an extended 5 year period to comply with engineering controls. OSHA concludes that as drafted the standard is economically feasible for this sector since the industry agrees with the extended compliance period.

Obviously a 5.0 ppm level is also clearly feasible since the 1.0 ppm level is, however, based on the risk assessment a 5.0 ppm level would achieve only a 50 percent reduction in risk, not the 90 percent reduction in risk rates that a 1.0 ppm level achieves. The 1.0 ppm level substantially reduces a significant risk which would exist at 5 ppm further and is clearly feasible. Consequently, the 5 ppm level is not appropriate.

OSHA concludes that the same reasoning applies to a 2 ppm level as to a 5 ppm level. Therefore, 2 ppm is not appropriate.

Several participants recommended that OSHA set basically a 1 ppm long term exposure limit rather than a 1 ppm 8-hour TWA. This issue (referred to as variability) is discussed in much greater detail both in the technical feasibility and exposure monitoring sections.

There is a certain amount of random day to day fluctuation around the average exposure level. With a 1 ppm 8-hour TWA, employers must keep exposures on average somewhat below 1 ppm so that there are few random daily fluctuations over the 1 ppm 8-hour TWA limit.

With a 1 ppm long term average limit (which could be achieved by several mechanisms discussed under variability in the monitoring section), as long as long term average exposure were under 1 ppm, daily fluctuation could be over 1 ppm. Consequently, this approach can lead to higher average exposures than a 1 ppm TWA approach.

As discussed in the feasibility and monitoring sections OSHA does not believe variability in the regulated industries is as great as some participants claimed and concludes that the 1 ppm 8-hour TWA limit is clearly feasible. OSHA concludes that the 1 ppm 8-hour TWA is also appropriate because actual reduction in risk of the new standard is then substantially greater than 90%. See the discussion in the significant risk section.

As discussed in the technical feasibility section, many of the same types of engineering and work practice controls which would achieve a 1.0 ppm level could also be used to attempt to achieve a 0.5 ppm level in the industries covered. More extensive use of the same type of controls and some technology forcing might achieve the 0.5 ppm in some operations but the record is unclear how extensively 0.5 ppm would be achieved.

The AFL-CIO and United Steelworkers have contended that OSHA should set a 0.5 ppm 8-hour TWA level. They stated that OSHA has authority to force technology and has not paid enough attention to what is achieved in the most modern facilities.

On the other hand, several industry participants stated that OSHA has not give sufficient thought to variability and some other technical problems in achieving 1 ppm. These matters are discussed in detail in the technical feasibility section.

OSHA has carefully considered the evidence and arguments. OSHA concludes that it has correctly determined that a 1 ppm 8-hour TWA and not 0.5 ppm is the lowest feasible level. The unions have pointed out some situations where controls might do somewhat better than 1 ppm. Industry has suggested some techincal difficulties which might create more of a technical challenge to achieve 1 ppm. OSHA believes it has chosen the correct balance at 1 ppm, as the level it can have a high degree of confidence is generally achievable. OSHA believes the action level will achieve in the case of benzene much of what might be achieved through a greater attempt to force technology and the history of the standard suggests that a high degree of confidence in feasibility has value. See the discussion in the technical feasibility section.

OSHA concludes that a 1.0 ppm TWA level with a 0.5 ppm action level will be substantially as protective as and more cost-effective than a 0.5 ppm TWA level in these circumstances. As a result of the action level, OSHA believes many employers, where it is feasible to achieve 0.5 ppm, will choose to achieve this level with engineering and work practice controls, in order to save on the cost of monitoring and medical provisions which are required for employees exposed over the 0.5 ppm action level.

When it is not feasible to achieve levels below 0.5 ppm, OSHA concludes that the industrial hygiene, monitoring and medical provisions will provide substantial protection for employees

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exposed between 1.0 ppm and 0.5 ppm. They will result in less exposure to employees through training, protective clothing and monitoring. The medical provisions will detect some abnormal blood conditions, which if detected early, make it possible to prevent or treat some conditions.

A 0.1 ppm permissible exposure limit does not, on the evidence now before OSHA appear to be technically feasible to achieve. To attempt to achieve it with engineering controls and work practices would appear to require major redesigns in large, capital intensive facilities such as refineries, coke operations and petrochemical plants and small business as well. Many large scale operations would need to be isolated or automated. Making major modifications for a large percentage of facilities in a number of the affected industries would not appear to be technically feasible at this time.

Short-Term Exposure Limit (STEL)

As discussed at greater length in the Permissible Exposure Limit part of the Summary and Explanation of the Standard, OSHA concludes it is appropriate to include a STEL of 5 ppm over a 15 minute period in the benzene standard. Animal studies indicate that intermittent exposures (a good model for fluctuating peaks) caused greater decreases in certain blood counts than continual exposures at the same level. Several case control studies of refinery workers show excess leukemia risk among pipefitters, maintenance workers and other jobs entailing exposure to benzene probably as intermittent peak exposures. This limit is feasible and adds little to costs because the 1 ppm limit will in general be achieved through controlling peaks. It will also reduce cumulative dose in some circumstances.

X. Summary and Explanation of the Final Standard

OSHA has determined that the requirements set forth in this final standard are those, based on currently available data, which are necessary and appropriate to provide protection to employees exposed to benzene. In the development of this standard OSHA has carefully considered the comments and data from interested parties submitted to the benzene docket. In addition, numerous reference works, journal articles, and other data in the record have been taken into consideration in the development of this standard.

The following sections discuss the specific provisions of the standard:

A. Scope and Application: Paragraph (a)

The standard is to apply to all occupational exposures to benzene with the specific exceptions set forth in the scope and application paragraph. The risk from benzene is, of course, dependent on the degree of exposure and not on the segment of industry where the employee may be employed. However, in some segments and operations, exposures are consistently below the action level because of the nature of the process. In those circumstances, OSHA is granting an exemption or partial exemption from the proposed new benzene standard. In general, initial monitoring for many operations where the evidence clearly demonstrates that exposures will be consistently below the action level does not appear necessary to protect employees nor cost-effective. The specific exemptions are discussed below.

It should be noted that OSHA has retained the 10 ppm level for sectors which OSHA has exempted from coverage of the new standard. This is not because OSHA believes the 10 ppm level is adequate for employee protection or that there will be employees approaching that level. OSHA believes that virtually all exposures in the sectors exempted form 29 CFR 1910.1028 will be under 0.5 ppm because of the nature of the process or other regulations and that is the basis for the exemption. However, there is a possibility that there may be an operation within the exempted sectors which OSHA is not aware of. The 10 ppm level will remain in backstop to prevent exposures from rising too high if such a situation exists in the interim until OSHA takes further regulatory action. The 10 ppm level is also retained as an interim engineering control level for reasons discussed below. This backstop approach has been recommended in several comments (Ex. No. 260, p. 7d).

Paragraph (a)(2)(i) *Fuels.* OSHA proposed to exempt from the benzene standard the storage, transportation, distribution, dispensing, sale and use of gasoline, motor fuels or other fuels containing benzene as a contaminant or small percentage constituent subsequent to its discharge from bulk wholesale facilities.

Based on data in the docket, OSHA determined that the benzene exposures in the retail gasoline sector were well under the proposed action level. In a 1977 NIOSH report (H-059, Exh. #93A), for example, the preponderance of the service stations surveyed had an 8-hour TWA of less than 0.1 ppm and only one of 37 stations surveyed had 8-hour TWA greater than 0.2 ppm (0.294 ppm). In a more recent survey submitted by Runion and Scott (Ex. No. 159-67), over 96 percent of the samples taken were below 0.5 ppm; and, although this survey does include some samples greater than the proposed 1.0 ppm PEL (0.9 percent), OSHA believes that the high readings were probably the result of improper work practices (i.e., standing downwind of the hatch during tank gauging, spills, etc.) and can easily be eliminated. The trend in recent years toward self service station; should also tend to reduce "occupational" exposures to benzene in this sector.

In addition to having low benzene exposure, the retail gasoline sector is characterized by a large number of facilities (an estimated 155 thousand in 1980 according to A.D. Little, H-059. Ex. No. 5A) with a largely transient work force, making it more difficult to implement many of the non-PEL requirements of the proposed standard (i.e., medical surveillance and training).

A number of comments were received on this proposed exemption. The API commented extensively supporting the exemption in their post-hearing comment (Ex. No. 260—Addendum D, pp., 5d-16d). They reviewed a number of studies of banzene exposures at gas stations and concluded that exposures were generally substantially under the action level and that the few exposures over the action level were rare random events which were not generally substantiated by repeat monitoring. They also argued that because a high employee turnover and the small business nature of the operations there might be feasibility problems with extensive regulation. They further argued that because of high turnover and the intermittent nature of pumping gas that cumulative exposures would be low. Finally, they noted that the EPA has taken a number of actions to reduce hydrocarbon emission from gas stations, which will also have the effect of further reducing potential employee exposures to benzene emissions. Similar comments were also received from individual petroleum companies and their associations (Ex. No. 201-39, for example).

The AFL-CIO and United Steel Workers agreed with the exemption for gas station and motor fuels (Ex. No. 262, p. 54). However, the reason they believed the exemption was appropriate was that they believed these operations could be better regulated by the EPA.

The Public Citizen Health Research Group opposed the exemption until further analysis of exposures was conducted. They pointed out that some exposures were over the action level and the possibility that benzene might

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be used as an octane enhancer (Ex. No. 201–41, p. 7).

OSHA concludes after reviewing the record that the general exclusion for gas stations and the storage, transportation and dispensing of gasoline, motor fuels and other fuels after final discharge from bulk wholesale storage facilities is appropriate. Exposures are generally well below the action level and there are very few measurements over the action level. Keeping exposures low is the small percentage of benzene in the fuels generally and that the work is generally intermittent and outdoors. In addition, this is an area where EPA is actively involved in regulating to protect the environment. The EPA regulation and controls (such as boots over gasoline hoses and other vapor recovery systems) are good methods of keeping worker exposure low. Indeed, the EPA has mandated these requirements for urban areas where high volume stations and operations are located.

An exception to this general exposure pattern was pointed out during the hearings. Dr. Frank Mirer of the United Auto Workers (UAW) noted the following during the public hearings that:

> [T]he cited data do not apply to many situations where motor fuels are dispensed.
>
> Gas pumping in a retail gas station takes place outside. The operation is generally intermittent. The ambient air movement outdoors confers much better dilution ventilation than any general ventilation system dreamed of indoors.
>
> So, the UAW recommends at the very *limit* that indoor operations dispensing motor fuels not be excluded from the standard [Tr, 3/25/86, pp. 10–11].

The Motor Vehicle Manufacturers Association did not address this issue in its post hearing submission (Ex. No. 248).

OSHA accepts the reasoning of Dr. Mirer, who is an expert in industrial hygiene matters, that in situations where an employee is continually pumping gas indoors for a full work shift other factors should be considered. Since natural ventilation and intermittent exposures would not necessarily act to keep benzene exposure low during indoor operations, samples taken outdoors at filling stations are not relevant to characterize indoor exposure.

Consequently paragraph (a)(2)(i) of the final standard provides that this exemption does not apply where gasoline or motor fuels are dispensed more than 4 hours per day indoors. Four hours was chosen as a reasonable period to differentiate between intermittent and non intermittent operations.

It should be noted that the initial requirement for operations not covered by the exemption is to initially monitor. If the exposures determined by the initial monitoring are below 0.5 ppm, the only ongoing requirement on employers is to periodically train employees in the hazards of benzene and remonitor if evidence comes to the employer's attention that exposure to benzene may have risen. If exposures are above 0.5 or 1 ppm the employer must undertake the other required provisions of the standard depending on the level.

OSHA's proposal exempted in addition to motor fuels "other fuels," which would exempt jet fuel and aviation gasoline. This exemption was supported by the National Air Transportation Association (NATA) (Ex. No. 201–21). They referred to a study introduced in the earlier benzene rulemaking which they indicated demonstrated that benzene exposures were low while dispensing such fuels.

The NATA stated in the earlier exhibit that:

> On June 15, 1977, personnel of the Gollob Analytical Service Corporation, Berkeley Heights, New Jersey, recognized experts in the field of mass spectrometry gas chromatography and lead detection, visited the site of AirKaman, Inc. (an NATA member), located at Bradley International Airport, Windsor Locks, Connecticut. The purpose of their visit was to monitor the ambient air in the breathing zone of the employees, in order to help us in reaching a conclusion whether or not there was "grave danger" for employees engaged in the business of retail aviation fueling. During the monitoring period, employees were exposed to a wide range of fueling operations. The range included minimal, normal, and extreme. In all cases, no benzene was detected, with the threshold of detection at less than 0.1 ppm.
>
> In addition, we provided the OSHA hearing panel with a copy of the communique sent to aviation fuel dealers of Texaco, Inc.[2]. . . This additional exhibit, further corroborated the findings of the Gollob Analytical Service Corporation, and should be used for present and future consideration [Docket H059, Ex. No. 217–37F].

In addition, OSHA received other comments (Ex. Nos. 142–3, 142–7, 142–10. 142–21, 142–31) urging the exclusion of other non-gasoline fuels, from the scope of the proposed standard. Although OSHA has not received any exposure data on their operations, the Agency believes employee exposures are well under the action level in the distribution of these other types of fuel because the operations are somewhat limited compared to the dispensing of motor fuel and the benzene content of these fuels is typically less than that of gasoline. Based on the evidence that exposures are low and the reasoning discussed for motor fuel, OSHA concludes that the proposed exemption for other fuels is warranted.

Paragraph (a)(2)(ii) Storage Facilities

In its 1978 benzene rulemaking process, OSHA proposed that marketing activities of fuels down stream of "bulk terminals" be excluded from the scope of the standard. This resulted in the exemption from the standard, as it was interpreted, of bulk plants which have the same type of operation and fulfill the same function as bulk terminals (the storage of fuel and the loading of trucks to distribute the fuel to service stations and larger scale users). The basis for not covering the bulk plants was that inadequate notice had been given for their coverage (43 FR 5943; Feb. 10, 1978).

The Agency received comments on the way the earlier exemption was drafted in response to its request for information under its current rulemaking process. Typical of the comments was the American Petroleum Institute's submission (Ex. No. 142–31) which states "OSHA's * * * contractor * * * concluded that this exemption was justified on the basis of very low benzene exposures at the worksites. The difficulty with this exemption was its arbitrariness. It did not cover gasoline 'bulk terminals' which are functionally identical (in terms of potential occupational benzene exposure) to the 'bulk plants' which were exempted."

Therefore, OSHA reexamined the basis of this exemption and concluded that the most appropriate basis for an exemption is exposure levels. If exposures are consistently substantially below the action level, then an exemption would be protective of employees. But if exposures are sometimes below the action level and other times above it or above the PEL, absent other compelling circumstances, a total exemption would not provide adequate protection since many employees would be exposed above the action level. (Obviously if the average exposure is approximately at the action level, approximately half of employees will be exposed above it).

The exemptions for the bulk storage facilities in the proposal were, therefore, based on the level of exposures. Two reports (Irving and Grumbles, 1979, Ex. No. 159–42 Phillips and Jones, 1976, Ex. No. 159–63) indicate that bulk plants and terminals with vapor control systems, either top or bottom loading, have average 8 hour TWA exposures substantially below 0.5 ppm (i.e. in the neighborhood of 0.1 ppm) with few 8-hour exposures above the action level,

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and peak exposures averaging 1 ppm for a 15 minute period.

Thus, OSHA concluded that the use of either type of vapor control system would result in average exposures virtually always below the action level and proposed to exempt from this section loading operations at both bulk plants and terminals which use the vapor control systems on this basis.

However, the same data indicated that bulk plants and terminals without vapor control systems have average 8 hour TWA's in the range of the action level which means many employees would be exposed over the level, and some over the PEL. Therefore, OSHA did not propose an exemption for bulk plants and terminals which do not have vapor recovered because that would not be sufficiently protective of employees. There are a number of simple inexpensive techniques which can frequently lower exposures below the action level and thereby increase employee protection.

API during the rulemaking submitted additional, albeit limited, data documenting low levels of exposure in loading operations using vapor recovery. Companies D and P reported, in response to API's supplemental survey, that *all* of their operations employ vapor recovery systems. The survey data supplied by these two companies demonstrate low levels of benzene.

API removed maintenance employee samples from Company D's marketing terminal results to arrive at corrected figures for loading exposures, and added to this data Company P's marketing terminal data. Of 39 samples from the two companies, only 3 (7.7 percent) were between .5 and 1.0 ppm, and all the remaining samples fell between 0.1 and 0.5 (14=35.9 percent) or below 0.1 (22=56.41 percent). These data confirm OSHA's findings that vapor recovery systems consistently reduce exposures to very low levels. [Ex. No. 204–7, pp. 70–71]

API's conclusion is "there is little doubt about the merits of OSHA's proposal to exempt bulk facilities equipped with vapor controls," and they supported the exemption (Ex. No. 210, p. 29d). The Society of Independent Gasoline Marketing of America also supported this exemption (Ex. No. 201–39).

The Public Citizen Health Research Group objected to this exemption. They argued that average exposures were well under the PEL, but considered there was a possibility of high peak exposures in transfer operations (Ex. No. 201–41).

The AFL-CIO and USW (Ex. No. 262, p. 54) opposed all exemptions except for the sale and transportation of gasoline. They argued that for those operations where exposures are consistently below the action level, OSHA should only give an exemption from initial monitoring. If exposure are indeed consistently below the action level, the AFI-CIO and USW argued that the employer would as "a practical matter have no obligations." However, if an employer is found to have exposures above the action level, the employer would then be covered they contended.

OSHA concludes after reviewing the record and comments that the exemption for bulk plants and terminals with vapor control is warranted. The exposure data indicate that exposures are well under the action level with few exposures over the action level. The vapor controls limit exposures at the exact time when needed, when trucks are opened for loading and unloading. Because of this, OSHA believes the operation of vapor control is such that it will keep exposures well below the action level and will eliminate high peaks.

The Health Research Group objected to the exemption, specifically, because of concern about short-term peaks. However, in response, the controls which result in an exemption will prevent short term peak exposures. Thus, OSHA has a high degree of confidence in vapor control technology and has granted the exemption because vapor control technology will keep exposures low. In addition, since very low levels of benzene are ubiquitous, OSHA believes the standard will be more effective if both the standard and the employers' compliance activities are concentrated in areas where there is a likely possibility of exposures over the action level.

However, one clarification is needed to the exemption. The preamble to the proposal makes it clear that the exemption is intended to apply only to loading and unloading operations at vapor controlled bulk plants. It states, "Thus, OSHA * * * has proposed to exempt *loading operations* at both bulk plants and terminals which use the vapor control systems * * * " (50 FR 50549) It was not the intent of OSHA to exclude maintenance and repair operations at those facilities because during those operations the vapor control system may be closed down or tanks and pipes may be opened for cleaning and repair. OSHA in its Preliminary Regulatory Impact Analysis includes costs for covering maintenance and repair at these facilities (Ex. No. 202 p. 2–41,2) and the API recognized this in its comments (Ex. No. 204–7, p. 17).

The final standard changes the words "The work operations at bulk wholesale storage facilities" to "loading and unloading operations at bulk wholesale storage facilities * * *." This clarifies OSHA's intent that operations not protected by vapor controls are covered by the standard.

It should also be noted that the exemption does not cover the emergency provisions of the standard and hazard communication requirements. If a vapor controlled loading facility has a major rupture, the emergency provisions such as respirator use and special medical exams may apply. In addition, under the hazard communication standard which is referenced by the benzene standard, workers are to be trained about benzene hazards if there is more than 0.1 percent benzene in the fuels at a facility. Such requirements are needed to protect workers during major spills and to make them aware of benzene's possible hazards so they are aware of the importance of the controls.

Conoco commended "OSHA for recognizing that vapor control systems effectively remove vapors from the work areas of bulk wholesale storage facilities" (Ex No. 201–46, p. 2). Conoco also suggested OSHA revise its definition of vapor control system to include "any equipment used for containing the total vapor displaced during the loading and unloading * * * and removing it from the work area" (Ex. No. 201–45, p. 4). After careful consideration of the Conoco comments, however, OSHA has decided not to revise the definition of vapor control systems.

OSHA adopted the definition from the EPA definition of Stage I Vapor Control System and the monitoring data used to justify the exemption for vapor control systems were obtained with Stage I systems in use. (API specifically notes this in its comments (Ex. No. 60A, p. 26d). While other systems may be effective in maintaining employee exposures below the action level, OSHA can not properly evaluate this assertion without monitoring data. Thus, if Conoco decides to install the containment system described in its comments, it may do so. If the results of initial exposure monitoring obtained after the installation of the equipment show that employee exposures are indeed below the action level as Conoco asserts, then no further action need be taken.

OSHA, however, did not propose exemptions for bulk plants and terminals without vapor control systems. The data (Ex. Nos. 159–42 and 159–62) indicate that bulk plants and terminals without (Stage I) vapor control

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systems have average 8 hour TWA's in the range of the action level which means many employees would be exposed over the level, and some over the PEL. Lack of vapor control creates the possibility of higher exposures while loading and unloading. Even if 8 hour TWA's are not high because of intermittent operations, the possibility of higher peaks exist.

OSHA received several comments about not including bulk plants without vapor recovery. The Society of Independent Gasoline Marketers of America (whose members own such facilities) while strongly support the exemptions for plants with vapor recovery, stated as to plants without vapor control equipment that they believe OSHA "overstates the cost-effectiveness" of the regulations and that OSHA should "revaluate" this issue (Ex. No. 201-3A) API stated "it is certainly possible to question" whether these operations should be covered but stated no firm view (Ex. No. 260, p. 28D). The Petroleum Marketers Association of America opposed mandatory conversion to bottom loading systems (Ex. No. 201-36). However, OSHA is not, of course, mandating that control or any system of vapor recovery, just granting an exemption if vapor recovery is used.

OSHA did have a contractor take measurements at three bulk plants without vapor recovery (Ex No. 240d). The plants did not know the benzene content of their fuels (If there is little or no benzene in the fuels, employees exposures would of course be low). The exposures measured were quite low the PMAA argued in a later submission that these data justified not covering those facilities (Ex. No. 230).

OSHA concludes that a total exemption for bulk plants and terminals without vapor recovery is not appropriate. There is the possibility of average exposures for some workers over the action level and of high peak exposures when loading and unloading fuels with more than a trace of benzene. The earlier studies indicate exposure averaged near the action level which means a substantial percentage of employee exposures over the action level. In addition, on engineering grounds these facilities do not have controls in a routine operation (loading and unloading) where exposures are likely to be higher.

The later monitoring results were on too small a scale to change this conclusion. OSHA agrees with PMAA that the later study does not justify coverage either, but OSHA believes the earlier data and sound engineering principles does not justify an automatic exemption.

OSHA has carefully crafted the provisions of the standard to minimize the impact of the standard on those bulk plants and terminals which are not exempted and to maximize the cost effectiveness of the standard while protecting employees. Those facilities not exempted must do initial monitoring. If exposures are below the action level, no further action is needed unless processes change. If exposures are above the action level, simple work practices may succeed in lowering them below the action level, employees will be protected and no further action need be taken by the employer. If these procedures do not succeed in reducing exposures below PEL, then simple engineering controls are available which will lower exposures to protect employees, reduce fire hazards and provide environmental benefits.

The PMAA states that the typical bulk plant averages $53,000 in net profits and some types of controls could cost several hundred thousand dollars. OSHA wishes to make clear it is not requiring any specific types of controls, is not requiring bottom loading and is not requiring vapor recovery. OSHA has carefully analyzed the costs and methods of compliance which are discussed above and in the Regulatory Impact Analysis. That analysis indicates that the average cost to come into compliance with the benzene standard is less than $450 per year per facility. Other facilities with the highest benzene exposures may need to make a capital expenditure as high as $20,000.

Paragraph (a)(2) (iii) and (iv) Containers and Pipelines

OSHA proposed to exempt from most provisions of the benzene standard sealed containers and transportation pipelines which contain or transport chemicals, which have benzene as a constituent or contaminant. Sealed containers and transportation pipelines with liquids containing more than 0.1 percent benzene would be covered by the emergency provisions of the standard requiring respirators and medical surveillance if there were an emergency. Sealed containers would also be covered by the Hazard Communication Standard, 29 CFR 1910.1200 (48 FR 53280; Nov. 29, 1983) if they contain more than 0.1 percent benzene. That standard would require, in conjunction with the benzene standard, labeling the containers to indicate that it contained benzene, a carcinogen: employee training specifying what to do if the container was opened or broken; and the supplying of material safety data sheets. Containers and pipelines, whether sealed or not, carrying substances containing less than 0.1 percent benzene were proposed to be completely exempt from this standard and would also be exempt from the Hazard Communication Standard because of the percentage of benzene present in the substance. (Obviously, the substance could be covered by the Hazard Communication Standard because of other chemicals present).

The basis for the exemption for sealed containers containing mixtures with more than 0.1 percent benzene was that it was unlikely on a regular basis for such containers to leak sufficient benzene to expose employees over the action level. The labeling and training provisions of the hazard communication standard already issued would provide sufficient protection in those situations where a container breaks so that employees will know how to handle and clean up a spill safely. The emergency provisions of this standard would cover major spills. The intention of this exemption was to cover warehouses, distributors, supply rooms and similar operations where the chemical containers are stored, transported or sold and not normally opened. However, operations where the containers are opened or the chemicals contained in them are used would be covered because of the possibility of exposure above the action level.

OSHA also proposed to exempt transportation pipelines for similar reasons. They are sealed and exposures tend to be low. This exemption was specifically designed for pipelines which transport gasoline, crude oil and other petroleum products, where the percentage of benzene tends to be under 5 percent so that irregular slight leaks will probably not lead to exposures over the action level on a regular basis. This exclusion does not apply to pipes in a manufacturing process which carry benzene or another chemical containing benzene. Unlike transportation pipelines, employees in a manufacturing process plant will likely be in the area on a regular basis and slight leaks may lead to regular benzene exposure over the action level. In addition, since benzene exposures of employees repairing or maintaining transportation pipelines could be substantial, the exemption does not extend to repair or maintenance operations. However, the exemption of pipes from labelling requirements in this standard and from the hazard communication standard does apply in all cases.

The emergency provisions of the benzene standard also would continue to apply to pipeline operators and the handling of sealed containers with more

than 0.1 percent benzene. This is a performance oriented provision. No specific quantity of benzene spilled or exposure level is stated as constituting an emergency. It is not possible to state such provisions specifically because of the large number of parameters in terms of percentage of benzene, quantity of benzene, size of area and ventilation rate. However, employers who have sufficient benzene present so that a container or pipeline break will lead to higher concentration of benzene are to keep appropriate respirators present for employees who must clean up the spill (See section (g)(1)(iv)) and a specific medical examination is required for employees who have been exposed to benzene in emergency situations.

The API supported the exemption specifically for crude oil and gasoline pipelines (Ex. No. 260, p. 24d). They referred to Runion and Scott who found that almost 95 percent of reported samples were of 1 ppm or lower, and over 90 percent of samples were at or below 0.5 ppm. API also supplied a limited amount of more recent additional data obtained during its final telephone survey which documents more recent sampling that obtained results even lower than those reported by Runion and Scott regarding pipelines. Company O supplied the results of 22 pipelines samples taken during 1984 and 1985. One of these samples (4.5 percent) showed exposure in the 0.5–0.99 ppm range, while all other samples were lower: 2 (9.1 percent) between 0.25 and 0.49; 2 (9.1 percent) between 0.1 and 0.24; and 17 (77.3 percent) less than 0.1 ppm (Ex. No. 204–7, p. 68–69). API concluded the low exposures, especially of the more recent survey supported the exclusion.

In further clarification it should be noted that exemption (a)(2)(iii) only applies when the containers and pipelines are sealed. When the containers are opened or filled or the pipelines repaired, the exemption does not apply since there would be the possibility of high benzene exposures. The API understood and agreed with this interpretation as to repair (Ex. No. 260, p. 25d).

In addition, the loading or unloading of pipelines where the operation is not sealed, is not covered by the exemption. That would not be an operation where the "transportation pipeline (is) sealed in such a manner as to contain benzene vapors." Unloading a pipeline with more than 0.1 percent benzene could lead to high benzene concentrations (and the percentages can go up much higher) if it is not sealed to contain benzene vapors and loading and unloading operations from pipelines may go on for more than brief periods. API's interpretation that all loading and operations from pipelines would be covered by this exemption is incorrect and would not be good policy since high exposures are a possibility (Ex. No. 260, p. 25d).

The exemption for containers and pipelines with mixtures containing less than 0.1 percent benzene applies even if they are not sealed. The basis is that when concentrations of benzene are as low as this, airborne exposures are unlikely to exceed the action level. The 0.1 percent level also ties in with the Hazard Communication Standard which requires no listing of the presence of carcinogens which are present at less than 0.1 percent.

The Independent Petroleum Association of America (Ex. No. 201–12) and Texas Oil and Gas Corp. (Ex. No. 201–8) stated that an exemption should be granted for natural gas. They stated that natural gas contains no benzene after processing and before processing contains well under 0.1 percent. Texas Oil and Gas included data showing that the inlet stream at natural gas processing plants was well under 0.1 percent.

Paragraph (a)(2)(iv) already excludes pipelines with mixtures of less than 0.1 percent benzene. So pipelines carrying natural gas both processed and not processed would be exempted because according to the data supplied the natural gas has less than 0.1 percent benzene. However, that paragraph as proposed would not cover natural gas processing plants. The other exemptions refer to liquid (not gaseous) mixtures.

OSHA has reviewed the record and the reasoning in its proposal. OSHA concludes that the exemptions are appropriate for the reasons stated in the proposal and restated above. One change is made. Paragraph (a)(2)(iv) is expanded to indicate that natural gas processing plant with less than 0.1 percent benzene is exempted as the same reasoning applies.

Paragraph (a)(2)(v) Percentage Exclusion

Benzene is a naturally occurring constituent of crude oil and as such is present in trace quantities in many products made from it. In the proposal, OSHA reasoned the standard would be protective of employees and more cost effective if employers who utilize chemicals, generally solvents with trace amounts of benzene, can be excluded from the standard when there is a high degree of confidence that the trace amounts of benzene present will not lead to airborne exposures over the action level.

During its 1978 benzene rulemaking effort, OSHA received numerous comments on this issue which eventually resulted in the Agency amending its standard to include a "liquid exclusion" provision (43 FR 27962; June 27, 1978). OSHA summarized its position at that time as follows:

> OSHA recognizes that the scope of the permanent benzene standard (29 CFR 1910.1028), unamended, is so broad as to encompass work place operations utilizing liquid mixtures with any amount of benzene, however, small * * *. However, because of the ubiquitous nature of benzene, i.e., its presence in a myriad number and type of worksites (benzene is a contaminant in most, if not all petroleum-based liquid mixtures), OSHA believes that it is proper to focus industrial hygiene and medical resources on those operations with higher exposures and which present the greatest potential risk to worker health. This decision is in accord with the evidence developed during the recent rulemaking which revealed the need to and appropriateness of limiting the scope of the standard (43 FR 27962; June 27, 1979).

Prior to its 1985 proposal, OSHA requested additional information on this issue. Many of the comments which were received (Ex. Nos. 142–11, 142–12, 142–31, 142–32) stated that there was no precise scientific formula for setting a liquid exclusion. The American Petroleum Institute for example, stated "the benzene content of a liquid is not the sole—or even the predominant—factor in predicting airborne concentrations * * *. Other facts, including temperature, agitation, ventilation, open versus closed systems, employee work practices, and the relative vapor pressure of the chemical constituents of the mixture, are also important, and may well be the more dominant factors * * *" (Ex. No. 142–31). This position is supported by Elkins (Ex. No. 142–28) and others.

OSHA, in the proposal, agreed that there was no such precise chemical model that would predict an exact percentage of benzene in a mixture which would result in exposures that would remain under the action level. OSHA contracted with JRB to have chemists explore whether or not a simplified formula taking into account not only percentage, but quantity of benzene, room dimensions, and simplified assumptions on air exchange rates and temperatures, would give better correlation with airborne levels and be workable. However, the formulas explored proved to be impracticable and not particularly more likely to lead to better results than a percentage exclusion.

OSHA stated in the proposal that although no precise formula can be

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stated, it was important that there be an exemption from the standard because benzene cannot be totally eliminated from many chemicals. The inclusion of all solutions containing benzene under the scope of the standard would require a large amount of industrial hygiene resources and would be very costly, since it would require every employer who uses a chemical with a tiny percentage of benzene present to monitor initially the employees who use that chemical. A properly determined percentage exclusion, however, would lead to lower employee exposures overall as suppliers are induced to market solvents and other chemicals with smaller percentages of benzene to meet the exclusion, thereby on average lowering benzene exposure for employees working with those chemicals. Thus, OSHA believed that it was necessary to make the best estimate of a percentage exclusion which is likely to keep employee exposure under the action level and yet feasible.

OSHA reviewed comments which addressed the issue of what percent liquid exclusion would result in airborne levels of less than the PEL under typical industrial conditions. Dr. Elkins, for example, stated that "for sake of simplicity, it is recommended * * * that the 0.5 percent exemption percentage be applied (to such liquids) if the airborne permissible exposure limit is 1 ppm * * *" (Ex. No. 142–28). This position was supported by the following: Uniroyal (Ex. No. 142–8), RMA (Ex. No. 142–9), and Firestone (Ex. No. 142–22).

In the proposal, OSHA preliminarily concluded that 0.5 percent level was too high for the long term. First, the percentage should be set to make it likely that exposures will be below the action level, since employees of exempt employers will not have the benefits of the medical and other provisions which are triggered by the action level.

Secondly, exposure data provided by the United Rubber Workers Union (Ex. No. 145) showed that even with solvents of less than 0.5 percent benzene some 2.8 percent of the workers are exposed to airborne benzene levels above 1.0 ppm. Data provided by the National Paint and Coating Association (NPCA) (Ex. No. 142–29) showed that almost one percent of the samples taken were above 1.0 ppm as the result of exposure to liquids with less than 0.1 percent benzene. Elkins (Ex. No. 142–28), also recommended that if operations involving heating of liquids or exposure of large surface areas are carried out, at least a one time monitoring of the area for benzene in air should be done, if the benzene content of the liquids exceeds 0.1 percent. Thus, OSHA determined that the additional protection of 0.1 percent exclusion was needed to assure that very few employees using excluded solvents are exposed over the action level.

Based on these comments, and the JRB analysis, which demonstrates the feasibility of reducing benzene contamination to below 0.1 percent in solvents, OSHA preliminarily concluded that excluding work operations which use liquids containing less than 0.1 percent benzene is both feasible and consistent with the employee exposure protection provided by the benzene standard. The proposal allowed a 5 year period before this provision would take effect in order to give time to adopt the processes which would achieve this level. In the interim, the exclusion level was proposed to be 0.5 percent which was being achieved at the time of the proposal.

Some comments were received on this issue. Several suggested that the percentage exclusion be 0.5 percent although no detailed analysis was provided. (See Conoco's comments (Ex. No. 201–46, p. 3).

Several major trade associations whose members would be directly affected supported OSHA's proposal. The National Paint and Coating Association (NPCA) (Ex. No. 201–40, pp. 3–4) agreed with it. They stated that 40–70 percent of solvents used in their industry contain benzene but predominantly the levels were already under 0.1 percent. They added that "some raw material used in the production of paints and coatings may contain slightly higher levels. For this reason, a five year phased reduction of benzene contamination is appropriate" (Ex. No. 201–40, p. 3).

NPCA presented an example which they argued was a worst case scenario. They calculated that a paint with 70 percent solvent containing 0.1 percent benzene spray applied in a 27 cubic meter room at 1 air change per hour would result in a benzene concentration of 0.2 ppm (The JRB report indicated that theoretical calculations and actual measurements frequently differ, however Ex. No. 153).

The Rubber Manufacturers Association whose members use solvents contaminated with a small amount of benzene supported the proposal (Ex. No. 201–27, pp. 10–12). They pointed out that they were already using solvents with below 0.5 percent benzene. They stated that corresponding airborne levels are almost always below 1 ppm. But they stated they support a 5 year phase down to 0.1 percent benzene in order to give the petroleum industry time to phase down to that level.

NIOSH stated that "since there is the potential for significant amounts of benzene to enter a workers body by dermal absorption, NIOSH urges producers to continue to make every effort possible to further reduce the benzene contamination of their solvents and other products" [Tr., 3/20/86, p. 8. NIOSH opposed the 0.5 percent benzene exclusion because "the data of Susten et al. clearly demonstrates significant benzene absorption can occur among workers who use solvents that contain about 0.5 percent benzene" [Tr., 3/20/86, p. 16].

Public Citizen Health Research Group opposed any percentage exclusion. They presented a worst case example which they argued indicated that a 0.1 ppm contaminant could lead to exposures as high as 20 ppm. They also stated that skin absorption data (which is discussed at length above in the section on skin absorption) indicating that 0.5 percent benzene might lead to absorption through stripped skin equivalent to that absorbed from 2 ppm benzene through 8 hours of inhalation. (Using the same calculations 0.1 percent benzene contaminants could lead to the equivalent benzene absorbed through the skin as 8 hours inhalation at the action level).

As discussed above, other calculation of skin absorption are less. But it is true that for workers who cannot wear gloves, skin absorption would add to the total benzene body burden.

The AFL–CIO and USW agreed with a percentage exclusion. They contended that in light of both airborne and skin data and their analysis of feasibility, that the 0.1 percent or less benzene contamination could be achieved quicker. They recommended that the percentage exclusion be set at 0.3 percent on the effective date of the standard in light of the purer solvents already available and reduced to 0.1 percent after 3 years. (Ex. No. 260, pp. 53–54)

Both they (Ex. No. 246) and the Painters and Allied Trades (Ex. 244) submitted a technical paper on the issue by Larson, *et al.* Attached to the paper were a "series of steady state calculations of the airborne concentrations in ppm for products consisting of" various benzene percentages, applied at various rates in a 1000 cubic foot room with different ventilation rates. The results of these calculations indicate that benzene concentrations from paints containing 0.1 to 0.5 percent benzene could result in

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exposures above the 1 ppm PEL under various conditions. For example, at an application rate of ¼ gallon per hour, the predicted airborne benzene concentration ranged from 0.3 ppm (under 1,000 cfm of ventilation) to 3.1 ppm (under 100 cfm of ventilation) [Ex. No. 244]. Thus, the Printing and Allied Trades recommended that OSHA act to set a percentage exclusion.

OSHA has carefully studied this submission, and believes the analysis conducted by Larsen et al. represents a worse case scenario and that the theoretical results are based on somewhat unrealistic assumptions. For example, these authors assume that the products are continuously applied over 8-hour in one room. Thus, the benzene that is removed from the air by the ventilation, is continuously being replaced by benzene evaporating from the newly applied materials. OSHA believes that under actual conditions, the paint will be allowed to dry. This will allow the ventilation to remove the benzene from the room and will result in the airborne benzene concentrations below those calculated by the authors.

Dr. Harris, who was invited to testify by OSHA, reviewed a University of North Carolina study (Ex. No. 211, pp. 3–5). This study indicated that in certain circumstances airborne exposures of 2.6 ppm could be expected from solvents with 0.5 percent benzene. However, for 0.1 percent benzene solvents exposure would be 0.04 ppm to 0.6 ppm.

The PMA (Ex. No. 257) pointed out that the 1983 JRB data indicated that 97 percent of exposures in rubber manufacturing were already under 1 ppm and estimated that in 1986 were over 99 percent. PMA also referred to data indicating that 66 percent of the solvents that they were using were already under 0.2 percent benzene and virtually all were already under 0.5 percent.

OSHA does not view these data as inconsistent. The Harris data indicate that 0.5 percent may in some circumstances lead to exposures over 1 ppm. The data referred to by the Rubber Industry indicated that they are generally using solvents with benzene contaminants well under 0.5 percent and that exposures are under 1 ppm.

OSHA has reviewed its proposal in the light of comments, and additional data. Based on that review OSHA believes a percentage exclusion of 0.1 percent is appropriate for the long term. A percentage exclusion is needed because benzene is present in tiny amounts in so many solvents and other petroleum based liquids used throughout industries. To require employers to monitor no matter how low the percentage of benzene present in solvents would require a large amount of industrial hygiene resources to be used in situations where one can be highly confident that exposures will be substantially below the action level. In addition, such an exclusion encourages manufacturers to lower benzene contamination below the percentage exclusion. There is a competitive advantage to do so since their buyers will not be covered by the standard. Consequently, benzene exposures will be lower overall.

Secondly, OSHA concludes that 0.1 percent is the appropriate level for the exclusion. That level is needed to give a high degree of confidence that resulting airborne exposure are below the action level. The Harris data and the theoretical analysis by the Paint and Coating Association demonstrate this.

In addition, the level is needed to prevent skin absorption of benzene to be above the level which would be absorbed by the body through inhalation at the action level. As the above calculations show, 0.1 percent is needed to prevent workers who cannot wear gloves and have calloused hands from getting above 6 or 7 milligrams absorbed utilizing the higher estimates of absorption ratios) in 8 hours which would be the same as inhaled for 8 hours at the 0.5 ppm action level. (It should be noted that if the lower estimates of absorption ratios are used, of course, the amount absorbed would be less at 0.1 percent. See the discussion above under skin absorption).

OSHA believes that there will be few workers who will receive the maximum airborne and skin absorption levels from 0.1 percent benzene contaminated solvents. But such workers would receive less than the equivalent of 8 hours of benzene inhaled at the 1 ppm the PEL.

OSHA, however, has concluded that the phase down to 0.1 percent benzene contamination should be in 2 years and not 5 years. The final standard provides that the percentages exclusion should be 0.5 percent for the first year, 0.3 percent for the second year, and 0.1 percent subsequently. As the above discussion indicates, 0.5 percent benzene contamination can lead to airborne exposures over the PEL and to skin absorption which would be equivalent to greater than the amount that would be inhaled at the PEL in certain circumstances. Consequently, OSHA believes it is appropriate it achieve 0.1 percent as soon as feasible.

The JRB report (Ex. No. 153) demonstrates that there are a number of processes technically available now to reduce benzene contamination to below 0.1 percent in solvents and other liquids. In addition, suppliers were selling such solvents prior to publication of the proposal. OSHA now believes that a 5-year estimate to achieve 0.1 percent was unduly pessimistic. The data supplied to the record show that 66 percent of the solvents used by the rubber industry, for example, are now below 0.2 percent benzene contamination. Therefore, not as much change is needed to achieve 0.1 percent as OSHA had originally believed. Consequently, OSHA concluded that production processes can be changed to achieve 0.3 percent in one year and 0.1 percent in 2 years from the effective date of this standard. In addition, that would be 3½ years from the date of the proposal.

OSHA is not requiring use of solvent with less than 0.1 percent benzene. An employer can use solvents with higher amounts. That employer will not be automatically exempted from the benzene standard, but will have to initially monitor employees to determine their exposure. If exposures are below 0.5 ppm, the only requirements are training and monitoring if processes charge. If exposure changes are over 0.5 ppm or 1 ppm the other provisions of the standard apply.

Finally, as discussed in the section on medical surveillance, the final standard requires medical surveillance for tire builders who are exposed to solvents between 0.1 and 0.5 percent benzene in the interim period. Those workers have regular skin exposures to such solvents and it will not be feasible for them to wear gloves. The medical surveillance will serve as a backstop to check on OSHA's judgement to permit interim exclusion levels.

Paragraph (a)(2)(vi) Oil and Gas Drilling, Production and Servicing Production

OSHA proposed to exempt oil and gas drilling production and servicing operations from the benzene standard. The basis for the exclusion was that exposures were under the action level and intermittent. OSHA had reviewed proposal comments on this sector (Ex. Nos. 142–1, 142–6, 142–13, 142–31, 142–32, 142–33). Most commenters recommended an exclusion based on monitoring data indicating that exposures at the production sites are believed to be low. Conoco (Ex. No. 142–1) for example, states "that both the personnel exposures and the ambient atmosphere at (these production) facilities were primarily in the 0.0–0.30 ppm benzene range. . . (And that) no readings greater than 0.5 ppm could be reproduced.

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Additional exposure data was submitted to the record after the proposal and the API extensively reviewed exposure data (Ex. No. 260, pp. 16d–24d). This indicated that exposures were generally well under the action level with few exposures over the PEL. This was because the percentage of benzene in crude oil was generally low. For example, API submitted survey data of the results of 145 samples taken during 1985. Only three of these samples (2.1 percent) were above 0.5 ppm, and only three more fell in the range of 0.25–5 ppm. Fully 85 percent of the samples (124) reflected exposures of less than 0.1 ppm. [Ex. No. 204–7, pp. 67–68].

Drilling and Servicing

API submitted additional data (Ex. No. 260A, Appendix C, Attachment (1) indicating average exposures of 0.07 percent for certain drilling and servicing activities. Shell submitted data on 164 samples from 55 field production units. One sample was at 3.2 ppm, a few were between 0.5 and 0.2 ppm and the rest were no greater than 0.1 ppm.

Although some of the studies indicated somewhat higher exposure (Ex. No. 204–7, ATT. 8 and Runion and Scott), none of the studies indicated more than 1.5 percent of samples over 1 ppm.

In addition, API stated that workers move from site to site frequently. Thus, it would be unlikely that any worker would work at a site with higher benzene levels in the crude oil for long periods (Ex. No. 260, p. 17d). Based on this evidence, OSHA concludes that average exposures are well below the action level and very few exceed it. Workers are unlikely to be exposed to any repeated exposures over the action level. On this basis the exemption is retained.

Paragraph (a)(2)(vii) Coke Oven Batteries

OSHA did not propose to exempt coke oven batteries and had not specifically considered the issue. The American Iron & Steel Institute (AISI) noted that the JRB report indicated that virtually all exposures were under the action level. In addition, AISI introduced additional data (Ex. No. 245D and E) indicating that no exposures were over the PEL, and in the more recent data, no exposures were over the action level. Based on this data, AISI argued that coke oven batteries should be exempted from the standard on the principle that there was a high degree of confidence that all exposures were under the action level. The request for exemption was not specifically opposed although the AFL–CIO and USW in their post hearing briefs had some disagreement with the principle.

OSHA agrees that the data indicates that there is a high degree of confidence that very few exposures to benzene will be over the action level in coke oven batteries and none will be over the PEL. A major reason for these low exposures is OSHA's coke oven emissions standard (29 CFR 1910.1029), which requires employers to ensure that employees in regulated areas are not exposed to coke oven emissions at concentrations greater than 150 micrograms per cubic meter of air. This standard limits the levels of benzene to which coke oven employees are exposed. This illustrates the fact that the installing engineering controls to reduce employee exposures to a specific chemical frequently has the side benefit of reducing exposures to other hazardous chemicals.

Based on this analysis and data, OSHA believes it appropriate to exempt coke oven batteries from the benzene standard. Paragraph (a)(2)(vii) does so. It should be noted that the exemption only apply to the batteries. Coke facilities have other non-battery operations (such as light oil by-product operations) where benzene exposures are well above 1 ppm. These areas are covered by the standard and are discussed elsewhere in the preamble.

Construction

OSHA proposed to cover construction under the benzene standard and pointed out that there would be little impact on the industry. The Agency noted that it was important to cover construction to insure that the industry utilize solvents with a low percentage of benzene contamination and to prevent a loophole from being created.

OSHA presented the standard to the Construction Advisory Committee, and they did not oppose the standard applying to construction. Some members believed it should be represented in 29 CFR 1926, the construction regulations.

There was little comment on the proposal. The AFL–CIO and USW strongly supported applying the standard to construction for the reasons stated. They also felt that painters should be covered because of the possibility of the use of paints with substantial benzene contamination which would lead to high benzene exposures (Ex. No. 260, p. 52, 53). They did not object to a percentage exclusion (which would cover paints) so long as OSHA instituted the 0.1 percent level quicker. The National Paints and Coatings Association did not object to the standard covering painting so long as there was a percentage exclusion. OSHA has followed these recommendations.

The AFL–CIO and NPCA presented somewhat different theoretical analyses of what worst case exposures would be from spray painting with paints less than 0.1 percent benzene contamination. But in view of the lack of substantive disagreement, it is not necessary to resolve that issue.

OSHA concludes that the final standard should cover construction. The standard has virtually no impact on construction. The only impact that OSHA is aware of on new construction from the standard is on the use of some solvents contaminated by benzene in construction. However by purchasing solvents with less than initially 0.5 percent benzene contamination, 0.3 percent after one year, and after 2 years 0.1 percent benzene contamination, which as discussed above is feasible and inexpensive, the construction industry will fit within the percentage exclusion and be exempt from the benzene standard.

As discussed above, a frequent source of significant benzene exposure is maintenance operations at refineries, petrochemical plants and other facilities. Engineering controls are often not feasible for these maintenance operations. Exposures during these operations may be relatively high and it is necessary, therefore, that employees wear respirators, receive medical examinations and be protected by other provisions of the proposed benzene standard. Sometimes such facilities hire outside contractors to perform maintenance operations. The contention is sometimes made that the maintenance operations should be considered to be construction activities and not subject to general industry standards.

Even though there will be little impact on construction. OSHA concludes that construction should not be exempted from the standard. If construction were exempted there would be no requirement that construction employees utilize solvents with a low content of benzene contamination. In addition, a loophole would be opened in the enforcement of the standard if construction were exempted. The distinction between maintenance and construction activities is often an ambiguous one. The independent contractors who perform maintenance oprations clearly need to be covered because of the possibility of higher exposures. If construction were excluded, these maintenance contractors might argue that their work is "construction" and that they are not covered by the standard. By covering

construction, this ambiguity does not arise. However, OSHA reiterates that there will be little actual impact on true new construction activities except for the need to purchase solvents with low benzene contamination.

OSHA is sympathetic to the view that health standards applicable to the construction industry be reprinted in full in Part 1926, Construction Standards. However, doing so substantially increases taxpayer costs for printing since a substantial number of pages are involved. Very few construction employers and employees will be directly affected by the Benzene Standard. Accordingly, the Agency believes it would be a better use of tax dollars not to reprint the standard in Part 1926.

Laboratories

The final standard, as did the proposal, covers laboratories subject to OSHA jurisdiction, including quality control and research laboratories. There are case reports of leukemia associated with benzene exposure in laboratories (Ex. No. 159–35).

Quality control laboratories in coke, petrochemical, tire, and refinery facilities usually repeat experimental procedures involving liquids containing benzene to test for product uniformity. Pure benzene is a commonly used chemical in research laboratories for many kinds of experiments. Because of benzene's volatility, the potential exists for significant exposures unless it is utilized properly under a hood.

OSHA has considered the few comments received on this issue, both in favor and opposed. Because of the direct evidence of health risk, frequency of use in laboratories and potential for high exposure, OSHA concludes laboratories should be covered.

Both quality control and research laboratories all have hoods. This would be the appropriate feasible engineering control which would succeed in keeping exposures below the PEL and generally below the action level. (See the discussion of the JRB report in the proposal and OSHA's proposed standard for laboratories).

OSHA believes that the monitoring requirements of the benzene standard would not be burdensome for research laboratories. A worst case initial monitoring conducted during the experiment with the greatest use of benzene could determine whether exposures were under the action level. If so, no further action need be taken. If exposures were over the action level, it would be appropriate to check the efficiency of the hood and the laboratory (work) practices to lower exposures. OSHA concludes that handling benzene under a hood would generally keep exposures below the action level; but if not, the rest of the standard would be applicable including medical surveillance.

OSHA proposed generally not to cover laboratories with substance specific standards but to cover them with a single generic standard (See 51 FR 26660, July 24, 1986). However, in that proposal, the Agency specifically recognized that benzene might be an exception, principally because of the need for a specific medical surveillance protocol for workers routinely exposed to benzene in laboratories (51 FR 26675). OSHA concludes that the benzene commonly used in laboratories may result in significant exposures if hoods are not properly used. Moreover, medical surveillance has clear benefits for employees including those who work in laboratories. The final laboratory standard has not been issued. Therefore, benzene use in all laboratories is most appropriately covered by this substance specific standard for the present time. OSHA will give additional consideration to this issue in the context of its final laboratory standard and then determine whether changes are appropriate once a final standard becomes effective. (No capital investment is required by this standard.)

Maritime Industries

OSHA proposed to cover the maritime industries. There was little comment expect for barge cleaning and repair and by implication tanker cleaning and repair. The AFL-CIO supported coverage (Ex. No. 262, p. 52). OSHA is covering these sectors for the reasons discussed. However, special provisions apply to ship and barge repair and cleaning. These are discussed below. OSHA intends shortly to issue a proposal on these operations.

Port facilities handling petroleum products generally handle petroleum products only and these products frequently contain a percentage of benzene. Most facilities are operated by the major oil companies. Benzene exposures over 1 ppm may result during the handling of these products. Compliance with the 1 ppm level can be achieved through the use of engineering controls which are located on the ship or barge.

Installation of this equipment is under the jurisdiction of the Coast Guard and not required by the proposed benzene standard. If these controls are not available compliance can be achieved with respirators.

As exposures can be over 1 ppm, employees of these facilities need the protection of the benzene standard. Although exposures may not be continuous, they may be high and occur on a regular basis (Ex. No. 159–67, Runion and Scott). OSHA, therefore, is including this segment in its standard and has covered it in the feasibility analysis.

Some of these operations may be longshoring rather than general industry. Facilities are generally utilized only for petroleum products and employees work there on a full-time basis exposed to benzene. The unique features of longshoring—many different types of cargoes, temporary employment and only occasional exposures—do not exist). Consequently, the benzene standard covers Part 1918, Longshoring and Part 1917, Marine Terminals.

Traditional longshoring operations may involve handling sealed containers holding benzene or liquids containing benzene. Those operations are generally exempted by the sealed container exemption. However, training is required to explain to the worker the importance of not breaking the containers and emergency protection is needed if there is a major spill of benzene or liquids containing a high percentage of benzene. Such provisions are in the standard and retained by the sealed containers exemption.

The standard is incorporated into 29 CFR 1915, Shipyard Employment for new constuction only and repair of ships and barges other than barges and ships containing petroleum products. There is little impact as they will comply by using solvents or paints with less than 0.1 percent benzene. However, coverage is needed so the yards will not use solvents or paints with a higher percentage of benzene.

Paragraph (a)(3) Cleaning and Repair of Barges and Tankers

This paragraph provides various exemptions from the benzene standard for the cleaning and repair of barges and tankers which carry oil, gasoline, other petroleum products and petrochemicals. As discussed in Section VIII B, Summary of RIA, above, special factors affect this sector: The proposal intended to fully cover this sector and indicated possible controls, but no detailed study was performed. At the hearing, industry representatives brought to OSHA's attention possible compliance difficulties and suggested a further study. OSHA recently completed a further study, but this was well after the close of the record.

Consequently, OSHA is exempting this sector from provisions where there might be compliance difficulties. OSHA

is not exempting this sector from provisions which are clearly feasible because part of the industry is already complying with them. OSHA intends to issue a proposal based on its recently completed study to develop standard provisions most appropriate for this sector.

Specifically, OSHA is exempting this sector from the requirements to achieve 1 ppm with engineering controls (paragraph f) based on industry testimony of possible difficulties to achieve this level with engineering controls. (The difficulties may not be as great as suggested because the relatively high measurements presented were of total hydrocarbons not just benzene). The requirement to achieve 10 ppm with engineering controls remains in effect. The industry testified they are currently meeting this requirement.

The permissible exposure limits of a 1 ppm TWA and 5 ppm STEL are to be achieved with any combination of respirators, work practices and engineering controls. Industry employees currently wear respirators, OSHA staff has observed this. Where oxygen efficiency is not a problem employees may wear air purifying mask respirators which do not substantially increase the difficulty of entering tight spaces. Welding hoods are available with respirator capabilities. Where welding goes on, provisions for airlines or power are needed, so it is feasible to have airlines for air supplied respirators as well. Where oxygen deficiency exists, provisions for air supplied respirators or self contained breathing apparatus (SCBA's) must be made to prevent asphyxiation. Consequently, it is feasible to achieve 1 ppm with respirators.

The industry is currently monitoring with indicator tubes which measure total hydrocarbons. These are not particularly accurate but will always error on the high or protective side for benzene. They have the advantage of giving an almost immediate reading. OSHA intends the industry to continue its current practice. Accordingly, it is exempting this sector from the provisions of paragraph (e) which would require greater accuracy, require full shift monitoring and would be inconsistent with the current practices. The industry is already monitoring much more frequently than the monitoring provisions of paragraph (e) require. OSHA recommends that current practice be retained.

OSHA is not exempting the industry from the other provisions of the standard. Exposures to benzene are frequent and often over 1 ppm. Respirator use is frequent. Consequently, there is a clear health need for medical surveillance and training. Some companies and sectors (such as the cleaners specifically) already receive medical exams and training, so it is clearly feasible.

The partial exemption applies to tankers as well as barges. No specific evidence was presented on tankers but OSHA infers that the same factors would apply. It will fully consider this in the future rulemaking.

OSHA wishes to thank the industry for its cooperation in the study performed after the close of the record. In the intended future proposal rulemaking, OSHA will address the factors specific to this industry.

B. Definitions: Paragraph (b).

"Action Level". The final standard retains the same definition of "action level" as was defined in the proposal. "Action level" is defined as an airborne concentration of benzene of 0.5 ppm calculated as an 8-hour time-weighted average. Where exposures are below the action level of 0.5 ppm, little further action is required of the employer. Above the action level, the monitoring, and medical provisions of the standard take effect. Of course, the employer is required to keep employees' exposures below the 1.0 ppm permissible exposure limit.

One purpose of the action level is to relieve the burden on employers by providing a cut-off point for required compliance activities under the standard. In addition, due to the variable nature of employee exposures to airborne concentrations of benzene, the concept of an action level provides a means by which the employer may have greater assurance that the employees will not be exposed to benzene over the permissible exposure limit.

The action level also increases the cost-effectiveness and performance orientation of the standard while improving employee protection. Employers who can, in a cost-effective manner, come up with innovative methodology to reduce exposures below the action level, will be encouraged to do so in order to save on the expenses for the monitoring and medical surveillance provisions of the standard. Their employees will be further protected because their exposures will be less than half of the permissible exposure limit. When employers do not lower exposures below the action level, employees above the action level will have protection of medical surveillance, monitoring and other provisions of the standard to give further protection from the effects of benzene.

There is a discussion in the proposal preamble on the statistical basis for determining the action level (see 50 FR 50552). OSHA's specific choice of setting an action level of one-half the PEL is based on its successful experience in utilizing one-half the PEL as the action level in many standards, such as arsenic, ethylene oxide and vinyl chloride.

There was little or no criticism of the action level concept and various comments supported it. See Uniroyal (Ex. No. 142–8, RMA (Ex. No. 142–9), CMA (Ex. No. 201–33, p. 181) and AFL–CIO (Ex. No. 282, p. 3). The AFL–CIO agreed that a 0.5 ppm action level was appropriate for 1 ppm standard although they recommended a 0.5 ppm PEL with a 0.3 ppm action level. (This later issue is discussed in the feasibility section).

It should be noted that the proposed standard required training consistent with the Hazard Communication Standard even when exposures are below the action level. (The preamble discussion was not clear on this aspect). Training is appropriate below the action level so that employees can recognize situations where benzene exposure might be increasing and avoid taking actions which might lead to higher exposures.

Based on the reasoning above, the generally supportive comments, and OSHA's successful experience with the concepts, the action level of 0.5 ppm as proposed is retained in the final standard.

"Assistant Secretary" and "Authorized person" are defined in the final as proposed. These are based on OSHA's experience and the definitions have generally not been commented on.

"Benzene" (C_6H_6) is defined in the final standard as liquid or gaseous benzene and liquid mixtures containing benzene and benzene vapors released by those liquids (subject to the percentage exclusion discussed above in the scope section). The definition excludes from coverage "unreacted benzene contained in solid materials." The latter is a change from the 1978 standard and intends to clarify some of the concerns raised by commenters. The American Petroleum Institute in its comments (Ex. No. 142–31) raised concerns that if the 1978 standard were interpreted literally, products such as polystyrene containing a few parts per million benzene in the solid form would have to be labeled as a cancer hazard. Other polymer manufacturers reported extremely low levels of benzene vapor emitted from solid products containing very low amounts of unreached benzene (Ex. No. 142–31, Attachment C, page 6).

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For example, ARCO stated "Tests conducted by ARCO Polymers on these products . . . demonstrate that even at the point where the highest concentration of benzene would be anticipated, the amount of benzene vapor in the air did not exceed the [0.5 ppm] action level. * * * In all cases but * * * one, if any benzene vapor was emitted it was undetectable using test procedures designed to detect levels as low as five parts per billion."

OSHA's chemical consultants at JRB concur with ARCO's findings and have informed OSHA that in their opinion it would be extremely unlikely that significant quantities of benzene would be emitted from solid materials, except in cases where the solid materials were being burned. Burning these materials would probably release quantities of toxins (such as styrene) with much more acute effects than the quantity of benzene being released. Since it is unlikely that unreacted benzene contained in solids will impose a significant health hazard, OSHA has excluded it from the scope of the standard.

The exclusion is intended to omit from the standard's coverage products that contain a very small amount of benzene in bound forms, such that they are incapable of releasing into the workplace, benzene vapors at levels which are greater than a small fraction of the action level.

"Bulk wholesale storage facility" is defined as a "bulk terminal or bulk plant where fuel is stored prior to its delivery to customers." The explanation for this definition is addressed in the Scope and Application section above.

"Container" means any barrel, bottle, can, cylinder, drum, reaction vessel, storage tank, or the like, but does not include piping systems.

"Day" is defined as any part of a calendar day. Therefore, if a requirement is applicable for an employee who is exposed to benzene for 10 days in a calendar year, that requirement becomes applicable to an employee who is exposed to benzene for any part of each of 10 calendar days in a year.

"Director" means the Director of the National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services.

"Emergency" is defined to mean any occurrence such as, but not limited to, equipment which may result in an unexpected significant release of benzene. Sections of the proposed standard that include provisions that must be met in case of emergencies include Respiratory Protection, Medical Surveillance, and Employee Information and Training.

Every spill or leak does not automatically constitute an emergency situation. The exposure to employees must be high and unexpected. This is a performance oriented provision relying on judgement. It is not possible to specify detailed circumstances which constitute an emergency.

"Employee exposure" is defined as that exposure to airborne benzene which would occur if the employee were not using respiratory protective equipment. This definition is consistent with OSHA's previous use of the term "employee exposure" in other health standards.

"Regulated area" means areas where airborne concentrations of benzene are in excess of the permissible exposure limit. This is discussed in the Regulated Area discussion below.

"Vapor control system" means any equipment used for containing the total vapors displaced during the loading of gasoline tank trucks and the displacing of these through a vapor processing system or balancing the vapor with the storage tank. This equipment also includes systems containing the vapors displaced from the storage tank during the unloading of the tank trunk which balance the vapors back to the tank truck.

With the exception of "Vapor Control System" the rest of the defintions are consistent with the proposal and reflect OSHA's past experience. There generally were no comments on those definitions.

There was one comment by Conoco suggesting this definition be broadened to include systems which dispurse vapors. OSHA does not believe that is protective. See the discussion under Scope and Application, Storage Facilities, Paragraph (a)(2)(ii).

C. Permissible Exposure Limits (PELs): Paragraph (c)

(1) Time-weighted average limit (TWA)

OSHA has decided to revise the permissible exposure limits for benzene by amending the current standard contained in 29 CFR 1910.1000, Table Z–2, which contains a 10 ppm 8-hour TWA, an "acceptable ceiling concentration" of 25 ppm and an "acceptable maximum peak concentration" of 50 ppm. (The Table Z–2 limits will continue to apply only where the new standard is not applicable). OSHA has decided to replace the 10 ppm 8-hour TWA for most industry segments with an 8-hour time-weighted average to airborne concentrations of benzene of 1 ppm. This new TWA is based on evidence that occupational exposure to benzene under current permissible exposure levels presents a significant risk to employees and that the new standard will achieve a significant reduction in that risk. The basis for the permissible 8-hour exposure limit is discussed above in the sections on significance of risk, feasibility and choice of exposure limit. In summary, OSHA has concluded that lowering the current PEL from a 10 ppm TWA to a 1 ppm TWA substantially reduces a significant risk and is feasible.

(2) Short-term exposure limit (STEL)

OSHA had decided to reduce the current short term exposure limits of a 25 ppm ceiling and a 50 ppm peak to a 5 ppm limit averaged over a 15-minute period. This decision is based on human and animal data indication that intermittent or peak exposures appear to cause greater effects than continual exposures to the same or lower levels.

OSHA, in the proposal, sought comment on the scientific principles it should use to determine the necessity for incorporating a STEL in the permissible exposure limit. It further sought comment on whether a STEL should be incorporated into the benzene standard, and if so, at what level. (See 50 FR 50552) and whether intermittent peak exposures to benzene carry any greater risk of disease than continuous low level exposures.

OSHA has reviewed the scientific principles concerning whether a short term exposure limit (STEL) should be set for a chemical substance and has also reviewed specific studies with regard to benzene, that are summarized here.

Dr. Richard Irons of the Chemical Industry Institute of Toxicology (CIIT) presented study results on benzene and stated:

> * * * our experimental evidence would highlight a concern that has been focused recently on transient exposure in the occupational environment rather than continuous low level exposure * * * where transient exposure is more important with respect to the individual than constant exposure to some low level or a time weighted average (Ex. No. 159–41A).

In a previous study Irons et al. had determined that the polyphenolic metabolites of benzene, primarily hydroquinone and catechol, appear to be responsible for benzene immune suppression and bone marrow suppression. Thus, for this study, mice were administered hydroquinone or catechol, on an intermittent basis or continuously. Irons stated:

> We found if we took the same dose of hydroquinone that we were giving repeatedly for a continuous regimen and gave it for three

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days and allowed the animals four days to recover, then gave it again, an intermittent exposure, so that over a 30 day period, for example, the animals are receiving approximately 45% of the dose they would have received with continuous exposure, and we have a very pronounced drop in bone marrow cellularity, we have a decrease, a progressive decrease in circulating white counts, primarily associated with the lymphocytes, we have progressive decrease in erythrocytes, circulating erythrocyte counts. We have followed these animals now out to approximately between 6 and 8 weeks. They're beginning to drop dead * * * with what would be considered a classic aplastic response or aplasia in bone marrow (Ex. No. 159–41A).

With repeated administration of the metabolites, only a transient effect which gradually returned to normal was observed. On the basis of these observations, Irons concluded:

* * * intermittent exposure appears to be much more potent at producing bone marrow effects than is continuous exposure, and it may be that protection of the worker in an occupational setting requires prevention of peak exposures rather than the progressive lowering of the TWA in the absence of regulating or limiting transient exposure situations (Ex. No. 159–41A).

In addition, short term exposures to benzene at relatively low concentrations have caused chromosomal damage in animals. Those include exposures at 28 ppm for 4 hours (Tice et al., 1982, Ex. No. 159–88), at 1 ppm for 6 hour (Erexson, 1986, Ex. No. 171), and at 6 ppm for two 8-hour periods (Gad-El-Karim et al., 1982, Ex. No. 159–32).

Dr. Raymond Tice, a cytogeneticist and staff scientist at Brookhaven National Laboratory, submitted data (Ex. No. 201–37) indicating that more bone marrow damage can result from less exposure to benzene under intermittent exposure conditions. DBA/2, C57B1/6 and B6C3F1 mice were exposed to benzene in air at 300 ppm for 6 hours/day for 13 weeks, either for 5 days/weeks or 3 days/week. The three days/week regimen was similar to that used by Dr. Irons in his experiments, except that Tice exposed mice to benzene and Irons exposed mice to metabolite of benzene. With the three day regimen, Tice observed a considerably longer depression of the bone marrow erythropoiesis than with the 5 day regimen, which adds support to Irons' findings that intermittent exposure may be worse than continuous exposure.

In a study of refinery workers (Devine et al., 1983, Ex. No. 142–32A), a significantly increased risk of death from leukemia was not observed among the entire cohort possibly due to limited statistical sensitivity. However, when a case control study was conducted of the leukemia deaths observed among this same cohort, the deaths were found to be significantly associated with a history of longest employment as general pipefitters (RR=2.7), maintenance and yard pipefitters (RR=2.8), or in utilities (RR=4.6) (Divine and Barron, 1983, Ex. No. 142–32B). The mode of benzene exposure in these latter jobs is considered to be through intermittent bursts, as pipefitters and utility personnel usually have major responsibilities for repairing broken pipes or leaking seals in streams that may contain from 5% to 100% benzene. Given the limited statistical sensitivity of the case-control study and yet the identification of a significant association between dying from leukemia and the mode of benzene exposure most likely to have been experienced by these workers, OSHA has concluded that exposure to short-term intermittent bursts of benzene was an important factor in the development of these leukemias.

In the study by Wong et al. (Ex. No. 151A) which demonstrated a dose-response relationship between cumulative benzene exposure and death from lymphatic and hematopoietic cancer, a relative risk of 3.4 was observed for those persons categorized as having experienced maximum peak benzene exposures below 25 ppm.

DOW Chemical Company submitted a report to EPA and to NIOSH shortly after the earlier OSHA administrative record on benzene closed in 1978 (Holder, 1978, Ex. No. 159–49). This study demonstrated significantly elevated chromosomal breakage in circulating lymphocytes among 52 workers employed in operations where 8-hour time-weighted average benzene concentrations ranged between 2-10 ppm. Peak levels of benzene associated with the TWA concentrations as determined by 2-3 minute sampling periods ranged from 50 to greater than 100 ppm. Ceiling concentrations as determined by 15-minute sampling periods were reported to have been 25 ppm (Holder, 1978, Ex. 159–49). Further analyses by level of exposure indicated elevated chromosomal damage at exposures averaging below 1.0 ppm, as well as a dose-response relationship between chromosomal damage and benzene exposure (Picciano, 1980, Docket #H–059. Ex. No. 230.X–6). Although the frequency of peaking is unknown, Holder implied that the chromosomal damage was due to the peak exposures (Holder, 1978, Ex. 159–49).

The American Industrial Hygiene Association (AIHA) (Ex. No. 201–19) commented in response to questions in the proposal. "For a STEL to be justifiable from a toxicologic perspective, there must be an additional toxic response beyond which the TWA is not adequately protective." It further stated that an example of such a toxic effect is "a disproportionate increase in responses for excursion doses above the TWA." AIHA also pointed out that there are physical criteria limiting combinations of excursion time and concentration profiles and suggested that professional industrial hygienists recommend such exposure limits, but made no specific recommendations regarding a STEL for benzene.

NIOSH (Tr. 3/20/86 pp. 7–8; Ex. No. 238) recommended a short term exposure limit. In support of its position, NIOSH described data on the pharmacokinetics, evidence of cytotoxicity, results from long and short term exposures and the contribution of skin absorption to the overall exposure to benzene.

Dr. Bernard Goldstein, who was requested to testify by API, stated:

* * * a short term exposure limit is reasonable for two reasons—one, there is evidence * * * that there may be a concentration effect. The second reason is * * *, a short term exposure limit is valuable in helping workplace managers focus on the potential within their workplace for sudden release of an adverse product (Tr. 3/26/86, p. 139).

In comments for the State of Wyoming (Ex. No. 201–2), Donald D. Owsley supported issuance of a STEL if the dose of benzene received is sufficient to promote an adverse effect. Based upon the findings discussed in the proposal of significant chromosomal damage after short duration exposure to benzene in peak concentrations of 50 to 100 ppm, he found it "imperative that a short term exposure level be included * * *."

Atlantic-Richfield Co. (Ex. No. 201–25) supported a STEL, from an industrial hygiene view-point, because a STEL for benzene "will help ensure that the PEL is not exceeded by establishing an operational bench mark for short duration tasks." Chevron Corporation and Phillips Petroleum Company supported retention of the existing 25 ppm STEL (Ex. Nos. 201–16, 201–18), but did not believe there was a health basis for lowering it.

Kenneth G. Gould, Medical Director, Exxon Co. (Ex. No. 201–15) commented that "petroleum industry hydrocarbon exposures typically result from a series of small to medium excursions over an 8-hour shift", but a STEL is not necessary for benzene, because there is no scientific basis for relating a STEL to

PEL, and excursions about 5–10 ppm likely to be sensed by the employee, particularly if in a mixture with other hydrocarbons. OSHA disagrees that excursions of 5–10 ppm are likely to be sensed by employees, since benzene has poor warning properties at those concentrations and is even more difficult to smell in the presence of other solvent mixtures. Furthermore, protective action taken after exposure achieves little in reduction of risks.

A few commenters suggested that a 1 ppm PEL automatically imposes a maximum 15 minute exposure limit of 32 ppm, assuming *no* benzene exposure for the rest of the 8-hour shift (Ex. Nos. 201–30, 258). OSHA is concerned that there is misunderstanding of the concept of a STEL. The STEL is not a maximum level, but is a 15 minute time weighted average, so that it is possible to exceed the STEL as averaged over the 15 minute sampling period.

Exposures could theoretically go up to 75 ppm for one minute and still be in compliance with a 5 ppm–15 minute STEL. (Exposures could theoretically go up to 480 ppm for 1 minute with no STEL and 1 ppm 8-hour TWA). Furthermore, in reality, while 15 minutes or longer periods may only be measured for compliance purposes, excursions can occur for any time period. The STEL is implemented to prevent excursions and/or keep them as low as is feasible in order to reduce the risks of exposure to benzene.

SOHIO commented (Ex. No. 201–13) regarding the STEL that there is no conclusive scientific evidence that a STEL affords additional protection from chronic effects of benzene, for the following reasons: "Exposure estimates in the various epidemiology studies are tenuous and approximate at best * * * no appropriate animal experiments are available to address the STEL question * * * because of the differences in toxic effects exhibited by man and laboratory animals in response to chronic benzene exposure, it may not even be possible to design appropriate animal studies to address the STEL question." OSHA believes that there is extensive scientific evidence indicating that a STEL would afford additional protection from the chronic effects of benzene exposure as discussed here.

CMA (Ex. No. 258) in its final brief, contended that there is no basis for a STEL in the benzene standard because "A STEL is not needed to prevent the occurrence of acute health effects. Similarly, since a dose-rate effect for benzene-related leukemia has not been demonstrated, a STEL cannot be justified in terms of preventing leukemogenic effects of benzene. In any event, the proposed standard would protect against high short-term exposures even without the adoption of a STEL" (Ex. No. 258, p. 5).

OSHA disagrees with all three points made by CMA with regard to the STEL. First, a STEL can prevent the occurrence of acute health effects that can result from high peak exposures still within the 8-hour TWA PEL of 1 ppm. Theoretically, a peak at 480 ppm for 1 minute with no exposure to benzene for the rest of the day, could occur and compliance with the PEL would be possible. This could occur in a situation where repairs were being made on pipes or pumps with benzene-containing streams. Acute effects of benzene exposure include any of the cytopenias, including pancytopenia and aplastic anemia. Repeated intermittent high peak exposures such as this, with inadequate recovery time between exposures could lead to serious adverse acute and chronic effects. These exposures could be limited by a STEL and prevent peaks that would not be controlled by the PEL from occurring.

Public Citizen Health Research Group (Ex. No. 201–41) commented that OSHA should issue a STEL. "Given the significant risk that persists even at the 1 ppm TWA, OSHA is duty-bound to enact the most protective provisions practicable to reduce that risk." Public Citizens reiterated the importance of the data and statements of Dr. Richard Irons of the Chemical Industry Institute of Toxicology, that mice exposed intermittently to hydroquinone (benzene metabolite) died of aplastic anemia at 45 percent of the cumulative dose received with continuous exposure, meaning that intermittent doses are more hazardous than continuous exposures. They also stated that epidemiologic and experimental evidence presented in the proposal supports the need for a STEL, and added two studies not discussed in the proposal (Brexson et al., 1986, Ex. No. 252A-17-25, and Styles & Richardson, 1984, Ex. No. 252A-17-77) indicating measurable DNA damage in mice and rats after exposure to 1 ppm benzene for one six hour period. Public Citizen also pointed out that several epidemiologic studies have shown cancer or chromosome damage from average exposures of about 1 ppm benzene. Public Citizen stated that the 1 ppm TWA alone does not protect workers from significant health risks and a STEL should be adopted to reduce significant risks at the 1 ppm PEL.

The United Steelworkers of America and the AFL–CIO (Ex. No. 262) believe that "the record evidence clearly justifies the establishment of a short term limit." They cited evidence in the record demonstrating that short-term intermittent exposures to benzene result in adverse effects, including cytogenetic effects in animals (Ex. No. 233), aplastic anemia in animals (Ex. No. 159–41A), the testimony of Dr. Marvin Legator (Ex. No. 233) on the meaning of the cytogenetic tests, epidemiological studies of refinery maintenance and repair workers (Ex. No. 142–32B), and the epidemiological study by Wong et al. suggesting that peak exposures contribute to benzene related leukemia (Ex. No. 151–A).

The United Steelworkers and AFL–CIO cited several industrial hygiene factors that should be considered in determining the need for a STEL. They cited testimony of witnesses who agreed that in circumstances where jobs and operations are characterized by short term high level exposures, a short term limit would be more appropriate for judging exposures than an 8-hour TWA; many benzene jobs are characterized by short term exposures, such as in coke by-product plants, petroleum refineries and chemical facilities (especially maintenance and laboratory workers). They further stated that Dow Chemical recognized the appropriateness of a STEL for chemical operations by establishing a 10 ppm ceiling as an internal Dow standard (Tr. 3/26/86, p. 68).

In addition, short term exposure limits reduce exposure excursions peaks, and limit exposure variability, and limit long term average exposures (Ex. No. 204; Tr. 3/13/86, p. 13; Tr. 3/19/86, p. 158). In their opinion, a STEL would prohibit excursions otherwise allowed by an 8-hour TWA PEL. The United Steelworkers and AFL–CIO believe there is more than adequate scientific justification for a STEL.

In summary, intermittent benzene exposure has been demonstrated to cause more chromosomal changes and aplastic anemia in experimental animals than continuous exposure to the same or lesser amounts of benzene. Average exposures of 1 ppm to experimental animals have caused chromosomal aberrations; slightly higher average exposures to humans have been associated with significantly elevated chromosomal breakage and leukemia. Jobs entailing intermittent peak exposures have also demonstrated significantly elevated risks of leukemia. Thus, modes of benzene exposure as well as average exposure levels currently found in the occupational setting have demonstrated the need for a STEL in addition to a TWA PEL in order to further reduce health risks associated with benzene exposure.

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Many parties to the rulemaking and scientific experts supported the need for a STEL based on biological data and modes of exposure to which workers are subjected.

Based on all the evidence, OSHA concludes that a STEL is necessary to prevent adverse health effects indicated by the biologic data. As discussed in the variability section, controlling peaks is also a good method of reducing cumulative dose. The existence of the STEL, the action level and the industrial hygiene provisions is the basis for OSHA's belief that risk will be reduced to levels lower than predicted by the risk assessments. (See the discussion in the significant risk and risk assessment sections). The 5 ppm STEL is feasible as discussed in Section VIII, D.

D. Regulated Areas: Paragraph (d)

The final standard retains the proposed requirement to establish a regulated area wherever the airborne concentration of benzene is above the permissible exposure limits. Access to the regulated areas is limited to authorized persons and the areas themselves are to be demarcated in any manner that limits the number of persons exposed to benzene within these areas. As in the proposed rule, the areas are demarcated by the employer in any manner that limits worker entrance into the areas.

The final standard gives employers a choice of whether to use, for example, ropes, markings, temporary barricades, gates, or more permanent enclosures to demarcate and limit access to these areas. Factors that employers might consider in determining the type of identification system include the configuration of the area, whether the regulated area is permanent, the airborne benzene concentration, the number of employees in adjacent areas, and the period of time the area is expected to have exposure levels above the PEL. Permitting employers to choose how best to identify and limit access to regulated areas is consistent with OSHA's belief that employers are in the best position to make such a determination based on the specific conditions of their workplaces.

The language of the final standard has been changed to include language in the "Definition" section that states that a regulated area is to be established where airborne concentration of benzene "exceed, or can reasonably be expected to exceed, the permissible exposure limits, either the 8-hour time-weighted average exposure of 1 ppm or the short-term exposure limit of 5 ppm for 15 minutes." The language in the standard itself, at (d)(1) has also been changed to reflect this new clarification. This conforms to the comparable provision of the recently promulgated Asbestos Standard (29 CFR 1910.1001). OSHA believes that this new wording more clearly defines the intent of the provision, that, when an employer reasonably expects exposures to be above the permissible exposure limits at a work location or site, he should establish a regulated area in order to prevent employees from unknowingly entering a high exposure area without the proper respiratory protection.

The final standard specifies two distinct permissible exposure limits: (1) An 8-hour time-weighted average exposure (TWA) of 1 ppm of benzene in air, and, (2) a 15-minute Short Term Exposure Limit (STEL) of 5 ppm of benzene in air. The standard requires the establishment of regulated areas when exposures are above either PEL.

Amoco Corporation, in its submissions (Ex. No. 201–22) stated that it was "not clear * * * whether OSHA expects a regulated area to be designated at any time and place the airborne concentration of benzene exceeds 1 ppm for any duration, or if this is required only when the airborne concentration is high enough for a long enough period of time that an employee continually present in the area might be overexposed." The Agency's intent in this provision is to require the establishment of a regulated area wherever exposures exceed the 8-hour time-weighted average limit or exceed the 15 minute STEL. Excursions above the PEL (but not exceeding the STEL) are allowed during the course of the workday so long as the TWA PEL is not exceeded.

The Chemical Manufacturers Association (Ex. No. 201–33) felt that OSHA's "definition should focus on potential employee exposure to benzene as an 8-hour TWA, not on the airborne concentration of benzene in a particular 'area.'" The intent of OSHA's regulated area requirement is to protect employees from unknowingly entering areas where their exposures would be expected to be above the PEL. The final standard, therefore, requires establishment of regulated areas where a reasonable expectation exists that the TWA or STEL would be exceeded if an employee were to work at that location all day. This both warns employees of the possible need to wear respirators and to keep out if they have no need to be present. An employee may not know how long he or she will be present in an area and should take precautions if the possibility exists that the employee will exceed the limit.

Regulated areas are to be established at all work areas where the TWA or STEL is exceeded, including maintenance operations. Areas such as maintenance operations where exposures are temporarily over the TWA or STEL need to be demarcated just as other areas of overexposure so employees who are not needed in these areas will keep out or wear respirators before entering them. The regulated area provisions of this standard are similar to other OSHA health standards.

E. Exposure Monitoring: Paragraph (e)

The final standard retains the requirements for employers to conduct employee exposure monitoring as originally set forth in the proposed standard, with some minor changes. OSHA's authority to establish monitoring requirements is found in section 6(b)(7) of the Occupational Safety and Health Act [29 U.S.C. 655] which mandates that any standard promulgated under section 6(b) shall, where appropriate, "provide for monitoring or measuring of employee exposures at such locations and intervals, and in such a manner as may be necessary for the protection of employees." The main purpose of monitoring is to determine the extent of employee exposure to benzene to determine if precautions are needed.

Exposure monitoring also informs the employer whether he is meeting the obligation imposed by the standard to keep his employees under the permissible exposure limits. In addition, exposure monitoring permits the employer to determine the source and extent of exposure and, with this information, evaluate the effectiveness of engineering and work practice controls, thereby preventing the overexposure of employees. Exposure monitoring is also necessary in order to determine whether respiratory protection is required, and if so, which respirator is to be selected.

Section 8(c)(3) of the Act [29 U.S.C. (c)(3)] requires employers to promptly notify any employee who has been or is being exposed to toxic materials or harmful physical agents at levels that exceed those prescribed by an applicable occupational safety or health standard. Exposure monitoring therefore enables employers to meet this legal obligation of the Act. Exposure monitoring data also are part of the information that must be supplied to the examining physician.

The results of exposure monitoring trigger the various provisions of the standard's requirements and are utilized by the employer to determine which

sections of the standard are applicable to exposed employees. Major sections of the standard are triggered if an employee is exposed above the action level and are not required if the employee is not.

All employee exposure monitoring required under the provisions of this standard is to be "personal sampling," as opposed to environmental or area sampling. Determinations of employee exposure are to be made from breathing zone samples representative of each employee's average exposure to benzene without regard to the use of respirators. Representative 8-hour time-weighted-average exposures are to be determined on the basis of one sample taken from the employee's breathing zone or on a series of consecutive samples taken over the full shift of the employee's exposure. Full-shift sampling is to be conducted for each job classification in each work area.

The final standard also contains the requirement that employees are not to be exposed above the short term exposure limit (STEL) of 5 ppm. Measurements for determination of compliance with the STEL are to be made from breathing zone samples measured at operations where there is reason to believe exposures are high. Examples given in the regulation include operations involving the opening of tanks for filling, loading or guaging, and/or where containers or process equipment are opened, resulting in expected high employee exposures. Also, where benzene is used for cleaning or as a solvent in an uncontrolled situation. STEL determinations are to be conducted. The employer may use short period measuring devices such as real time instrumentation or detector tubes to determine where short term measurements are needed.

Except for initial monitoring requirements, where an employer can document which shift at a location has the highest exposures, the employer needs to monitor only representative employees on the shift with the highest exposures. The language has been slightly clarified from the proposal to reflect a CMA comment (Ex. No. 201–33).

Representative initial employee monitoring is required of all employers who have a workplace covered under the scope of this standard. In its comments to the record, the Penzoil Company (Ex. 201–29) recommended that previous monitoring results collected in response to OSHA's several rulemaking efforts since 1977 should be allowed to be "grandfathered" into satisfying the initial monitoring requirements of this final benzene standard. The final standard allows initial monitoring data collected up to one year prior to the effective date of the standard to be relied upon to satisfy the initial monitoring requirements. The Agency feels that allowing employers to utilize this data provides reasonable flexibility to employers in meeting this requirement. Monitoring data more than one year old would not reflect the current conditions of the workplace.

The results of the initial monitoring represent the data that will be used to determine when further periodic monitoring is necessary. Periodic monitoring is required every six months for employees exposed above the PEL, and every year for those exposed at or above the action level but at or below the PEL. When two consecutive measurements taken at least 7 days apart indicate that the employee's exposure has decreased to the PEL or below but is at or above the action level, the frequency of monitoring for this employee can change from semi-annually to annually. If exposures are found to be below the action level, then monitoring may cease, unless production or process changes occur which may lead to higher exposures.

Additional monitoring is required of an employer in the form of repeating either initial or periodic monitoring as appropriate (see paragraphs (e)(2) and (e)(3)) when a change has occurred in his workplace that would make the employer suspect that new or additional exposures are occuring to his employees. Examples of when such new or additional exposures could occur include changes in production, processes, control equipment being utilized and changes in personnel or work practices in use.

The Monsanto Company, in its comments on this issue (Ex. No. 201–30) felt that additional monitoring specified in this section should not be required when changes are implemented that would reduce employee exposure, such as local exhaust ventilation changes. OSHA disagrees with this position since remonitoring is the only way an employer can be sure that the control measures implemented actually are being effective and are functioning properly in reducing employee exposure.

Section (e)(5)(ii) has been reworded to clarify that additional monitoring is required whenever spills, leaks, ruptures or other breakdowns occur that may lead to employee exposure. The employer shall monitor after the cleanup or repair to ensure that exposures have returned to the levels that existed prior to the incident.

Several commenters stated that OSHA's requirement for this additional monitoring should be tied to employee exposure. Monsanto suggested that "a more performance oriented approach will allow the employer greater latitude in choosing the more appropriate monitoring technique, such as area samples or short term consecutive source samples."

OSHA concurs with Monsanto in that a "performance oriented approach" will allow the employer greater latitude in choosing the more appropriate monitoring technique. The employer will have flexibility of utilizing either area or personnel monitoring or a combination of these methods in order to characterize potential worker exposure after a spill or leak.

As set forth in the proposed standard, the final standard retains the requirement to utilize monitoring and analytical methods which have an accuracy (at a confidence level of 95%) of not less than plus or minus 25% for airborne concentrations of benzene. Information on sampling and analysis can be found in Appendix D. Sampling and analysis may be performed by portable direct reading instruments, real-time continuous monitoring systems, passive dosimeters or other suitable methods. The employer, however, has the legal obligation to select a monitoring method which meets the accuracy and precision requirements of the standard. Equipment companies have been working on developing detector tubes with improved accuracies which read over 15 minutes. When they meet the stated accuracy, they can be used to monitor for the STEL.

Employers are required to notify employees in writing within 15 working days after the receipt of the results of any monitoring performed on them. This may be done either individually or by posting the results in an appropriate location that is accessible to the affected employee. The employer is also required to notify employees of the correction action(s) that are to be taken whenever the PEL is exceeded, in order to reduce exposure below the permissible levels. These provisions are required by section 8(c)(3) of the OSH Act and are further explained in the proposal at 50 FR 50557.

The Impact of Exposure Variability

Exposures at most locations are not identical to the average concentrations each day, but fluctuate somewhat because of minor changes in operations or environment. This is known as variability. Some variability is controllable and some is not. Employers

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must keep average exposures somewhat under the PEL so that overexposure will not likely occur.

In drafting the benzene proposal, OSHA followed the same approach that it has taken since 1974 when it developed the vinyl chloride standard. Thus, a permissible exposure limit (PEL) of 1 ppm in the case of benzene, was proposed as an 8-hour time-weighted average. Firms were required to conduct exposure monitoring to determine the benzene level to which employees are exposed. If the monitoring reveals that workers are being exposed to benzene levels averaged over 8-hours in excess of the PEL, then the firm must develop and implement a compliance program in order to reduce exposure, primarily by means of engineering controls and work practices.

The proposal included several provisions to give extra flexibility to this approach. First, because monitoring results may not reflect the "true" employee exposures because of sampling and analytical error (SAE), OSHA has explicitly stated that it will not issue a citation on the basis of a single OSHA sample result unless the result exceeds the PEL plus the SAE (determined to be 25% in the case of benzene). Thus, a citation for exceeding the 1 ppm benzene PEL will not be issued unless the result for a benzene sample is greater than 1.25 ppm.

Also, OSHA has long recognized that there will be some day-to-day variability in employees' exposure due to environment variables. Its feasibility analyses take into account variability in determining the lowest feasible level. The OSHA Industrial Hygiene Technical Manual (p. 10–7) directs compliance officers to consider long term historical exposure patterns in reaching compliance determinations. So if a compliance officer finds an exposure over the PEL for a location, and the employer has many measurements under the PEL, the compliance officer will investigate the problem. If that investigation reveals that the compliance officer's sample may not be a true representation of the employee's exposure, the compliance officer may decide to remonitor first before deciding whether to issue a citation. However, the compliance officer may issue a citation for a single 8-hour TWA over the PEL plus the sampling and analytic error and normally would do so if the circumstances indicated in the manual did not apply. Employers generally keep their exposure levels on average somewhat under the PEL so if the measurement is high on the day of inspection, the measured exposure will still be under the PEL.

OSHA has been following this approach to enforcement, essentially since its inception 16 years ago. All 1910.1000 Tables Z–1, Z–2 and Z–3 standards and all section 6(b) health standards promulgated since 1974 (i.e., those that do not require closed systems) have been enforced this way. In OSHA's experience it has been protective of workers, has given reasonable certainty to employers who, if they have installed appropriate controls, have achieved the levels set consistently, and makes reasonably efficient use of the compliance officer's time.

However, prior to the publication of the benzene proposal, OSHA received a comment from the API recommending that the Agency reconsider its policy in the case of benzene. Specifically, the API submitted a draft of a study by Dr. Spear (Ex. No. 179) which appeared to indicate that there was a greater than average degree of random variation in exposures associated with some operations in the petroleum industry. If this higher degree of variability was not controllable, then employees in the petroleum industry would have to keep average benzene exposures well below the PEL in order to ensure that there are few random exposures above the PEL. Thus, API suggested that OSHA consider adopting a new enforcement policy in the case of benzene because of the variability problem or raising the PEL to 2 ppm so that they could achieve the PEL with few excursions.

OSHA retained its long standing policy in the proposal but requested that the public submit comments on this issue (50 FR 50513, 50555). Possible alternatives mentioned were a 40-hour TWA, a higher exposure limit or averaging exposures.

OSHA received a number of comments in response to these questions which can be classified into several broad categories. The first group is concerned with the impact of exposure variability on the feasibility of meeting the 1 ppm PEL. The second group is concerned with the "fairness" of OSHA issuing a citation based on a single observation in excess of the 1 ppm PEL. A third group believes the traditional OSHA approach was best. OSHA has carefully reviewed all the comments and data. The technical feasibility discussion (Section VIII.D.) demonstrates that the 1 ppm level is feasible, taking into account the variability that exists. The following section discusses other issues.

Dr. Spear performed an in-depth statistical analysis of sampling data obtained from many different sources (e.g., companies, plants, process units, etc.) and using many different sampling methods over different sampling periods (Ex. No. 204–7). Dr. Spear and his colleagues consulted with industry experts, and organized the data into 123 "relatively homogeneous" job groups. According to Dr. Spear, data on 19 of the groups proved to be extensive enough for detailed statistical analysis. (Exhibit 204–7. pp. 7–8).

API supplied OSHA with both a tape which continued the raw data used by Dr. Spear and a key which could be used to organize the data into the job groups developed by Dr. Spear (Ex. No. 250). Table I presents a summary of the benzene exposures of the 19 groups.

A comparison of these statistics with those presented in the Spear report (Ex. No. 204–7, Table 2, p. 21) revealed that most of the statistics presented in Table I are within 98% of those presented by Spear, with two exceptions. (Spear did not report the arithmetic means, and, it appears that one observation below the level of detection was placed in job group 5 by Spear and in job group 6 by OSHA.) Since these minor differences can be explained by the fact that Spear made some slight modifications to his data sets in order to take advantage of hard copy information which was not available to OSHA, it appears that both analyses were essentially based on the same data.

Table I presents data which provides some information on the degree of variability which existed several years ago when the data was gathered and when the exposure limit was 10 ppm so there was no requirement to keep exposure below 1 ppm. In 10 out of the 19 jobs groups, more than 9 percent of the observations exceeded the proposed 1 ppm PEL even though the arithmetic means of the observations in these data sets were below 1 ppm. In 3 of these 10 cases, nearly 10 percent of the observations exceeded 1.0 ppm even though the arithmetic mean of the observations was less than one-half of the proposed PEL.

Since the exposures for the job groups exhibit the pattern of concern to some commenters (i.e., high probability of random observation above 1 ppm when average exposures are below 1 ppm), they represented an opportunity to examine the variability issue further. Much of the analysis which follows is based upon Table I and the assumption that there is equal chance of obtaining any observation in the data set associated with each group. The

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parametric approach based upon the assumption that the underlying distribution of exposures was log normal could have alternatively been used (Ex. No. 204–7, p. 26, Table 7) and would have led to similar results.

Based upon comments made to the record and the analysis of the Spear study that follows, OSHA reached the following conclusions. First, the impact of exposure variability on the ability of firms to comply with the 1 ppm 8-hour TWA PEL is greatly overstated. Next, compliance with the 1 ppm 8-hour TWA PEL is feasible and will not result in unfair citations. And, finally, OSHA's current enforcement policy is more protective of workers than the other alternatives that have been suggested.

TABLE I.—SUMMARY OF BENZENE EXPOSURES FOR 19 JOB GROUPS

Job group	No. of observations	No. of employees sampled	Percent of samples below the level of detection	Percent of samples exceeding 1 ppm	Percent of samples exceeding 2 ppm	Arithmetic mean * (ppm)
1	205	40	27.3	0.5	0.0	0.10
2	171	44	8.2	1.2	1.2	0.29
3	83	21	15.7	13.3	6.0	0.82
4	58	24	0.0	13.8	3.4	0.62
5	54	15	1.9	9.3	5.6	0.33
6	67	22	9.0	16.4	13.4	0.66
7	80	20	2.5	20.0	10.0	1.30
8	161	37	3.1	24.2	16.8	1.69
9	124	23	10.5	10.5	3.2	0.51
10	97	25	18.6	9.3	7.2	0.49
11	113	33	15.9	1.8	0.0	0.25
12	98	25	14.3	6.1	1.0	0.36
13	79	19	25.3	5.1	1.3	0.29
14	89	17	14.6	9.0	3.4	0.44
15	177	25	24.3	11.9	7.9	0.58
16	90	18	2.2	1.1	0.0	0.26
17	59	20	0.0	16.9	5.1	0.71
18	48	24	6.3	25.0	18.8	2.47
19	55	18	9.1	14.5	1.8	0.50

Source: U.S. Department of Labor, Occupational Safety and Health Administration, Office of Regulatory Analysis.
*When computing the arithmetic mean, values below the level of detection were assumed to equal 0.05 ppm.

Impact of Exposure Variability on the Feasibility of the 1 ppm PEL

While the technological feasibility of meeting the 1 ppm PEL was previously discussed in this preamble (See Section VIII, D., Summary of Regulatory Impact and Flexibility Analysis), several points are worth noting in this section. First, not all of the variation in exposure is the result of either random chance or environmental factors. Many high exposures result from clearly identifiable causes. Many companies, in fact, recognize that exposures are not truly random and record information such as the weather and the operating conditioning of the plant at the time samples are taken (Ex. No. 253). And, as the API noted, many companies tend to concentrate their hygiene efforts on the conditions associated with the highest exposures (Ex. No. 204–7, Confidential Survey).

Secondly, it is possible to devise strategies to control the peaks. For example, Dr. Mirer of the UAW stated:

> Every industrial hygienist knows that occupational exposures vary within the workplace. Interpreting this variability and understanding the reasons for it are the basic activity of the profession.
>
> Exposure varies from day to day, based on differences in production rate, material composition or character, process controls, work elements, process upsets or breakdowns, environmental emissions control changes, adjacent exposure sources, and sampling or analytical variation.
>
> The causes of variation in exposure are largely the elements which the employer is required by a standard to control by the implementation of feasible engineering and administrative controls and work practice controls.
>
> The control methods are supposed to be designed to protect, under a variety of conditions, overexposures or violations of the standard which should be abated by the installation of controls to prevent the overexposures.
>
> I should also add that most of this variation is not the result of any physical law or principle or inevitable characteristic of industrial operations. It's actually socially determined—such factors as production rate—and well under the control of employers (Tr., 3/25/86, pp. 40–41), Dr. Harris testifying at OSHA's request (Tr., 3/19/86, pp. 7–8).

Dr. Mirer's position that much variability is controllable was supported by several witnesses in the hearing including Dr. Spear testifying at the request of API (Tr., 3/21/86, pp. 40–41, Dr. Harris testifying at OSHA's request (Tr., 3/19/86, pp. 158–159), and Dr. Lynch, testifying at CMA's request (Tr., 3/26/86, p. 92). SOHIO, as discussed below in Methods of Compliance, pointed out that in their pure benzene facility, engineering controls consistently kept exposures below 1 ppm (Ex. No. 201–13, p. 13) indicating that they had controlled variability well in a difficult circumstance. Dr. Snyder testified on behalf of CMA as to how engineering controls reduce variability to low levels. He stated,

> . . . higher standard deviations [of variability] do occur when controls are not fully implemented. As controls are applied, the standard deviation does come down a little bit but in our own plants-where the control is quite good we've gotten down in the vicinity of 2 [standard deviations] or maybe a little under 2 [a low level of variability] (Tr., 3/26/84, p. 91).

Various control strategies are described in both the JRB report (Ex. No. 153) and the Regulatory Impact and Flexibility Analysis, including the institution of a leak detection repair program, the installation of better seals and gaskets, and the use of dilution ventilation. API (Ex. No. 204–7, pp. 56–65) and CMA (Ex. No. 258, pp. 167–170), have noted that there are some circumstances, where respiratory protection is appropriate and is common industry practice. Identification when

exposures are likely to be over 1 ppm and respirators needed is important to make this strategy work. Thus, the percent of employee exposures currently exceeding the 1 ppm level need not remain constant after the promulgation of the 1 ppm PEL. Indeed, the primary purpose of revising the benzene standard is to reduce this percentage.

OSHA, therefore, concludes that exposure variability does not represent a feasibility problem. As was discussed at length in the feasibility sector, OSHA's conclusion is that it is feasible to achieve 1 ppm with a high degree of confidence day in and day out so that employers will not face a substantial amount of random variation over the PEL.

Exposure Variability and Various Monitoring Approaches

Some commenters suggested that the high exposure variability associated with outdoor work operations makes OSHA's current enforcement policy unfair to the conscientious employer who maintains typical employee exposures below the PEL but who has some employees exposed above the PEL due to random chance. For example, Mr. William F. O'Keefe, V.P. of API stated:

> [T]his phenomenon [day-to-day exposure variability] is commonly observed for workplace contaminants, and means that even employers whose workplaces typically are far below an OSHA standard face a measurable risk of a citation for violating OSHA's never-to-be-exceeded PELs. Such citations are inherently unfair, since the occasional "outlier" samples cannot be anticipated. . . . We think that the issuance of a citation where average exposures are plainly below the OSHA PEL is unfair and unnecessary, and that the standard OSHA issues for benzene should have a built-in mechanism for preventing such a result [Ex. No. 204-7, pg. 19-22].

OSHA concludes that the following discussion demonstrates that OSHA's monitoring approach is not unfair.

Dr. Spear suggested that OSHA should concentrate on the mean exposures rather than the peak exposures when chronic and not acute effects are at issue [TR., 3/21/86, pp. 30-31). For several reasons, however, OSHA does not agree with the premise that only the mean exposures are of concern. First, studies, such as those of Irons [Ex. No. 159-42A] and Tice [Ex. No. 201-37], discussed in the STEL section, suggest that intermittent exposures may have more harmful effects than continuous exposure to a relatively greater amount of benzene. Second, a careful consideration of the implications of a higher than average degree of variability indicates that OSHA's enforcement policy does not generally lead to unfair citations. Finally, as is discussed in the section on the PEL, in attempting to reduce the possibility of a random exposure exceeding the 1 ppm PEL, employers will generally reduce average exposures to well below 1 ppm. This strengthens OSHA conclusion that the actual risk will be well below that predicted by the risk assessments at 1 ppm. If, OSHA concentrates on the mean exposure, however, the Agency anticipates that average exposures will not decline as much, and OSHA could not be as confident that risk will be below that predicted by the risk assessment at 1 ppm.

The following discussion reviews the various alternatives considered and the reasons for the above conclusions. These alternatives can be divided into the following four broad classifications: (1) Adopting the 1 ppm as a 40-hour TWA; (2) raising the 8-hour TWA PEL so that there is a lower probability of detecting the outlier; (3) in the event a compliance officer obtains an initial reading above the 8-hour PEL, requiring OSHA to resample before issuing a citation in order to determine whether the high exposure was representative or was due solely to chance; and, (4) allowing the use of employer data—which demonstate that average exposures are below the 8-hour PEL—to rebut the presumption, based on a single high reading obtained by OSHA, that exposures exceed the PEL. Each of these approaches is discussed in the following sectors.

Adopting the 1 ppm as a 40-hour TWA

Question 2 of the proposal requested the public to comment on the appropriateness of adopting a 40-hour TWA [50 FR 50512]. OSHA received several comments in response to this request. Some comments opposed the 40-hour TWA PEL because it would be both expensive and difficult to implement. For example, Phillips Petroleum stated that:

> Phillips is in favor of the eight-hour TWA limit. The longer forty-hour limit may be more representative of true exposures, but because of the logistics of getting an employee to carry a sampler for consecutive work periods totaling 40 hours and varying work schedules, it is impractical to set a forty-hour limit. The eight hour time weighted average is more efficient and practical at whatever PEL is set. [Ex. No. 201-18, p. 2].

The AFL-CIO and USWA were also against the 40-hour TWA. They stated.

> The 40 hour averaging scheme would not only allow great peaks in exposure (particularly if there is no STEL in the final standard), but would be very difficult to implement. Determining 40-hour time weighted averages would require greatly increased sampling time and resources for both employers and OSHA [Ex. No. 262, p. 40].

Other comments were in favor of the 40-hour PEL because it addressed the problem of unusual work days. For example, Standard Oil of Ohio stated that:

> We find general "adjustment factors" for novel work schedules such as those which are replete in the industrial hygiene literature, are unsatisfactory (e.g. Chapter XIII Modification of PEL's for Prolonged Exposure Periods, in OSHA's Industrial Field Operations Manual). Adjustment factors should be tailored to the specific toxicologic and pharmacokinetic properties of the chemical in question. * * * Given the lack of scientific evidence to support the application of any adjustment factors. Sohio supports a 1 ppm PEL with a 40-hour weighted average. [Ex. No. 201-13]

Sun Company also supported this position.

> The adoption of a formula for calculating the exposure representative for a 40-hour work week would resolve problems of technical and/or environmental variability without resorting to the arduous log-normal statistical calculations expounded by compliance theorists. [Ex. No. 201-9]

Based on these comments and its experience, OSHA has concluded that the adoption of a 40-hour TWA is inappropriate. First, OSHA's current enforcement policy for addressing non-standard work days has been tested over several years under actual field condition. Second, and more importantly, since the benzene standard covers a very wide scope of establishments it must be drafted to limit the compliance burden on typical firms while still protecting worker. While Sun Company and Standard Oil may have the resources to conduct monitoring over a 40-hour period, most firms and OSHA do not.

A 40-hour TWA would have two harmful impacts. It would place an unfair burden on the majority of firms covered by the standard (many of which are small businesses) by greatly increasing monitoring costs and it would reduce the protection afforded most employees because monitoring over 40 hours would greatly constrain the number of worksite that OSHA could inspect. Finally, a 40-hour TWA will be less protective of workers than an 8-hour TWA because a 40-hour TWA will permit more excursions above the PEL and will probably result in higher average exposures than an 8-hour TWA.

Companies which have unusual workshifts which they believe are not appropriately covered by OSHA's enforcement guidelines to cover such

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situation, should write to OSHA's Field Compliance staff explain their situation. If the facts justify it, OSHA would consider adding to its guidelines covering non-standard shifts.

Raising the PEL

Another approach recommended in some comments to handle variability was to raise the PEL and keep the same enforcement approach. CMA, for example, stated that OSHA should:

> establish a higher PEL than OSHA has proposed *e.g.*, a PEL of 2 ppm * * * [In] order to comply with a 2 ppm standard, employers would have to maintain average exposures at less than 1 ppm [because of the high exposure variability, a point that was confirmed at the hearing. Thus, a 2 ppm standard, effectively requiring that long-term average exposures be maintained at or below 1 ppm, would provide all of the health benefits that OSHA has calculated for the proposed 1 ppm standard [Ex. No. 258, pp. 130–131].

Table I reveals that only one of 19 Groups (i.e., Group 6) had a greater than 9 percent probability of exceeding 2 ppm when the arithmetic mean was below 1 ppm.

This approach suffers from a major defect. It would permit much higher average exposures than can be feasibly achieved and is likely to lead to increased risk. As Ms. Seminario of the AFL–CIO stated.

> We turn to the * * * proposal to increase the standard to 2 parts per million. I think the only point that needs to be made there is indeed 2 parts per million is in fact, given OSHA's procedures to allow for variation in analytical and sampling techniques, is really a 2.5 part per million standard. When we deal with that, we have to look at it that way, and look at it as increasing the risk proposed to workers. It allows greater exposures no matter how you look at it (Tr., 3/27/86, p. 77).

Table 1 clearly illustrates the point that with a 2 ppm limit there could easily be average exposures over 1 ppm and few readings over 2 ppm so that OSHA would rarely issue citations. For the three groups that have arithmetic means greater than 1 ppm (i.e., 7, 8, and 18), only 10–19 percent of the observations exceeded 2 ppm. This means, that contrary to CMA's assertions, an employer could keep average exposures over 1 ppm and face only a 10–19% chance of being cited for violating 2 ppm. Consequently, some employers might choose not to keep average exposures below 1 ppm with a 2 ppm limit. Thus, this approach must be rejected on the basis that it is less protective of workers and clearly would permit higher average exposures than 1 ppm.

Two Consecutive Readings Above the PEL

The third approach is for OSHA to issue a citation only in cases where the compliance officer obtains two consecutive readings above the PEL. Dr. Spear stated:

> [C]onsider the likelihood of the inspector obtaining two consecutive samples above the PEL. If the sampling is independent then the probability that two consecutive measurements exceed 1 ppm is simply the square of the probability (of one sample exceeding 1 ppm) * * * Unless the two measurements are taken sufficiently close together in time to be highly autocorrelated, it would appear probable that the long-term average exposure is likely to exceed the PEL in environments where two consecutive samples are found to exceed the PEL. Therefore * * * [this] proposal appears to be a sensible check * * * [Ex. No. 204–7, p. 29]

If one makes the assumption that the exposures are truly random and independent, then it can be shown by using this approach (i.e., simply taking the squares of the percentage of observations exceeding 1 ppm in Table I), that the probability of two consecutive measurements exceeding 1 ppm is less than 3 percent for the 16 job groups that have average exposures below the proposed 1 ppm PEL. Even in the case of Job Group 6, which has the highest probability of the 16 Job Groups, the probability of two consecutive measurements exceeding 1 ppm is only 2.7 percent (i.e., 16.4% x 16.4%). Thus, this approach makes it highly unlikely that OSHA would issue a citation for violations of the 8-hour PEL in cases where the average exposures are below the PEL. These estimates were made without consideration of the SAE. If the SAE had been included then the probability of not catching an average exposure above the proposed 1 ppm PEL would be even higher.

This approach suffers from several major defects. As was discussed previously, not all high exposures are truly random. Some are due to specific causes under the employer's control. If a compliance officer is required to obtain two consecutive samples above the PEL before a citation can be issued, the employer can take steps to alter the conditions in the plant which will result in lower exposures when the compliance officer returns. While this may seem like a good approach to get the employer to take action, it must be remembered that some of the steps that can be taken (such as reducing the process rate or avoiding certain operations) are not permanent. Thus, this approach could make the standard unenforceable. The employer could, by slowing operations on the return day, register low exposures even though normal exposures are over the limit.

Second, this would mean that averages over the limit would often be missed even without action by the employer. For example, under the assumption of random and independent events, the probability of obtaining two consecutive observations above the 1 ppm from Job Group 18, where the arithmetic mean is over twice the proposed PEL, is less than 7 percent. (i.e., 25% × 25% = 6.25%). Finally, this approach greatly reduces the number of employers who can be inspected.

Thus, this alternative must be rejected on the grounds that it is not protective of workers since long-term average exposures well over the PEL will generally not be detected. Dr. Spear did recognize this when he stated, "I think the idea of requiring them [the compliance officers] to have two consecutive samples over the PEL [before issuing a citation] was not a very good way to go" (Tr., 3/27/86, pp. 82–83).

Averaging Exposures

The final approach, which received the most support by industry, is to allow the use of employer data to establish the average exposure, and this average would be used as part of the basis for the determination of compliance. The rationale behind this approach was summarized by the CMA, in its post-hearing brief:

> In short, there was widespread agreement at the hearing that average exposure over a long period of time is the relevant parameter for estimating cancer risks associated with low level occupational exposure to benzene and that, accordingly, a better relationship between the PEL and the health risk of concern would be achieved if the standard were implemented on a basis that takes account of average exposures in determining compliance [Ex. No. 258, p. 117].

According to Dr. Spear, the averaging approach appears to have the advantage of being more closely tied to the "health risk of concern" than the other approaches. In addition, it also encourages employers to collect more exposure data. More observations may lead to a greater probability of identifying a problem if one exists (Ex. No. 218B, p. 21).

As discussed in the STEL section, however, the long term average exposure may not be the only concern. Occasional "outliers" may also be important.

However, the averaging approach would be extremely difficult to implement. It does not take into account the need to ensure that the average

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computed by the employer is representative of the same conditions sampled by the OSHA compliance officer. If the employer's and OSHA's samples were taken under different conditions, then the results are meaningless. According to Dr. Spear, "if you mix apples and oranges, you can sample until hell freezes over and you are not going to get an adequate characterization" of exposures (Tr., 3/27/87, p. 50).

This concern was stated by Margaret Seminario of the AFL-CIO.

> * * * the point I was trying to make earlier was that when you look at the data, and you take an arithmetic mean, * * * you are taking an awful lot on faith that indeed those samples do represent that worker's particular exposures, [and] that exposure measurements are representative * * * (Tr., 3/27/86, p. 122).

If the samples were taken under differing conditions, then a problem situation may go undetected, resulting in inadequate worker protection. According to Dr. Spear,

> it doesn't make any sense * * * to average across different people if you cannot assure yourself, and whoever might be scrutinizing your data, that these people do have similar exposures, because * * * you may * * * have one individual * * * who has higher average exposure than another individual, and clearly, by averaging the two, you are not protecting the person with the higher exposure (Tr., 3/21/86, p. 42).

The result of pooling samples, taken under very different conditions is to create a heterogeneous population. Dr. Lynch noted that the problem would result in "speading the data all over the place" (Tr., 3/26/86, p. 92). Ms. Seminario stated that,

> There may be overlapping distributions or several distinct distributions of exposures, which cannot be accurately represented by the simple log normal model. Grouping this data in one distribution may * * * increase estimates of the probability of higher exposures occurring [Ex. No. 204-9, p. 7].

For this reason, the AFL-CIO requested that if the averaging approach was permitted, then OSHA should require the employer's data to meet several criteria in order to ensure that the employer's data represented the true exposure of specific individuals. For example, the following criteria were suggested:

> (1) "Employer data will only be considered if it is data on the same worker doing the same job."
>
> (2) "There must be more than 5 employer exposure measurements for the individual worker taken over the past year, and those samples must represent the full range of possible exposures" [Ex. No. 262, p. 44].

This would be a substantial body of documentation for the employer to gather and for OSHA's compliance office to review.

In order to further study the problem of obtaining representative samples of worker exposure and avoiding overlapping distribution. OSHA conducted statistical tests on some of the jobs groups in the Spears study. OSHA attempted to determine if the mean exposures of the group would be substantially different when some quantifiable characteristic was taken into account. The purpose of this is to determine whether the degree of variation stated indicated true variation or that the groupings included different conditions and did not represent nearly homogeneous groups. In the latter case, the study would exaggerate the degree of variation because it included different conditions in each group. OSHA used Dr. Spear's report as a basis for this analysis because he and his colleagues spent considerable effort to attempt to obtain "nearly homogenous groups" [Ex. No. 207-7, p. 2-4].

The analysis was conducted in the three steps. First, each group of observations was transformed from a presumably log normal distribution to the normal distribution required for the tests (i.e., each observation was converted to its logarithmic value). Next, the data in each group was stratified according to two identifiable characteristic (i.e., operating condition), so that the subgroups could be tested to determine if they came from the same parent population group. Finally, the following tests were conducted: The F-test, the t-test, and two "goodness-of-fit" tests for normality.

The two tests for normality—the Kolomogorov D for subgroups with more than 50 observations and the Shapiro Wilk for subgroups with less than 51 observations—were important, because normal distributions were required for the other tests. In addition, while these tests were not sufficient to ensure that there were no overlapping distributions, they did provide OSHA with some confidence that the observations did not come from the very different distributions (which might have, for example, resulted in multiple peaks in the frequency distribution). The F-test was used to test the hypothesis that two normal populations have the same variance, and, the t-test was used to test the hypothesis that two normal populations with same variance also has the same mean. Taken together these tests revealed whether or not it was safe to assume that the two subgroups came from the same population because the normal distribution is fully characterized by two parameters, the mean and variance.

While this analysis was not designed to be generally representative of all situations, it does reveal the difficulty in implementing the averaging approach. (This is especially true given the considerable effort spent by Dr. Spear and his colleague in obtaining "nearly homogeneous group" [Ex. No. 204-7, p. 2-4], an effort that is highly unlikely to be duplicated under most field conditions.)

Since codes for at least 3 different operating conditions (e.g., routine, turnaround, and other) were available for 12 of 19 job groups, it seemed reasonable to conclude that some plant peronnel may have been concerned about differences in exposures resulting from different operating conditions. Thus, this seemed to be an ideal starting point for the analysis of Dr. Spear's groups. Further examination of the data, however, revealed that six of the 12 groups only contained observations on one operating condition.

Two of the job groups (i.e., 7 and 8) contained at least two normally distributed subgroups of at least 10 observations each and were used for further testing. (The hypothesis of normality could not be rejected at the 95 percent confidence level).

Job Group 8 had two subgroups that could be tested, exposures taken during running conditions (OPC=1) and exposures taken during turnarounds (OPC=2). Based on the values presented in Table II, an F-statistic of 1.66 was calculated and the hypothesis that the two subgroup variances came from the same normal population was rejected at the 95 percent confidence level.

A similar procedure was followed for job group 7 using the values in Table III. Job group 7 had two subgroups of over 30 observations (i.e., running conditions and turnarounds) and one subgroup of exactly 10 observations (i.e., partial shutdown).

TABLE II.—TEST VALUES FOR GROUP 8

Description of parameter	Value of parameter	
	Running	Turnaround
Number of observations	69	71
Arithmetic mean of the logs	−1.64	−1.31
Arithmetic standard deviation of the logs	1.56	2.01

Source: U.S. Department of Labor, Occupational Safety and Health Administration, Office of Regulatory Analysis.

The first round of tests were conducted on the two larger subgroups. An F-statistic of 1.39 was calculated and

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at the 95 percent confidence level the hypothesis that two variances came from the same normal population was not rejected. A T statistic of 1.7 was calculated, which proved to be indeterminant at the 95 percent confidence level. The hypothesis that the two means came from the same normal population was rejected under a one-tail test but was accepted under the two-tail test. Not having plant-specific knowledge, it was not possible to determine which test should be used. (However, the mean for the turnaround operation should probably be higher than the mean for running conditions, thus justifying the use of a one-tail test).

Next, the arithmetic mean of the observations were examined. This examination revealed that although the arithmetic mean of all 80 observations for Job Group 7 was 1.3 ppm (See Table I), the arithmetic mean of the 67 observations in both of these subgroups were only half that value (i.e., 0.66 ppm). Clearly, some other condition was contributing to the high average exposures of Group 7. This other condition, which proved to be partial shutdown (an arithmetic mean of 10 observations of approximately 6 ppm), is subject of the next series of tests.

Based on the value presented in Table III, an F-statistic of 3.12 was calculated by using the variances for partial shutdown and running condition, and the hypothesis that these two variances came from the same normal population was rejected at the 95 percent confidence level. An F-statistic of 2.25 was calculated by using the variances for partial shutdown and turnaround, and the hypothesis that these two variances came from the same normal population was rejected at the 95 percent confidence level. Finally, an F-statistic of 2.51 was calculated by using the variance for partial shutdown and variance for the combined observations for turnaround and running condition (arithmetic standard deviation of the logs equal to 1.63), and the hypothesis that these two variances came from the normal population was rejected at the 95 percent confidence level.

Thus, it appears that operating conditions may exert a significant influence on exposures and that relatively rare events (such as partial shutdowns) may have a major impact on average exposures. This conclusion is of particular concern because of the lack of information on operating conditions in many of data sets used by Dr. Spear. It would be even less likely to have such data from less sophisticated employers. Thus, if OSHA adopted the averaging approach, the Agency would not be able to apply these tests in the many situations.

In lay terms, this analysis indicates several things. First, the Spear data probably does not demonstrate as much variability as has been suggested. Where the hypothesis could be tested, the data indicate that several different operating conditions were combined into a single data group. These different conditions had different average exposures. So the degree of variation was exaggerated because different conditions were pooled.

Table III.—Test Values for Group 7

Description of parameter	Value of parameter		
	Running	Turnaround	Part shutdown
Number of observations	31	36	10
Arithmetic mean of the logs	−2.00	1.33	−0.88
Arithmetic standard deviation of the logs	1.46	1.72	2.58
Arithmetic mean of observations	0.46	0.83	5.97

Source: U.S. Department of Labor, Occupational Safety and Health Administration, Office of Regulatory Analysis.

Second, an averaging approach is very difficult to implement. Before OSHA can adopt the averaging approach, there must be a procedure in place to ensure that the average is computed from a representative sample, because an average computed from observations taken under statistically different conditions may lead to the underestimation of the exposures of some workers. It would be difficult for the smaller employer to implement such system, it would take much greater resources from all employers, and it would be very difficult for OSHA to review the data to determine whether it was representative of a specific condition.

According to Dr. Spear, "* * * representative is the key word. I think that the burden * * * that it places on OSHA [is] to ensure that the employer's data is in fact representative. * * *" [Tr., 3/21/86, p. 128.] But, it is very difficult, if not impossible, for someone to determine whether or not the observations represent a particular situation without having an extensive knowledge of the process and unit in question.

Even such a sophisticated statistician as Dr. Spear did not achieve truly representative groups though he made a substantial effort. For example, the tests conducted above on the statistical significance of different operating conditions on exposures were all based on codes supplied by the companies. Without these codes (most groups either did not have the codes or had only one code), it would not have been possible to determine the homogeneity of the data nor would it have been possible to determine that the high average exposures for Job Group 7 were primarily due to exposures during partial shutdown.

Third, this approach gives employers an incentive to measure low days and not to measure and take actions to control high exposures, conditions like the partial shutdown for Group 7. Under current OSHA policy, firms have the motivation to stratify their data in order to determine if the high exposures are associated with some specific condition, because if a random OSHA inspection detects that condition a citation may be issued. Thus, it is common practice for firms to take a great percentage of their samples during problem situations (Ex. No. 204-Z, p. 37), (Ex. No. 204-7, pp. 43-55). Under the averaging scheme, however, firms will have the motivation to avoid taking samples during the problem situations in order to keep their average exposures below the PEL.

The chances that a compliance officer, who does not have plant-specific knowledge, will detect the omission of data for specific situations are remote. A compliance officer will not know if, as in the case of Group 7, the partial shutdown data are combined with the running and/or shutdown data. A compliance officer is unlikely to know whether the sampling was representative of all factors (e.g., weather, product mix, production levels, maintenance in the unit, maintenance in adjacent units, etc.) or know whether a specific high exposure condition was under-represent in the data base, thereby making the arithmetic mean lower than the true average exposure.

Consequently, it would be extremely unlikely for OSHA to find a violation of the PEL on the initial visit, even where long-term worker exposures actually exceed the PEL. Thus, OSHA would have to remonitor. According to Dr. Mirer of the United Auto Workers, "a policy like that would probably grind OSHA enforcement of health standards to a total halt, and put OSHA out of the business of enforcing health standards [Tr., 3/25/86, p. 21]. This is because the chances of obtaining two consecutive readings above the PEL (i.e., the initial one and the follow up) are extremely small as was demonstrated earlier.

Finally, the averaging approach would permit employers to maintain higher

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average exposures than OSHA's traditional approach and then it would be feasible to achieve. Consequently, OSHA would not be able to say as confidently that actual risks are substantially below the risks predicted by the risk assessments. It should be noted that OSHA would reach the conclusion not to adopt the averaging approach, even apart from its analysis of the Spear data, based on the other factors discussed.

Conclusion

The preceding analysis and that in the Technical Feasibility section has shown that compliance with the 1 ppm benzene PEL is feasible even taking into account exposure variability. Much exposure variability is not random and employers can take steps to protect workers from being exposed to high benzene exposures by controlling it. Some variability is outside of the employer's control, but OSHA's technical feasibility analysis shows that controls are available to keep exposures reasonably consistently under 1 ppm.

The preceding analysis also indicates that variability is not as great as some suggest. Alternative compliance strategies have many disadvantages. They are difficult and expensive for employers to carry out. They greatly increase OSHA compliance officer time per inspection, thereby greatly reducing the number OSHA can perform. These approaches can lead to higher average exposures than can be feasibly attained. An averaging approach discourages an employer from measuring high exposures in order to be in position to reduce them. They make it less likely that compliance officers will detect conditions of true overexposure.

OSHA's current enforcement approach has a number of advantages. It makes more efficient use of compliance officer's time permitting OSHA to make more inspections, detect more over exposures if they exist and hence protect more workers. It encourages employers to try and detect high exposure conditions and take actions to reduce them. This reduces variability, reduces average exposures and reduces peak exposures. OSHA has been successfully carrying out this enforcement approach for over 15 years. It avoids the substantial statistical complications that other approaches entail and which are very difficult to carry out in this field. As a matter of statistics in situations of high variability, one high reading indicates the likelihood of high cumulative dose because of the influence of the tail on the average exposure (Tr., 3/19/86, p. 158; Tr., 3/21/86, p. 48). Finally, OSHA's compliance manual directs the compliance officer to consider employer data and workplace conditions before deciding whether the compliance officer should cite or remonitor based on an exposure over the limit.

F. Methods of Compliance: Paragraph (f)

OSHA proposed that feasible engineering and work practice controls be the primary method of reducing exposures in production and distribution operations where exposures are more continuous in nature. Engineering controls are generally more effective in practice than respirators. However, the proposal indicated that in many "maintenance and repair activities" and operations where "exposure are intermittent in nature and limited in duration," engineering and work practice controls may not be feasible. Thus, respiratory protection could be the primary means of control. See paragraph (g)(1)(ii). In addition, OSHA proposed that employers could utilize their choice of control strategies, including respiratory protection, engineering controls, work practices or any combination of these methods when benzene is present in an area of the workplace fewer than 30 days in the year.

The comments and evidence received were generally supportive of the proposal. Accordingly, the final standard includes the proposed provisions.

In response to the Request for Information, many commenters discussed appropriate compliance strategies. As elaborated below, a number of commenters such as Du Pont and Shell stated that they generally rely on engineering and work practice controls to control benzene and that these controls and generally achieved 1 ppm at their workplaces. However, these and other companies noted that in certain maintenance and repair operations which result in intermittent employee exposures, engineering controls either would not be feasible or be extremely wasteful and that respiratory protection would be appropriate and afford adequate employee protection.

For example, SOHIO (Ex. No. 142-6) recognized the general effectiveness of engineering controls to reduce employee exposures to benzene, but pointed out that there were certain working situations and conditions "under which exposure could not be reduced" regardless of how extensive the use of engineering controls was and respirators were appropriate.

In its response to the request for information, Shell Oil Company (Ex. No. 142-13) outlined the engineering and work practice controls used by Shell and other companies operating as oil and chemical processing industries. Shell stated that when these types of controls are coupled with respiratory protection programs, proper personal protective equipment and an effective training and education program, "these engineering and work practice controls are normally adequate to ensure that actual employee exposure does not exceed 1 ppm TWA."

Du Pont (Ex. No. 142-35) stated that, along with various listed engineering control options, "a number of familiar work practice controls can (and should) be utilized, including extensive training, well-established procedures for particular operations, proper maintenance and good housekeeping. Given an adequate phase-in period, such controls could probably be implemented by Du Pont to operate at 1 ppm." Du Pont pointed out, in further comments, that there were circumstances where "respirators will always be required for some tasks even though engineering controls are in place, whenever the potential for unexpected employee exposure exists (for example, possible equipment failure)."

In the proposal, OSHA also discussed the reasons why the Agency and the general industrial hygiene community believes that engineering controls should be the primary means of compliance. An effective method of controlling employee exposure is to control the emission of toxic substances at their source through mechanical means combined with the use of work practices. Good engineering and work practice controls also help to minimize splashes and spills. An added benefit of these controls is reducing dermal exposure to employees.

In addition, it is very difficult to wear respirators full time in production operations. If active movement is required respirators create safety hazards since they limit vision and communication. They also tend to slip during heavy physical labor and sweat may create skin irritation at the seal.

Specifically in the case of benzene, as discussed in the respirator section, there is no MSHA/NIOSH approved negative pressure respirator for benzene at 1 ppm because benzene has poor odor warning properties below 12-15 ppm and the possibility of filter breakthrough without warning exists. Although OSHA believes the provisions in this proposed standard in regard to filter changing minimizes this problem, nonetheless the problem is sufficiently great so that it would not be protective for a large

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number of employees to wear respirators when feasible engineering controls exist. However, OSHA also recognized that respirators may provide acceptable protection when an employer establishes stringent procedures and then carefully supervises their implementation on a continuous basis.

OSHA elaborated on its preliminary conclusions at greater length in the preamble to the proposal. (See 50 FR 50558–50562). OSHA requested comments on its proposal and these issues. It received a number of comments and some testimony. Many supported the proposal and the preference for engineering controls. Industry comments did not oppose the preference for engineering controls so long as the flexibility contained in the standard was retained. Very few comments specifically opposed a preference for engineering controls.

OSHA requested Dr. Robert Harris, Professor of Environmental Engineering at the University of North Carolina, an expert in this field, to testify on this issue. He stated,

In Industrial hygiene practice, engineering controls are recognized as the preferred means of control whenever they can be applied. The fundamental reason for this is that the elimination or control of exposures by engineering means, which are independent of workplace occupancy, and of the integrity and proper use of personal protective equipment, results in the most effective and reliable protection of workers (Ex. No. 211, p. 13).

The National Institute for Occupational Safety and Health (NIOSH) presented the most extensive comments on this issue, an 18 page report with an extensive bibliography (Ex. No. 201–42, Attach 2). They strongly supported the preference for engineering controls and summarized their position as follows:

Should OSHA require the use of feasible engineering controls in preference to the use of respirators?

Yes, in most circumstances the use of engineering controls (and not administrative and work practice controls) are the clearly superior means of employee exposure prevention.

The hierarchy of control solutions should be followed in developing a worker protection strategy. Each element of the ordered hierarchy:

(1) Preventing or containing hazardous workplace emissions at their source,

(2) Removing the emission from the pathway between the source and the worker, and

(3) Controlling the exposure of the worker with barriers between the worker and the hazardous environment, should be sequentially applied in descending order to the extent feasible before the next lower element is considered.

The application of engineering controls is effective for all three elements, while respirators are only effective for the third element. Years of public health experience in controlling infectious disease as well as industrial hygiene experience have shown that the first two elements are the more practical and substantially more effective approach. Respirators are limited to the third element of the prevention hierarchy, which for decades have shown to be the least reliable and least consistent approach to exposure prevention.

What factors indicate that engineering controls in the workplace better protect employee health?

When discussing "better" employee health protection it is important to define what is meant by "better." Better protection will provide more reliable, more consistent, and higher levels of adequate protection to a larger number of workers. A control solution with better protection will have increased feasibility for demonstrating the protection afforded each individual worker throughout the lifespan of the system. Better protection will have less dependence on human intervention for its efficacy so as to increase its reliability. Finally, better protection will create fewer additional problems of its own. Properly designed, installed, operated, and maintained engineering control systems can have all of the preceding characteristics, thus they definitely can better protect employee health.

Engineering controls are designed to prevent a hazardous agent from being emitted into a workplace and reduce the airborne levels of substances already released. For a work environment with minimal contamination, there is assurance that inadvertant entries into the workplace by other employees do not expose those employees to the hazardous agent. Respirators, on the other hand, do not reduce the environmental levels of a contaminant, but can only provide a very localized barrier of questionable reliability. Respirators cannot reduce or eliminate hazardous material from the workplace that may be absorbed by workers through their skin or by ingestion.

The exposure control performance of engineering control systems can be frequently monitored by valid real-time techniques that are inexpensive and quick. Therefore, a gradual or sharp reduction in system control effectiveness for large numbers of workers can be detected. With respirators, however, there is no system to detect defects in their use in the workplace; this is one of their most severe deficiencies.

Engineering controls, by generally relying more on mechanical devices or design features, are less subject to human error. Engineering controls require less personal involvement and intervention, thus they can be substantially more reliable and consistent in the levels of protection provided to workers. The effective application of respirators as controls requires effective training of each and every worker that must depend on the respirators for health protection. Acceptance and effective cooperation by every worker, proper wearing each and every time by every worker, and verification that this is occuring are some of the necessary assumptions for effective respiratory protection dependent on respirators. These are fragile and questionable assumptions for many respirator programs.

Mr. Nelson, a certified industrial hygienist employed by DuPont testifying on behalf of the Chemical Manufacturer's Association stated.

The determination of when engineering controls or respirators should be used to protect the health of employees has, for some time, been a controversial subject. Our belief is that each employee's work environment should be maintained at safe levels through the implementation of engineering controls, when the use of engineering controls would be cost-effective, augmented as appropriate by personal protective equipment, and/or work practice controls. (Tr. 3/26/86, pp. 5–6)

Dr. Snyder testifying on behalf of CMA pointed out another advantage of engineering controls, they reduce exposure variability (See the discussion on variability). He noted "higher standard deviations (of variability) do occur when controls are not fully implemented. As controls are applied, the standard deviation does come down a little bit but in our own plants where the control is quite good, we've gotten down in the vicinity of 2 (standard deviation) or maybe a little under 2" (Tr. 3/26/85, p. 91).

Mr. Michael Wright, Director of Safety and Health for the United Steel Workers, a qualified industrial hygienist, also strongly supported the preference for engineering controls. He stated as additional reasoning for the preference.

In fact, respirators are an even worse choice for benzene than for other chemicals. Benzene has poor warning properties at 1 and 0.5 ppm, making it difficult to detect filter break-through. (Benzene getting through the filter of an air purifying respirator into the breathing zone.)

Air supplied respirators are infeasible in many benzene jobs. A worker would either have to change air bottles many times during the workday, or drag an air hose hundreds of yards in a refinery or chemical plant, a practical impossibility (Tr. 3/25/86, pp. 50, 51).

He also strongly supported OSHA's requirement of a compliance plan stating,

In order to ensure that feasible engineering controls are in fact installed, companies should be made to prepare detailed written compliance plans on the model of lead standard (Tr., 3/25/86, p. 51).

The comments of the major chemical companies, petroleum companies and their trade associations were virtually identical. They did not object to the general preference for engineering

controls. However, they strongly supported the need for the exceptions incorporated by OSHA in the proposal for that general preference. These exceptions were for maintenance and repair activities, occasional and intermittant activities, and when benzene is present in the area fewer than 30 days in the year. See the comments of SOHIO (Ex. No. 201–13), EXXON (Ex. No. 201–15, Monsanto (Ex. No. 201–30), CMA (Ex. No. 201–33, p. 158) and API (Ex. No. 206, p. 61d).

For example Monsanto stated,

As standard practice, Monsanto Company makes every attempt to reduce workplace exposures through the use of sound engineering controls and has over the last several years instituted major control efforts at our benzene handling locations to lower potential worker exposures to the lowest level practical. Although our control efforts are ongoing, we still rely on respiratory protection during nonroutine tasks or where other controls are not feasible. (Ex. No. 201–30, p. 1).

Exxon stated,

Exxon concurs with OSHA's proposal to '. . . specifically recognize that in maintenance and repair operations engineering controls may not be feasible or an efficient use of scarce resources.' The cross-reference between paragraphs (f) and (g) is an appropriate mechanism to tie these together (Ex. No. 201–15, p. 4).

Sohio pointed out it had recently constructed a facility to produce pure benzene to achieve 1 ppm with engineering control with occasional short term use of respirators. (Obviously a pure benzene facility will have greater difficulties than a facility with only 5 or 10% benzene in the process stream, other things being equal). They stated,

Sohio's experience with our benzene manufacturing facility indicates that we can achieve a TWA of 1 ppm with engineering controls. However, TWA exposures of less than 1 ppm can be achieved only though the use of PPE.

In 1984 Sohio constructed a benzene production facility at our petroleum refinery in Lima, Ohio. Best available control technology was used to minimize benzene emissions at all locations. This facility cannot consistently achieve 0.5 ppm 8-hour time weighted average exposures. Since the beginning of the start-up 15 months ago short-term exposure to benzene vapor above 1 ppm has been controlled by employee use of airline respirators and self-contained breathing apparatus during some non-routine and maintenance tasks. This respirator program is closely operated and supervised by the facility safety department.

This facility has these engineering controls in addition to many others:

—Storage tanks each with an internal floating roof secondary seal and automatic gueging device.

—Pumps, each with double mechanical seals flushing system and failure indicator.

—Closed drain system.

—Closed-loop sampling station and sample bombs.

Closed loading system with vent scrubber to control emissions during railcar loadings.

Covered API separator.

Local mechanical exhaust ventilation and makeup air systems in two quality control laboratories.

In addition to these engineering controls the facility utilizes at least one administrative control: frequent manual leak detection surveys and prompt repair of leaking equipment. The Lima facility cannot achieve a benzene concentration of 0.5 ppm 8 hour time weighted average. Ex. No. 201–13, p. 2)

CMA stated as regards to the engineering control paragraph (f) and respirators the following:

* * * respirators may be used to comply with the standard, * * * (1) where "benzene is present in a work area less than a total of 30 days per year" and (2) in "work operations for which the employer establishes that engineering and work practice controls are not feasible such as maintenance and repair activities, vessel cleaning, or operations where engineering and work practice controls are infeasible because exposures are intermittent in nature and limited in duration * * * These two respirator use provisions are both appropriate and extremely important. They respond to critical feasibility concerns and represent an attempt to make the standard as cost-effective as possible, consistent with the protection of worker health. As OSHA recognizes, "[e]ngineering controls may be impractical if used only a few days per year, and * * * respirators present fewer difficulties to the wearer if used intermittently." For these reasons, we strongly support these respirator use provisions (Ex. No. 201–33, pp. 158 159).

The only major comment which specifically objected to the preference for engineering controls was the Respiratory Protection Group of the Industrial Safety Equipment Association which represents manufacturers of respirators. They stated that the employer should be required to "maintain a written assessment of the feasibility and efficacy of the method used whether it be engineering control respiratory protection or a combination of both methods." The employer would then choose based on that analysis of cost and employee acceptance (Ex. No. 201–17A).

Finally the AFL–CIO and USWA summarized their position as follows in their post hearing brief:

OSHA should continue to rely on engineering controls and work practices as the primary means of compliance. In fact, the poor warning properties of benzene make respirators even less effective.

Feasible engineering controls and work practices should be required for all jobs, not just those which involve more than 30 days exposure per year (Ex. No. 282, pp. 3–6).

OSHA, after reviewing the record, concludes that the provisions on methods of compliance in the proposal are appropriate for benzene. Indeed there was no significant opposition to them in the comments. OSHA is currently considering its policies on methods of compliance generally. (See 48 FR 7473, February 22, 1983, and the 1987 Regulatory Program of the United States Government). Decisions made in rulemaking on that issue would, of course, be based on the evidence in that record.

OSHA has considered whether different principles should apply as to methods of compliance for the STEL, such as using respirators to meet the STEL but not the TWA. In the existing benzene record, commenters did not address this option. In the absence of comments on such alternative approaches, the provisions of (g)(1)(ii) give appropriate guidance and will lead to a protective and cost-effective approach. However, this matter will arise in the proceeding on methods of compliance. (See the 1987 Regulatory Program of the United States Government.) If evidence appropriate to benzene is submitted in the methods of compliance rulemaking, OSHA will consider making appropriate changes to the benzene standard.

Benzene and chemicals containing benzene or made from it are generally produced and processed in closed systems. There are effective controls for transfer points. Consequently engineering controls and leak detection are generally very effective and efficient, maintaining the closed nature of the system.

As NIOSH pointed out, engineering controls for benzene will provide the most effective worker protection. It is much easier to tell whether the engineering controls are working than whether a respirator program is working. They are the most reliable and hence the most protective controls in this circumstances since they are much less susceptible to human error. In addition they greatly reduce the possibility of skin absorption or ingestion.

Respiratory protection is not as effective, especially for production activities or other activities which require their use a substantial percentage of the time. A good respirator program requires careful supervision and extensive training and fit testing. Proper respirator use also

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reduces productivity. Although a careful respiratory program increases the protection respirators afford, such a program is expensive. Enforcement of a good program by OSHA is relatively difficult.

Respirator use reduces vision and communication. Thus, their use may create safety hazards. In addition their use may lead to face irritation. Consequently, there is an incentive for unsupervised employees to not use them when required or not use them properly.

In the case of benzene, as Mr. Wright pointed out, there is a further disadvantage of extensive reliance on respirators. Since 1 ppm is below the odor threshold, the worker would receive no warning if there was filter breakthrough in an air filtering respirator. Self-contained breathing apparatus is heavy and supplied air respirators require an airhose which is difficult to use when a worker must move around. (There is no NIOSH/OSHA approved air filtering respirator for benzene at 1 ppm. However, OSHA does permit their use with requirements to alleviate the difficulties. See the discussion in the respirator section below.)

Every qualified professional industrial hygienist who testified on the issue, including Mr. Wright, Dr. Harris, and Dr. Nelson of the CMA panel, stated that engineering controls were the preferred control methodology.

Industry did not dispute this general principle (though they strongly supported the modifications to it in the OSHA proposal). In the several specific examples of benzene facilities discussed on the record, both Monsanto and SOHIO pointed out how they had successfully utilized engineering controls to reduce exposures to low levels, lower than required at the time. This indicates industry practice is to prefer engineering controls.

OSHA experience is that engineering controls have worked best. As this has been required in prior standards, OSHA now has experiential evidence demonstrating the advantage of this approach. For example, engineering controls for vinyl chloride have been very protective of workers, cost one-tenth the amount OSHA's contractor estimated and improved industry efficiency. The cotton dust standard with its preference for engineering controls has greatly reduced the level of byssinosis in the cotton industry, increased the industry's productivity and competitiveness, and cost one-half of OSHA's estimate (50 FR 51121). The evidence in this proceeding indicates that OSHA's coke oven emission standard with its preference for engineering controls as an additional benefit has already reduced benzene exposures at coke oven batteries below the action level. So substantial additional health benefits than originally considered have been achieved by that standard.

However, as OSHA pointed out in the proposal, the general preference for engineering controls applies with greatest force to production activities and other activities which require employees to wear respirators a greater percentage of the time. OSHA in all of its standards has pointed out that feasible engineering controls may not be available for maintenance and repair activities. By definition, these activities are intermittent, scattered and in the case of repairs result from the breakdown of machinery. In addition, these operations should only require workers to wear respirators part of the time. It is easier to wear respirators because of less irritation and easier to insist that they be worn when respirator use is intermittent.

OSHA also indicated in the proposal that engineering controls are often infeasible when exposures are intermittent in nature and limited in duration. For the same reason as maintenance and repair activities, extensive attempts at engineering controls are often not practical where exposures are both brief and occasional. It is both difficult to keep operable and a not very productive use of valuable industrial hygiene time, as well as often very costly, to try to provide engineering controls for very brief, intermittent exposures. (There are often effective engineering controls for regular intermittent exposures.) In addition, for such intermittent and irregular exposures, employees can wear respirators with less difficulty.

In addition, virtually all the industry comment supported OSHA's proposal for maintenance and repair activities. There was no significant opposition to these provisions. Consequently, OSHA retains both of these provisions for the reasons stated here and in the proposal.

OSHA also proposed that the employer may choose any combination of engineering, work practice and respirator controls when that employer can document that benzene is used in the work area 30 or fewer days in a year. OSHA stated in the proposal,

> Engineering controls may be impractical if used only a few days per year, and, as discussed, respirators present fewer difficulties to the wearer if used intermittently (50 FR 50559).

As citations above indicate, this provision was strongly supported by industry. CMA supported it for the reasons stated by OSHA and also argued "* * * [the provisions] respond to critical feasibility concerns and represent an attempt to make the standard as cost-effective as possible, consistent with protection of worker health" (Ex. No. 201-33, p. 159).

CMA also contends that the provision should be broadened to read, "Where the employer can document that employee exposure to benzene on a job assignment occurs for less than a total of 30 days per year * * *". They argued that this would place the focus on employee exposure and not on work areas. They also refer to a question their attorney asked of an OSHA employee.

> Q. Is the focus of the proposed standard on employee exposure to benzene as opposed to airborne levels of benzene that may be in an area where employees are not spending time?
>
> A. I think the purpose of the standard is, of course, to reduce employee exposures, and not theoretical exposures where there are no employees" (Tr. 2/18/86, pp. 76-77).

OSHA has concluded that the provision should be retained as originally proposed. When an operation occurs only briefly in a year, it may be impractical to install engineering controls since they will be used for such a brief period. Indeed it may be a waste of industrial hygiene resources to install major engineering controls which will be used only temporarily. For this temporary period, a carefully supervised respirator program may be effective. Consequently, the additional flexibility of the provision is appropriate.

However, this approach is not appropriate for exposures which continue for a substantial part of the year, even if a particular employee does not come into contact with benzene for more than 30 days. The reason is that this would permit employee rotation. For example, an operation could continue for one-half the year. But 6 employees could be rotated in for 30 days each.

Under CMA's approach there would be no preference for engineering controls, but in fact, this is not a temporary situation but a regular situation. Engineering control would keep 180 employee days of exposure per year under the PEL. It would be a worthwhile use of IH resources to keep exposure below the PEL with engineering controls. The better protection of engineering controls would extend over 180 exposure days. Avoidable respirator use under the CMA alternative would be substantial, just divided up over many employees.

In addition, the CMA approach would create a substantial paperwork burden to identify employees in an area each

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day. It also would be difficult for OSHA to determine if individual employees were exposed more than 30 days in one area.

Finally, OSHA believes that the CMA recommendation encourages employee rotation. OSHA opposes rotating employees into areas of higher exposures to carcinogens to reduce individual exposure because this does not reduce cumulative exposure as reducing exposures with controls would. It is inappropriate to encourage employers to expose a greater than necessary number of employees to a carcinogen. (This argument applies to employees wearing a respirator, as well, because their respirators might not be worn properly and leak. Indeed by requiring more employees to wear respirators the possibility of less effective training, supervision and skill in use increases.)

Several commenters suggested that OSHA in the preamble list jobs for which the preference for engineering controls is not appropriate (Ex. No. 358, pp. 168–9; Ex. No. 201–18, p. 1). OSHA believes that the regulatory requirements it has incorporated in the standard based on sound industrial hygiene principles are the most specific regulatory language appropriate. It is impractical to list jobs since there is no consistency of names within companies as well as across companies. Further, a detailed job analysis is not generally appropriate at the rulemaking stage unless a specific job is clearly defined and widespread. For an illustration of the application of the principle see the proposal at 50 FR 50558, col. 3.

Finally, paragraph (f)(2) requires an employer who has exposures over the PEL to establish and implement a written compliance program which describes the methodology to be used to reduce employee exposure to or below the PEL within his workplace. (If the employer is already in compliance, no plan is required.) The plan should provide for this to be accomplished where feasible through engineering and work practice controls. These written plans must include a schedule for implementation and must be furnished upon request for examination and copying to OSHA, NIOSH, and affected employees or their representatives.

Once a workplace is in compliance with the standard, the compliance plan need not be updated. If exposures later increase over the PEL; however, an update must be prepared.

These written compliance plans are to be revised as appropriate. Appropriate circumstances may include a change in controls or substantially different exposure conditions. The plan need not be updated merely because some controls have been installed since the last update, or because not all have been installed pursuant to the schedule, or because of new monitoring results which are similar to prior results.

Their was little comment or criticism of this provision in the rulemaking and it is incorporated with little change in the final. Such provisions have been in other OSHA standards and in OSHA's experience lead to a systematic and efficient reduction in exposures to below the PEL. A plan is also standard industrial hygiene practice.

G. Respirator Protection: Paragraph (g).

The final standard requires or permits that respirators be used to limit employee exposure to benzene in the following circumstances:

(i) During the time period necessary to install or implement feasible engineering and work practice controls;

(ii) In work operations for which the employer establishes that compliance with either the TWA or STEL through the use of engineering and work practice controls are not feasible such as some maintenance and repair activities, vessel cleaning, or other operations where engineering and work practice controls are infeasible because exposures are intermittent in nature and limited in duration;

(iii) In work situations where feasible engineering and work practice controls are not yet sufficient or are not required under paragraph (f)(1)(iii) of this section to reduce exposure to or below the PEL; and

(iv) In emergencies.

These limitations on the required use of respirators are consistent with the requirements of other OSHA health standards (e.g. asbestos, 1910.1001; ethylene oxide 1910.1047) and with good industrial hygiene practice. They reflect OSHA's determination, as detailed in the preceeding section on methods of compliance, that respirators are inherently less reliable than engineering and work practice controls. OSHA believes, therefore, that relying on respirators to control exposures to the PEL must be confined to the designated situations.

Many commenters gave their support for the use of respirators in work assignments, where benzene exposures are intermittent in nature and limited in duration. CMA (Ex. No. 258) strongly endorsed the proposed OSHA provisions permitting use of respirators in such cases and also where the use of engineering and work practice controls would be infeasible because of the nature of exposures and the impracticality of utilizing engineering controls. Other commenters who shared similar views were Exxon Company (Ex. No. 201–15), Phillips Petroleum Company (Ex. No. 201–18); and testimony of Margaret Seminario on behalf of the AFL–CIO (Ex. No. 204–9). See also discussion in the preceding section.

OSHA has concluded that if the permissible exposure levels for benzene are exceeded, and engineering and work practice controls are infeasible, employers must provide respirators as a secondary means of protection. However, the goal of the standard is the control of emissions at the source, which will minimize the need for routine use of respirators.

The final standard requires that whenever respirators are necessary to reduce employee exposure to or below the PEL, the employer must provide respirators at no cost to the employee. The standard requires the employer to select respirators in accordance with Table 1 (in the regulatory text) from those jointly approved by MSHA/NIOSH. The respirator selection table will enable the employer to provide the type of respirator which affords the proper degree of protection based on the airborne concentration of benzene. To comply with this requirement the employer must perform initial monitoring as described in paragraph (e)(2) to accurately determine the airborne concentration of benzene to which employees may be exposed. While the employer must select the appropriate respirator from the table on the basis of the airborne concentration of benzene, he may always select a respirator providing greater protection, that is, one prescribed for higher concentrations of benzene than present in his workplace.

For lower concentrations of benzene, OSHA proposes to permit the use of air purifying respirators provided that the filter element is replaced at the beginning of each work shift. Benzene has poor odor warning properties at low levels, and OSHA is aware that MSHA/NIOSH would not approve the use of air-purifying respirators in this situation because users would be unable to detect the benzene if breakthrough occurs. However, OSHA believes that filter elements of the type approved by MSHA/NIOSH for use with organic vapors would provide sufficient service life for the intended application as prescribed in Table 1 if replaced with the required frequency.

Adequate employee protection is achieved by the replacement of the filter element. To ensure that filter elements are changed in time, the employer is required to date the filter elements when

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they are installed in the respirators. Some contaminants absorbed on the sorbents of the cartridges or canisters tend to desorb upon storage. Consequently, immediate breakthrough can occur when the respirator is worn on the next day. Since the desorption characteristics of benzene on the sorbent are not known, multi-day use of filter elements is not permitted. If filter elements having end-of-service life indicators are developed and approved, the standard permits their use.

The final standard permits the use of any full facepiece powered air-purifying respirator (PAPR) with MSHA/NIOSH approved organic vapor canisters for exposures up to 100 ppm. The device contains a blower and a sorbent to purify the contaminated air to breathable air. In order to assure adequate canister capacity, OSHA requires that each organic vapor canister provide a minimum service life of 4 hours when it is tested at 25 C, 85% relative humidity, 64 liters per minute air flow and at the challenge concentration of 150 ppm benzene. The air flow will be 115 and 170 liters per minute respectively for tight and loose fitting powered air-purifying respirators.

Where employees are exposed to levels of benzene greater than 100 ppm, positive pressure atmosphere supplying respirators must be used. These respirators use uncontaminated air rather than mechanically cleaning the benzene contaminated atmosphere. OSHA allows only supplied air or SCBA's which operate in the positive-pressure mode because their performance is much better as facepiece leakage is minimal with positive pressure.

The standard permits employees to leave the regulated area to readjust the respirator facepiece to their faces for proper fit. It also permits them to leave the regulated area to wash their faces to avoid potential skin-irritation associated with respirator use.

The employer is also required to assure that the respirator assigned will fit properly. Proper fit of the respirator is essential to the performance of negative pressure air purifying respirators. As a negative pressure is created within the facepiece when the wearer breathes, unfiltered benzene contaminated air may enter the facepiece if gaps exist in the facepiece seal.

Obtaining a proper respirator fit on each employee may require the employer to provide two or three different mask sizes from several manufacturers to select the facepiece with the best fit (least leakage around the faceseal). A properly fitted facepiece will reduce the inhalation leakage to a minimum. Fit testing is especially important for benzene because of benzene's poor odor warning qualities at the level set by the standard. An employer must not permit or direct an employee to enter an area where exposures are over the PFL, or if the fit tests indicate a respirator is not providing a proper fit.

OSHA is permitting the employer to choose either quantitative or qualitative fit testing to add to the performance orientation of the standard and permit the employer to tailor the testing to the circumstances of the employer's establishment. Protocols for the type of testing the employer chooses are set forth in Appendix E.

Quantitative fit testing is a procedure whereby the level of penetration of a test agent of a known concentration is measured inside the facepiece of the respirator. Quantitative respirator fit testing is generally recognized as the better method for determining how well a respirator fits any one individual. It allows the employer to continue testing until the optimum or best fitting respirator is identified and selected for the employee. Quantitative fit testing requires the use of moderately sophisticated testing equipment and is more expensive than qualitative fit testing to perform.

Qualitative fit testing is a technique whereby a person wearing a respirator is tested to see whether a test agent with a low odor threshold can be detected inside the respirator. Qualitative fit testing is a more subjective test than quantitative testing because it depends on the individuals ability to detect the test agent but if performed right can be reliable.

OSHA believes that while quantitative fit testing may have some advantages, qualitative testing which is conducted in accordance with the protocols described in Appendix E accomplishes the intent of the standard to assure that each employee receives and wears the respirator which provides an appropriate level of protection.

Several commenters such as CMA suggested that OSHA's qualitative fit test protocols were too complex and suggested alternatives. OSHA greatly appreciates the time and effort which went into the comments. However, OSHA will shortly be issuing a proposal to amend 1910.134 the respirator program section. OSHA believes that rulemaking is a better forum to concentrate on this relatively narrow and technical issue. OSHA will reconsider the issue in that rulemaking and if appropriate adopt their suggestions then for benzene. For now, OSHA has decided it is appropriate to adopt a more detailed protocol which it knows is protective enough. OSHA has made some changes in the protocol to clarify and simplify it however.

All employees who wear respirators more than 30 days per year must receive as part of the medical surveillance program a pulmonary function test and a cardiopulmonary examination. Respirator usage presents an additional burden to the pulmonary system of the employee. This burden may result in symptoms such as shortness of breath, chest pain, dizziness or fatigue. All of these symptoms may be exacerbated by pre-existing lung disease such as chronic bronchitis, emphysema, asthma or pneumoconiosis. It is, therefore, important that all employees who will be wearing respirators more than a minimal number of times be medically screened to determine fitness for respirator usage.

From past experience, OSHA is aware of the problems of respirator use as the primary means of exposure control. Proper facial fit is essential, but variations in individual facial dimensions, as well as facial hair, scars or growths, make it difficult to maintain this facial fit. Fatigue and reduced efficiency may occur because of increased breathing resistance when negative-pressure respirators are used. Additionally, heat stress, reduced vision, and other safety problems presented by respirators should be considered by the employer. Visual impairment could pose a significant problem where physical hazards exist and the ability to see is important. Speech is also limited by respirator use. Voice transmission through a respirator can be difficult, annoying, and fatiguing, and communication may make the difference between a safe and efficient operation and a hazardous operation, especially in dangerous jobs.

OSHA does not presently believe that respirators should be considered the primary means of employee health protection against exposure to benzene for activities where engineering controls are feasible. However, despite these problems OSHA has concluded that if the permissible exposure level for benzene is exceeded, employers must provide respiratory protection as a supplementary means of protection. However, the goal of the standard is the control of emissions using engineering and work practice controls which will minimize the need for routine use of respirators.

A good respirator program is needed so that respirators will provide sufficient protection. The employee must be properly trained to wear the respirator,

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to know why the respirator is needed, and to understand the limitations of the respirators. An understanding of the hazards involved is necessary to enable the employee to take steps for his or her own protection. Accordingly, the employer must implement a respiratory protection program meeting the requirements of 29 CFR 1910.134(b), (d), (e) and (f) as well. That section contains basic requirements for proper selection, fit, use, cleaning and maintenance of respirators.

OSHA is currently developing a proposed rule to amend its generic respiratory protection standard at 1910.134. When this rule is finalized, OSHA intends to amend the respiratory protection requirements in its other standards in order to make them as consistent as possible with 1910.134. Commenters to this record may wish to also provide comments to the record for the respiratory protection standard.

H. *Protective Clothing and Equipment: Paragraph (h).* The requirement for the employer to provide protective clothing and equipment at no cost to the employee and to assure its use where appropriate to prevent eye contact and limit dermal exposure to liquid benzene has been retained in the final rule. Eye and face protection is to meet the requirements of OSHA's provision at 29 CFR 1910.133, "Eye and face protection." Protective clothing and equipment is to be used as necessary to protect employees during their particular work experiences from exposure to benzene, including, where appropriate, such items as face shields, gloves, aprons, coveralls, or footwear.

As discussed in the preamble to the proposed rule, the requirements for this section differ from the final standard for benzene (1978) in that personal protective equipment is now required "where appropriate to limit dermal exposure to liquid benzene." Previously, "impermeable protective clothing and equipment" had been specified. Dermal contact is to be "limited," and obviously, prevented where possible. The language of the final rule is performance-oriented to allow the employer sufficient flexibility to provide the protective equipment for dermal exposure which will be necessary to protect employees in their particular work situations. Eye contact, however, is to be prevented. Employers closely following the provisions of § 1910.133 and providing appropriate protective equipment when required can be reasonably assured of meeting this goal.

OSHA did not receive comments generally questioning the feasibility of the protective clothing and equipment requirements of the standard. However, as discussed in the proposed rule, representatives of the tire manufacturing industry stated that tire builders cannot use gloves in their assigned tasks since gloves interfere with tire production and can partially dissolve becoming sticky or tacky when exposed to benzene-containing solvent. The dissolution of gloves during these situations can create a safety hazard, since a worker's hand could become stuck to a rotating unfinished tire. Furthermore, the industry stated that manual contact with the rubber on each ply of the tire is necessary for positioning the rubber plies on the drum and for ensuring complete adhesion between plies or between plies and tire treads. Representatives of the United Rubber Workers Union agreed with this analysis. Tire manufacturers may comply with the dermal exposure limitations of this section without requiring gloves by complying with the standard's percentage exclusion using solvents with very low percentages of benzene contamination as specified by paragraph (a)(2)(v). This provision was agreed to by both industry and union representatives. As a general statement, however, direct skin contact with hydrocarbon solvents is in general not a good idea and should be avoided wherever possible. Since benzene is absorbed through the skin, gloves and other protective clothing are to be used to prevent or limit contact with liquids containing benzene over the percentage exclusion.

The requirement to provide and ensure the use of personal protective clothing and equipment when working with benzene generally met with approval by commentors on the proposed rule. This approach is performance-oriented. It requires the employer to consider each of the processes of his workplace where employees may have eye or dermal contact with liquid benzene and then implement the most efficient means to achieve the goal of the standard. The provision is not intended to allow the employee to come into regular contact with benzene or benzene contaminated substances.

The Public Citizen Health Research Group, in its comments on the proposed standard (Ex. 201–41) felt that the types of protective clothing required by the standard should be specified, and that the requirement as written was "unreasonably vague in light of the rapidly growing body of data on the disparate permeabilities of different protective clothing materials." OSHA believes that by retaining performance language for the use of protective clothing employers have more flexibility to utilize new and improved clothing and equipment as they are developed.

Public Citizen also suggested that OSHA "specify suitable protective clothing based on specific chemical/material permeation tests under actual condition of use, e.g. temperature, flexing, or bending." The protection provided by protective clothing does vary upon its conditions of use, and it is these very conditions that differ between workplace and worker and situation of use. OSHA does not have data available to specify suitable tests.

While OSHA's performance-oriented approach grants an employer flexibility to achieve the goal of minimizing benzene contact, it does not allow him to allow employee to come into regular contact with benzene, especially when it can be avoided. Contact is to be minimized to the extent possible and prohibited where possible. A conscientious approach to this requirement by the prudent employer would be the constant upgrading of the protective clothing and equipment in use at his establishment in order to meet the intent of the standard by the best available means, and, as always, to avoid contact with liquid benzene or solution containing it wherever possible.

I. *Medical Surveillance: Paragraph (i)*

Where appropriate, medical surveillance programs are required by section 6(b)(7) of the OSH Act, to be included in OSHA health standards to aid in determining whether the health of workers is adversely affected by exposure to toxic substances. The requirements contained in this final benzene standard are designed to detect changes in the hematopoietic system resulting from occupational exposure to benzene. Although most of the medical surveillance provisions remain the same as the proposal, several changes have been made. These changes include: enlarging the scope to include employees involved in tire building (tire building machine operations) who use solvents containing greater than 0.1 percent benzene; requiring the periodic physical examination to be administered annually instead of semi-annually; requiring all laboratory work be conducted in an *accredited* laboratory; deleting the requirements for chest X-rays in the initial examination and thereafter; removing the numerical definition of normal red cell blood parameters and substituting the more suitable *normal limits* as established by accredited laboratories and changing the emergency examination to require immediate blood counts after the exposure and then follow-up monthly blood counts for a duration of three

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months. In addition, the Agency has expanded the medical removal paragraph to include a provision for wage rate retention. In other respects, the medical surveillance requirements parallel the proposed standard's provisions except where editorial changes have been added to clarify the Agency's intent.

The purpose of medical surveillance is the prevention or detection of abnormalities which may occur in some benzene exposed workers early enough to prevent further deleterious health effects. The risk assessment indicates that there is a quantified increased incidence of leukemia. The survey of the literature indicates that cytopenias and aplastic anemias also may occur. For these reasons, OSHA considers regular medical surveillance for benzene workers exposed at or above the action level to be necessary. In addition, there will be a number of workers who have an increased risk of developing leukemia as a result of past exposures to concentrations above 10 ppm, and these workers also need medical surveillance.

Yandl's submission to the 1977 benzene hearings reviews a number of papers which indicate that removal from exposure will in most cases result in reversal of cytopenias and a high percentage of aplasias. There is also evidence from Legge, Hunter, Hamilton and Vigliani that progressive reductions in benzene exposures have resulted in a reduction in the number of cases of benzene hemopathy, including leukemia. However, direct observation of the reduction in cases of leukemia following reduction in exposure is less easy to quantify than other effects on the blood, principally because most studies have not had a continuous follow-up for more than 10 years subsequent to reduction or elimination of benzene exposures (Hernberg; Vigliani; Ex. Nos. 159–36; 128–15).

With very few exceptions, interested parties who submitted written comments to the record and those who testified at the hearings generally supported the concept of medical surveillance even though they disagreed on specific provisions. Dr. Daniel T. Teitelbaum, testifying for OSHA, stated that "medical surveillance * * * is based on sound medical practice" (Ex. No. 221, p. 18). Dr. Bernard Goldstein, testifying for the American Petroleum Institute (API), recommended medical screening for workers exposed to 1 ppm (Tr. 3/26/86, pp. 162, 176). The American Iron and Steel Institute (AISI) commented that OSHA had identified the appropriate elements for examinations and laboratory tests for workers above the PEL (Ex. Nos. 201–44, p. 53; 259, p. 44). The Chemical Manufacturers Association (CMA) noted in their brief that they had previously determined the medical surveillance provisions to be well conceived over all (Ex. No. 258, p. 137). CITGO commented that an "annual examination coupled with emergency examinations as required by the standard are adequate to detect any significant impairment from benzene exposure" (Ex. No. 201–14, p. 4).

Some opposition to medical surveillance came from Dr. John M. Bennett testifying for API, who stated: "there are no current technologies available to take advantage of a possible benefit from early detection of adverse effects at present day exposure levels" (Ex. No. 260, p. 33d, Tr. 3/26/86, p. 176). Dr. Bennett recommended a prospective laboratory screening program be instituted to identify early indicators of marrow injury and generate data on the effectiveness of a medical screening program (Tr. 3/26/86, p. 129). OSHA agrees with Dr. Bennett that further research to define benzene effects is important, but the Agency is convinced the current evidence supports a need for medical surveillance at this time. OSHA concludes from the evidence reviewed that the medical surveillance in this final standard is both appropriate and essential.

The specific aims of medical surveillance were summarized in the proposal as follows:

1. Early detection and reversal of cytopenias and aplasias.

2. The prevention of some leukemias by reducing dose to the more susceptible workers.

3. Early recognition and treatment of those cases of leukemia which might occur and improvement in remission rate and duration.

4. Better evidence of the effectiveness of the proposed standard.

At the hearings, a number of physicians addressed these aims. As noted above, OSHA's expert witness, Dr. Teitelbaum stated in his submitted testimony that using "medical surveillance for these ends is based on sound medical practice" (Ex. No. 221, p. 18). NIOSH testified that "* * * medical surveillance may enhance worker protection." NIOSH further stated that "the program should be designed so that it accomplishes the goal of identifying exposed populations and giving early indications of potential disease thereby allowing intervention" (Tr. 3/20/86, p. 17). Dr. Bennett questioned the medical surveillance aims on the basis of his belief that is not possible to make a judgment on whether universal blood screening for benzene exposed workers will yield substantial benefits; nor did he believe early diagnosis substantially improved the prognosis for patients who develop leukemia. Additionally, Dr. Bennett did not think benzene-included cytopenias or aplasias would be found in workers exposed below 10 ppm (Ex. No. 260, p. 34d). Although Dr. Goldstein recommended medical screening for workers exposed at 1 ppm (Tr. 3/26/86, p. 162), he later qualified that statement, under questioning by API, to the effect that if he were certain the workers were only exposed to 1 ppm there would be no need for the program (Tr. 3/26/86, p. 167). Representatives of labor groups generally supported these aims. (e.g. Tr. 3/25/86, p. 72; p. 85).

The Agency believes the evidence in the record suggests these aims represent appropriate targets for the medical surveillance program. In addition to expert opinion that does support these aims, OSHA believes the gravity of the diseases caused by benzene is a further reason for the Agency to require affected industries to institute a medical surveillance program designed to meet multiple targets. Moreover, the Agency is persuaded that a comprehensive approach to these aims is further justified by the fact that current knowledge of these diseases is far from complete and methods of detection and treatment continue to evolve.

It is known that cytopenias and aplasias can be treated and reversed. Therefore, detecting cytopenias or aplasias due to exposure to benzene at a stage when these conditions are reversible and treatable and reducing or eliminating further benzene exposure will result in improved prognosis for workers who develop these conditions. This is sufficient evidence by itself to support a medical surveillance program.

It is recognized that as a result of medical surveillance some individuals may be removed for blood dyscrasis such as cytopenias and aplasias not due to benzene exposure, but since these individuals may have compromised bone marrow function, their removal from benzene exposure may prevent the progression of such disease.

The second aim, the prevention of some leukemias by reducing dose to the more susceptible workers, is still subject to scientific dispute, but it is certainly consistent with a reasonable interpretation of some of the expert opinion expressed to OSHA and embodied in the literature. The same can be said for the third aim of early detection resulting in possible remission

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and/or increased survival time for those who have already developed leukemia. This, too, is one of those gray areas of medicine where it is not known for certain if early detection (and treatment) improves prognosis, but some types of leukemia have a better prognosis and all physicians recommend this for their patients.

Finally, medical surveillance for all workers exposed to benzene above the action level will provide more comprehensive information on the effectiveness of the proposed standard in reducing disease than has previously been possible.

The benzene proposal referenced salient papers in the medical literature and opinions of scientific and regulatory bodies which have a special bearing on medical surveillance (Ex. Nos. 2–3; 128–59; 126; 159–105) and presented additional opinions in standard medical and hematological textbooks to explain the reasons for the tests specified and their frequency. The information reflected a consensus of the vast majority of the medical community and forms a basis for the expected toxicity and illness which a medical surveillance program must target for prevention or detection.

The large volume of published medical literature on benzene toxicity unequivocally establishes that chronic exposure to this chemcial is causally associated most commonly with actute myelocytic leukemia (AML) and its variants, as well as aplastic anemia and varied combinations of suppression of the erythrocyte count (anemia) and/or the leukocyte cell count (leukopenia) and/or the thrombocyte count (thrombocytopenia). When all of these cell counts are below normal the condition is designated as pancytopenia. Benzene has also been associated to a lesser degree with other hematologic disorders, including chronic myelogenous leukemia, acute and chronic lymphatic leukemia, multiple myeloma, paroxysmal nocturnal hemoglobinuria (PNU) and various forms of lymphoma including Hodgkins disease.

Cecils's Textbook of Medicine (Ex. No. 159–105) states that:

> Workers exposed to benzene have an increased risk of acute myelogenous leukemia (AML). In these patients, bone marrow hypoplasia and/or pancytopenia often precede the diagnosis of leukemia.

Harrison's Principles of Medicine (Ex. No. 159–82) states:

> By far the most important manifestation of chronic exposure to benzene is bone marrow depression, which may progress to aplastic anemia and complete aplasia of the bone marrow. Individual susceptibility to this affect varies greatly and may not become apparent for months after the initial exposure of the poison.

In Cancer Medicine 1982 (Ex. No. 159–26), it is stated that:

> The drugs implicated in leukemogens are all known to cause bone marrow depression and/or aplasia. The only compound with an unequivocal relationship to AML is benzol [benzene]. Exposure to benzol sometimes seemingly trivial, has been followed by the development of AML with or without the clinically recognized intermediate steps of aplastic anemia, other cytopenias, myelofibrosis or myeloid metaplasia.

Wintrobe's textbook (Ex. No. 159–102) states:

> A variety of chemcials and drugs have been suggested as possible leukemogenic agents in human leukemia, but only benzene can be unequivocally implicated. Disturbances of the hematopoietic system, especially marrow aplasia with pancytopenia, in workers chronically exposed to benzene, have been recognized for many years. The overwhelming predominance of AML or closely related syndromes, often preceded by periods of aplasia with pancytopenia in such workers, provides compelling evidence for an etiologic relationship.

Wintrobe further states:

> Benzene has been known as a cause of fatal aplastic anemia since Santesson's description (1897) of 4 cases in workers in a bicycle tire factory * * * the classic picture of leukopenia, thrombocytopenia, and poisoning by benzene. Among exposed workers the most common abnormality reported was anemia (48 percent). Next in frequency was macrocytosis (47 percent), thrombocytopenia (33 percent) and leukopenia (15 percent).

Wintrobe adds:

> There are great variations in susceptibility to benzene poisoning. Evidence of poisoning may appear in a few weeks or only after many years of exposure, or it may not be discovered until the onset of infection long after exposure has ceased. Any degree of exposure is potentially dangerous.

The information cited establishes those medical conditions which a surveillance program for benzene exposed employees must be designed to prevent or detect. The screening test for that purpose is a complete blood count (CBC) including platelet count, white blood cell differential, white blood cell count, red blood cell count, hemoglobin, hematocrit and red cell indices. From the information cited above, it seems reasonable to conclude that early detection of a dose related marrow suppression and removal from benzene exposure may prevent the progression to a more serious disease such as aplastic anemia or leukemia.

Because case recognition by routine monitoring may not necessarily detect leukemia before the clinical manifestations appear, OSHA believes that any individual who develops early signs and symptoms of leukemia, such as fatigue, bruising, bleeding or any other symptoms which might be attributable to benzene exposure should consult the physician who normally carries out routine surveillance as soon as possible.

General Provisions

As in the proposed standard, this final rule requires medical surveillance be provided to employees who are or may be exposed to benzene at or above the action level 30 or more days per year, employees who are or may be exposed to benzene at or above the PEL 10 or more days per year, employees who have been exposed to more than 10 ppm of benzene for 30 or more days in a year prior to the effective date of the standard when employed by their current employer, and employees who have been exposed to an emergency situation 1910.128(i)(1)(i)). In addition, OSHA is including employees involved in tire building operations called tire building machine operators, who utilize solvents containing greater than 0.1 percent benzene to the medical surveillance coverage.

Several commenters raised questions about the scope of medical surveillance. Some, like the AFL–CIO and USW in their post-hearing brief, recommended coverage be expanded to require employers to make medical surveillance available to former employees after they leave employment (Ex. No. 260, p. 46). Dr. Goldstein commented that workers previously exposed to air levels higher than 10 ppm benzene should have their blood examined when the new standard is promulgated (Ex. No. 159–106).

Dr. Parkinson, testifying for USW, expressed concern that the OSHA standard did not provide for continuing medical surveillance for workers who leave their jobs (Tr. 3/25/86, p. 84). Mary-Win O'Brien, an attorney for USW, agreed with this concern, and cited OSHA's coke oven standard to show that the Agency has in the past required medical surviellance for employees whose exposure was not immediate, in the case of coke oven employees for as long as an employee remains employed with that employer. She also cited OSHA's Hazard Communication Standard to show that the Agency has regulated outside the employer/employee relationship, since that standard requires manufacturers to

provide information to downstream employers (Tr. 3/25/86, pp. 86–87).

Other commenters, primarily industry trade associations, favored a narrower scope. AISI argued that medical surveillance should be limited to those employees whose current occupational exposures exceed the PEL for 30 or more days per year or who are inadvertently exposed to high concentrations of benzene in the event of an emergency (Ex. No. 259, p. 44). CMA supported providing medical surveillance to all employees that OSHA proposed covering except "employees (much less former employees) who are not currently exposed to benzene simply because they were exposed to benzene in the past (e.g., exposed to more than 10 ppm * * * for more than 30 days in a prior year)" (Ex. No. 258, p. 137).

API questioned OSHA's proposed requirement to include previously exposed workers on what they suggested were: (1) the dubious value of medical surveillance generally, (2) the unlikelihood of finding any marrow suppression because the low 10 ppm standard had been in effect for 15 years, and (3) the difficulty and burdens (time and expense) of estimating past exposure (Ex. No. 260, pp. 36d–38d). API also objected to post-employment examinations on the bases of their belief that the (1) benefits of medical surveillance are doubtful, (2) OSHA does not possess the statutory authority to require employers provide post-employment examinations and (3) the impracticality or infeasibility of this requirement (Ex. No. 260, pp. 39d–46d). API stated that the most OSHA should consider * * * is * * * [to require] the . . . physician to *consider* whether to advise particular employees to continue receiving regular medical check-ups and hematologic tests after they have left the job. (Ex. No. 260, p. 46d)).

Nearly all commenters supported medical surveillance for employees who have been exposed during an emergency situation.

In addition to the workers OSHA proposed to include in medical surveillance, the Agency is adding employees involved in hand tire building operations who are called "tire building machine operators" who utilize solvents containing greater than 0.1 percent benzene, because they cannot decrease their dermal exposure to benzene by wearing gloves or using barrier creams. These workers are being included in medical surveillance in the final standard because the combined exposures they receive from dermal absorption and inhalation may equal the exposure of other workers who will be receiving medical surveillance.

A NIOSH study of benzene absorption in hairless mice indicated approximately 1 percent of applied benzene was absorbed through the skin whether undiluted benzene or 0.5 percent benzene in rubber solvent was applied to the skin (Ex. No. 252–17–78). On the basis of this study, NIOSH estimated that workers building 150 tires a day could absorb approximately 6 mg. of benzene a day through intact skin. The 6 mg. is similar to the 7 mg. of benzene that would be absorbed by a worker whose exposure was due to inhaling 0.5 ppm over an 8-hour day.

NIOSH also indicated that workers building tires frequently had cracked and fissured skin. To estimate the possible effects of cracked skin on the total benzene absorbed, Professor Maibach applied solvents containing benzene to patches of stripped skin of rhesus monkeys (Ex. No. 134–2b). The amount absorbed through the stripped skin was 5.3 times greater than the amount absorbed through intact skin. When the increased rate of exposure to benzene due to its absorption through cracked or fissured skin is applied to the previous study results by NIOSH, absorptions totaled 32 mg. (6 mg. x 5.3) per day for workers using solvents containing 0.5 percent benzene, and 16.2 mg. a day for workers using solvents containing 0.25 percent benzene. Both of these absorption figures exceed the comparable figure of 14 mg. of benzene that a worker inhaling 1 ppm over an 8-hour day could be expected to absorb. Indeed, the use of a solvent containing more than 0.1 percent benzene will result in a potential for benzene skin absorption equal to or above the amount taken into the body through the inhalation of 0.5 ppm benzene, the action level above which medical surveillance is required.

The Rubber Manufacturers Association (RMA), supported exemption of workers utilizing benzene solvents with less than 0.5 percent benzene concentration initially, later falling to 0.1%. They argued that employees using such liquids are not exposed to atmospheric levels posing demonstrated health risks. RMA estimated that since benzene content has been decreasing steadily since 1978, 99 percent of airborne samples would show levels below the proposed 1 ppm permissible exposure limit (Ex. No. 257, p. 4). They therefore argued that in most instances airborne exposure would be below permissible exposure levels and medical surveillance is not appropriate. However, this argument does not take into account the increased exposures from dermal absorption.

Because tire builders using solvents with more than 0.1% benzene are exposed to combined dermal and airborne exposures about equal to workers who receive medical examination, OSHA is providing them with medical examinations. Since the percentage content of benzene in rubber solvent necessary to bring the tire builders within the scope of this final standard is being reduced to 0.1 percent over the years following promulgation of the standards, OSHA anticipates that the tire building operations will switch to solvents containing less than 0.1 percent benzene as soon as possible, thereby making medical surveillance for the tire builders likely to be a short-term proposition.

OSHA has considered all the evidence in the record on the issue of the appropriate scope of medical surveillance. Some comments have recommended expanding or restricting the groups of workers to be covered, while others supported the coverage OSHA proposed. The Agency believes its coverage is both reasonably related to achieving medical benefits and is administratively practical. For example, including employees exposed above the action level for 30 days and those exposed above the PEL for 10 days insures that employees, for whom medical surveillance will be of most benefit, receive it. At the same time, the duration of exposure trigger enables employees to avoid spending valuable medical surveillance resources on workers with very low exposures, thereby allowing these resources to be properly focused on the workers with higher exposures. Covering employees who have been exposed to more than 1 ppm for 30 or more days in a year prior to the effective date of standard when employed by their current employers strikes a balance between the need to extend medical surveillance to workers with high exposures in the past and the administrative difficulty of keeping in touch with former employees who may well have moved on to other jobs at far away locations. The provision is a reasonable and administratively convenient way to provide benefits to these workers.

In order to effectuate the major purpose of the medical surveillance, the prevention or detection of hematological abnormalities which may occur in workers exposed to benzene, the Agency finds the coverage as stated in paragraph (i)(1)(i) adequately protects workers at risk from occupational exposure to benzene. The employees OSHA proposed to cover and the tire builders are the workers at greatest risk

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of adverse health effects. Moreover, employees at greatest risk are most likely to benefit from the medical surveillance provisions.

For all the above cited reasons, OSHA believes its coverage will most adequately protect workers.

The final standard requires all medical examinations and procedures to be performed by or under the supervision of a licensed physician and to be provided without cost to the employee (paragraphs (i)(1) (ii) and (iv)). Clearly, a licensed physician is the appropriate person to supervise and evaluate a medical examination. However, certain parts of the required examination do not necessarily require the physician's expertise and these may be conducted by other suitably qualified health care personnel under the supervision of the physician.

OSHA has also added the requirement that examinations be provided without cost to the employee, and at a reasonable time and place," paragraph (i)(1)(iv). Dr. Parkinson testified that he had seen many situations where the worker was expected to drive 15 miles on his off-duty time in order to consult with the physician because the physician never visited the plant (Tr., 3/25/86, p. 82). In order for the health benefits to accrue to the employees, the examinations must be convenient to them and the above requirements insure that they will be. Moreover, OSHA has included this provision in other standards, e.g. EtO, 49 FR 25798 and Asbestos, 51 FR 22737.

OSHA is adding the requirement at paragraph (i)(1)(ii) that all laboratory work be performed by an accredited laboratory. Dr. Teitelbaum pointed out in his statement that accreditation by a national accrediting body or its state equivalent means that the laboratory has participated in a recognized quality assurance program. This, Dr. Teitelbaum wrote, tends to assure long-term stability, allowing assessment of population trends and trends in the individual benzene worker (Ex. No. 221, pp. 26, 27). Dr. Parkinson supported this position (Tr. 3/25/86, p. 79). Dr. Teitelbaum further stated that adding this requirement will not significantly increase the cost of any test since the laboratories currently performing most of these analyses are appropriately accredited (Ex. No. 221, p. 27). No commenters opposed this recommendation. OSHA agrees that it is important that laboratories performing the tests be accredited and accordingly has added the requirements in performance language.

Since there are several nationally recognized accreditation programs, such as those of the American College of Pathologists and the Joint Commission for Accreditation of Hospitals, OSHA is not requiring a laboratory to be accredited by a particular organization. Successful completion of the accreditation process will assure that the laboratory has demonstrated consistently acceptable results in a proficiency testing program.

Similarily, in order to assure the pulmonary function tests are correctly administered, the Agency has added a requirement at paragraph (i)(1)(iii) that " * * * *persons other than licensed* physicians, who administer the pulmonary function test * * * shall complete a training course in spirometry sponsored by an appropriate governmental, academic or professional institution." This provision is consistent with OSHA's recently promulgated standard for cotton dust (50 FR 51220).

The medical surveillance program can be divided into four distinct categories: the initial examination, the periodic examination, the additional examination when blood conditions are abnormal and the surveillance examination requirements following an emergency exposure to benzene. OSHA believes that adherence to the requirements of the medical surveillance program will enable the physician to detect adverse health effects of benzene exposure at an early and therefore sometimes correctable stage, and will aid in determining whether an individual can wear a respirator.

Initial examination. Consistent with OSHA's proposal, the initial examination is to include a detailed occupational and medical history, complete physical examination and pertinent laboratory evaluation. The following areas are to be covered:

Occupational history. Any past exposure to chemicals known to adversely affect the bone marrow or any past hematologic abnormalities which are potentially work-related should be recorded, as well as details of any exposure to radiation.

Medical history. Any past illness or abnormality of the hematopoietic system should be carefully evaluated. Any medications with adverse effects which impact on the hematologic system should be carefully noted. Smoking habits and hobbies should be recorded.

A complete physical examination of all systems. Laboratory evaluation. A complete blood count, including a thrombocyte count, erythrocyte count, a leukocyte count with differential, hematocrit, hemoglobin and erythrocyte indices must be performed. Any additional tests as necesary in the opinion of the examining physician shall also be administered.

For workers who may wear a respirator for more than 30 days in a year, the initial examination also includes:

A thorough history of the cardio-pulmonary system should be noted. Aspirometric test of pulmonary function shall be performed. The spirometry shall be consistent with the recommendation of the American Thoracic Society, and include at a minimum a forced vital capacity (FVC) and a forced expiratory volume at 1 second (FEV_1). The test shall be carried out by a physician or by a qualified technician. It should be kept in mind that normal values for spirometric tests in blacks can be lower than those for the general population (Ex. Nos. 159–49, 159–107).

The purposes of the initial medical examinations are: (1) establish the current health status of an employee and whether employment in areas with benzene exposure is appropriate, (2) to determine adverse health effects resulting from previous exposures to benzene or other chemicals, or radiation, (3) to provide a baseline against which future occupational health examination results may be measured, and (4) to determine whether the individual can safely wear a respirator. OSHA believes that the described examination will elicit the appropriate information to assess the worker's initial health condition and allow for effective medical monitoring.

The detailed medical history will aid the physician in interpreting the results of the tests. The baseline blood count is especially important. First, individual counts vary and knowing the individual baseline allows the physician to more precisely monitor changes which may result from benzene exposures. Secondly, most of the employees monitored will have had prior benzene exposures, many at levels higher than the new PEL. The intial count will provide information for the physician to base a recommendation on whether further benzene exposure is appropriate. Dr. Goldstein testified that he thought routine complete blood counts were of value for asymptomatic workers with benzene exposure and that platelet counts should be included (Tr. 3/26/86, p. 159).

OSHA specifically sought comment on whether a peripheral blood smear and reticulocyte count should be required. Dr. Goldstein testified that he would recommend a reticulocyte count on initial screening as a baseline, but would not include the test as part of routine screening. Regarding the

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peripheral blood smear, Dr. Goldstein stated he would want to have a blood smear available or be able to obtain one rapidly (Tr. 3/26/86 p. 166–167). This would be for follow-up of any abnormalities detected on initial screening.

Dr. Bennett did not believe in the need for a reticulocyte count and a peripheral blood smear in routine surveillance since they are not included in routine laboratory blood screenings. Moreover, regarding the reticulocyte count, he testified that "the range of normal is between 0.4 and 1.5 percent and therefore it allows for a fair amount of error" (Tr. 3/26/86, pp. 131, 132).

Although Dr. Teitelbaum supported including a reticulocyte count and a peripheral smear in the laboratory evaluation, he acknowledged the difficulty in preparation and analyses of the specimen. It was his opinion that including these tests would require some retraining of the medical community and close supervision of testing by a qualified hematologist or pathologist (Ex. No. 221, pp. 24–26).

In view of the evidence, OSHA does not consider the peripheral blood smear and the reticulocyte count to be necessary components of medical surveillance for benzene exposure. Transportation and storage problems for these tests, coupled with the complexity of preparation and interpretation of results, suggest the decision regarding whether to carry out a reticulocyte count and a blood smear is best left to the examining physician (See Appendix C for further discussion of these tests).

Many commenters addressed the requirement in the proposal that employees who wear respirators more than 30 days per year have a chest x-ray in the initial examination and then every 5 years thereafter. Most of the commenters stressed the independent health risks and questionable benefits presented by the ex-rays (e.g., Ex. No. 260, pp. 49d; Ex. No. 201–16, p. 3; Ex. No. 201–13; p. 6; Ex. No. 255D, p. 3). Dr. Parkinson testified at the hearing that he would leave the question of the frequency of chest x-rays up to the discretion of the individual physician (Tr. 3/25/86, p. 78). OSHA agrees with the commenters that the examining physician is in the best position to determine whether the benefits of this technique would outweigh any risks to an employee. Therefore, OSHA has deleted the requirement for a chest x-ray from both the initial and the periodic examinations.

During the physicial examination for employees who may be required to wear a respirator, special attention should be given to the eyes (contact lenses or spectacle wearing may interfere with the effectiveness of a full face mask respirator or half mask respirator); ears (perforated tympanic membranes), facial contour (respirator fit); skin (facial irritation from respirators) and cardio-pulmonary system.

The pulmonary function test (PFT), required as a baseline procedure, is to assure that those employees who are required to wear a negative pressure respirator are not compromised by a pulmonary deficit that has not been detected by regular clinical examinations. The pulmonary function test will detect obstructive and restictive pulmonary disease.

In addition, the physician should consider if, in his or her opinion, it is necessary to evaluate the worker's ability to wear a respirator during a simulation of the physicial stresses of the actual work environment, and consider whether additional laboratory tests such as an electrocardiogram, single breath diffusing capacity or other pulmonary function tests are necessary.

Periodic Examination: OSHA proposed periodic medical examinations to be administered twice yearly in order to detect, at an early stage, the pathological changes that could lead to the more serious diseases caused or aggravated by benzene exposure. By detecting abnormalities early, workers may be removed from further benzene exposure. These measures could prevent significant morbidity and may improve prognosis in individual cases.

OSHA's preliminary determination that examinations should be given twice each year was based upon the fact that the serious diseases associated with benzene exposure can develop rapidly and therefore relatively frequent examinations at appropriate intervals are necessary to institute removal and so avoid exposure to a greater total dose.

There were a number of comments on the frequency of periodic examinations. CMA suggested that since, in its view, medical surveillance had "limited usefulness" and that the counseling of employees could be done as effectively with less frequency, the appropriate frequency for periodic examinations is annually. (Ex. No. 258, pp. 147–149) API agreed (Ex. No. 260, pp. 33d, 35d). API further noted that where voluntary medical programs are in place, they generally provide for annual examinations (Ex. No. 260, pp. 35d).

On the other hand, Dr. Goldstein testified that he anticipated twice-yearly medical and/or laboratory examinations would have a higher yield of true hematologic problems when compared to yearly examinations (Tr. 3/26/86, p. 128). Lori Abrams of the Public Citizen Health Research Group recommended blood testing four times per year in order to catch blood disorders that develop rapidly (Tr. 3/20/86, pp. 119–120).

After considering all of the above recommendations, the Agency has decided to require the periodic medical examinations be given annually rather than semi-annually. The tests that make up the parts of the medical examination are useful, but they could never be administered often enough to discover all the blood abnormalities as they occur. Consequently, a reasonable period must be chosen. The practice of the medical profession of yearly exams in industry now provides a reasonable basis for judgment. OSHA is persuaded that examinations given on a yearly basis will provide the appropriate protection for workers. The Agency believes the yearly examinations will be almost as likely to pick up blood abnormalities as the semi-annual examinations. Finally, OSHA agrees with commenters that the Agency's second goal for periodic examinations, employee questioning and counseling, can be accomplished on a yearly basis as well as on a semi-annual basis.

OSHA's proposed periodic medical re-evaluation of workers required to wear respirators is being carried forth in this final standard. The evaluation is necessary because the development of an illness or the use of a new medication which may affect the cardiovascular system must be assessed for its possible bearing on respirator wearing. This will enable the physician to determine whether the individual can safely continue to wear the respirator or whether the employee should be fitted with another type or removed from any area for which a respirator may be necessary.

As proposed, pulmonary function tests need not be repeated on an annual basis since little additional information is likely to be derived from such practice. However, repetition following a three year period is required because retesting as that frequency will provide reasonable assurance that the worker who must wear a respirator has not developed some significant pulmonary disability over the preceeding three years.

Dr. Teitelbaum testified that PFTs should be performed initially to provide a baseline and annually thereafter in order to find out when a worker's pulmonary function deteriorates before the deterioration places a worker in a life-threatening situation (Tr. 3/24/86, pp. 5, 48). On the other hand, Dr.

Parkinson testified that the three year interval was appropriate (Tr. 3/25/86, p. 146). CMA, in their comments, also endorsed the three year interval (Ex. pp. 139–142). OSHA agrees with Dr. Parkinson and CMA and has therefore concluded that the proposed frequency provides adequate protection. However, as with all components of the medical examination, the required frequency of the PFT is a minimum standard and if the physician feels that testing should be done on a yearly basis, the physician is free to exceed the required frequency.

Additional Examinations. The purpose of the initial and periodic examinations is to screen for employees who have developed abnormalities. When abnormalities in the blood are detected, an additional blood examination shall be carried out to confirm the findings 1910.1028 (i)(5). If the second test shows abnormalities which cause concern to the physician, the employee shall be removed temporarily from exposure to benzene and the examining physician shall refer the employee to a hematologist/internist for further examination, unless the examining physician has good reason to believe such additional referral is not needed. The purpose of removal at this stage is to avoid the possibility of deterioration in the employee's blood picture due to continued exposure to benzene. The purpose of consultation with a hematologist/internist is to provide the necessary special tests and expertise to make a diagnosis, to advise on treatment and also to advise whether continued or future exposure would be an unacceptable risk to the health of the worker (Evidence indicates there are enough specialists in the country (Tr. 3/26/86, pp. 174–7; Ex. No. 159–1)).

Certain abnormalities found through routine screening are of greater significance in a benzene-exposed worker and warrant immediate consultation with a specialist. Macrocytosis may be an important early indicator of toxicological effects; anemia, leukopenia, thrombocytopenia, and an abnormal differential count are significant hematological signs. In the case of microcytic anemia, a thorough search for other causes of this type of anemia should be made prior to deciding that referral to a hematologist/internist is necessary.

In this final standard, paragraphs (i)(5)(A) through (C) contain the criteria that mandate further laboratory testing and referrals. OSHA proposed further testing and referrals be triggered by specific numerical findings (i.e. a hemoglobin level below 14 grams precent for males or below 12 grams percent for females). However, throughout the course of this rulemaking different definitions of normal blood parameters and trigger points have been presented to OSHA.

Data from the First National Health and Nutrition Examination Survey shows variations in the normal range for white cell counts related to age, sex, race, and smoking habits (Ex. No. 159–56). Similarly, variations occur in the normal ranges for other blood elements especially with regard to sex and geography. Thus, all these factors need to be considered when defining acceptable levels of formed blood elements for pre-employment assessment, as part of routine medical surveillance and for decisions to refer benzene workers to a hematologist/internist.

OSHA recognizes that there are no absolute "normal values" for the various blood parameters. Therefore, any choice of "normal ranges" of blood parameters and "trigger values" for referral will be arbitrary to some extent and have limitations. OSHA has selected the normal ranges and trigger points for referral that it believes are the most practical and have the fewest limitations.

Clearly, an important element in the medical evaluation is the preemployment white cell count. Any progressive change in the white cell count of any other blood parameter must be carefully monitored, taking into account not only the precision of the method but also the variation which occurs. A count of 4000 white blood cells per mm^3 is being carried forward from the proposal as the lower limit for normal, below which referral is necessary. Any value below this also needs to be assessed against the preemployment level taking into account the factors cited above. Comparison of blood cell counts against the individual's baseline count from a previous evaluation will be helpful in detecting whether any abnormality exists.

Raised white blood cell counts may be caused by various infections, allergies, physical activity, some drugs and smoking. However, a rapid increase in white blood cells particularly with abnormal differential count may indicate the onset of leukemia. Since such an onset may be sudden and progress rapidly, any benzene-exposed worker who feels unwell and manifests symptoms of fatigue, weakness, loss of appetite, bruising, hemorrhage, or unexplained fever should be encouraged to report at once to a physician. Medical and blood examinations should be carried out immediately. If the physician considers it necessary, the worker may be referred directly to a hematologist/internist.

Setting the upper limit of the white blood count (WBC) that requires consulation is more difficult. Wintrobe's *Clinical Hematology* recommended an upper limit of normal of 10,000 cells/mm^3. However, it has been pointed out in Wintrobe's current textbook (Ex. No. 159–102) that using this value in the working population, where external stresses such as exercise and infection can produce an elevated white cell count with a normal differential count, may be problematic.

The main screening goal at the upper limit of normal in this working population is the detection of leukemia. *Cancer Medicine* reports that the median white count of over 1500 patients with AML was between 15,000 and 20,000/ul. However, ten percent of the patients had white counts lower than 2000/ul and slightly over one-quarter of the patients had white counts of less than 5000/ul. *Cancer Medicine* also states that, "When the leukocyte level is elevated the circulating cells are usually predominately leukemic." (Ex. No. 15–26)

Therefore, recognizing elevated white cell counts can occur with numerous etiologies (i.e. infections) other than benzene exposure and that a large number of leukemia patients have WBCs below 10,000, OSHA has decided not to include an upper level of normal for WBC. Worker protection will be maintained by the requirement that the physician consult with a hematologist or internist when the WBC is below 4000 per mm^3 or when there are abnormalities in the leukocyte differential count.

There were various recommendations made in the testimony regarding the normal range for red blood indices. The limitations of absolute values for hemoglobin and hematocrit were also discussed. For example, Dr. Parkinson testified that workers in some areas have normal hemoglobin values as high as 16mg (Tr., 3/25, p. 79). Variations from "normal" blood parameters may be related to a number of factors. For example, hemoglobin values are known to vary according to altitude, thus ensuring that no specific fixed level is appropriate for all geographic areas. Higher levels are normal at higher altitudes since more hemoglobin is necessary in these settings to transport adequate oxygen to the tissues.

Because the hematocrit and hemoglobin levels vary by geographic area, OSHA has deleted the absolute

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...vels and substituted the normal limit, ...ich is determined by all laboratories ... their reference populations and ...nsists of limit within a 95 percent ... confidence interval (C.I.).

In this final standard as in the proposal, a fall in the hemoglobin level from an individual's baseline, even if the level remains within the normal range for the reference group, will trigger a repeat test and consideration for referral, paragraph (i)(5)(i)(A). Several physicians emphasized the clinical significance of such a finding, stressing the need to compare an individual's test values to the baseline tests as well as to compare the individual's test results to the reference population (e.g., Ex. No. 221 pp. 22; Tr. 3/25/86, pp. 79–80).

A change has been made for the thrombocyte (platelet) count, which must now vary more than 20 percent from the employee's most recent values or fall outside the normal limit (95 percent CI) as determined by the laboratory in order to trigger a referral. Dr. Goldstein testified that the proposed trigger variation of 15 percent was too small and that 20 percent would be more appropriate (Tr. 3/26/86, p. 159). Dr. Bennett noted that the 15 percent figure was not in common usage and that further testing should be triggered only if the platelet falls below the lower limit as established by the reference ...aboratory (Tr. 3/26/86, p. 131) or two ...tandard deviations below the normal. OSHA agrees that the 15 percent variance figure for platelets was too low and had therefore set the final variance at 20 percent.

OSHA emphasizes that the criteria listed in paragraphs (i)(5)(i)(A) through (C), while representative of the major hematological findings that warrant further investigation, are not the only conditions that may require further testing or referrals. For example, several of the medical experts emphasized the need to recognize trends, comparing results to baseline tests, to consider all blood parameters, and to identify patterns. (Tr. 3/26/86, pp. 160; Tr. 3/25/86, p. 77). Physicians should be aware of the fact that there may be other conditions requiring further investigation.

Physician discretion in ordering retests and making referrals to hematologists/internists has been retained in two ways. First, the hematocrit and hemoglobin findings and platlet and WBC will require retesting and/or referral only when the abnormal count or trend in counts cannot be explained by other medical reasons, (paragraph (i)(5)(i)(A)). Secondly, the exception in the provision for referral to a hematologist or an internist that was in the proposal has been retained in paragraph (i)(5)(ii) in this final standard. This provides for referral "unless the physician has good reason to believe such referral is unnecessary." OSHA believes all the changes reflect current expert opinion and knowledge, and will protect workers whose blood counts become abnormal while ensuring sufficient physician discretion to prevent unnecessary tests and referrals.

OSHA believes that the above requirement for interpreting the CBC, including consideration of referral to a specialist when counts reach the specified levels, are supported by current medical knowledge and are necessary to adequately protect workers. Some commenters, such as API (Ex. No. 142–31) have criticized similar CBC interpretation guidelines because of the number of evaluations that will be triggered by abnormal blood counts. However, OSHA believes the risks of serious adverse health effects such as ...lenkemia, aplastic anemia, cytopenias or pancytopenia, coupled with the possibility of reversal, treatment and improved prognosis, warrant the above enumerated provisions. The lowering of exposures to 1 ppm will mean that the number of referrals will be small.

Emergency Exposures. Following an emergency situation in which a worker is exposed to an excess amount of benzene, *documentation* of enhanced absorption of benzene through a uninary phenol test is required so that increased medical surveillance can be initiated, if needed. The most extensively used and validated method of defection in this situation is the urinary phenol test (Ex. No. 159–82). Elevated urinary phenol levels can occur without benzene exposure (Ex. No. 159–29), but these instances do not detract from the overall effectiveness of the test when overexposure has occurred. Testimony at the hearings generally supported a urinary phenol test following emergency exposures.

OSHA proposed to require that the employer also provide an employee whose urinary phenol is above 75mg/L with a complete blood count at the end of 3 months following the emergency exposure in order to determine if blood abnormalities have developed from the exposure. OSHA noted that if abnormalities develop, a referral to a specialist for diagnosis and treatment may be needed. Dr. Parkinson testified that the one blood count is inadequate. He stated that an immediate blood count is necessary to ensure the worker's baseline blood indices are within normal limits at the time of the emergency. Moreover, he stated that monthly counts following the emergency exposure were necessary to detect possible marrow suppression than can occur over time with acute high dose exposure. (Tr., 3/25/86, pp. 77–78). OSHA agrees. Therefore, paragraph (i)(4)(iii) now requires employees be provided with "a complete blood count * * * immediately and at monthly intervals for a duration of (3) months following the emergency exposure.

Additional Provisions. The final standard retains the requirement in the proposal that the employer provide the examining physician with certain information (paragraph (i)(6)). This includes:

(1) A copy of the regulations and appendices.

(2) A description of the employee's duties as related to exposure.

(3) The employee's actual or representative's exposure level.

(4) Information regarding the use of personal protective equipment.

(5) Information from previous employment-related medical examinations not otherwise available to the physician.

The purpose of making this information available to the physician is to aid in the evaluation of the employee's health in relation to assigned duties and to help the physician determine fitness to wear personal protective equipment when required.

For each examination required under this section the employer shall obtain a written opinion from the examining physician which shall include:

1. The occupationally pertinent results of the medical examination and tests.

2. The physician's opinion as to whether the employee has any detected medical conditions or is taking any medication which would place the employee at increased risk of material impairment from exposure to benzene or from the use of personal protection equipment.

3. An opinion as to the employee's ability to wear a respirator when it is required.

4. A statement that the employee has been informed by the physician of the results of the medical examination and any medical conditions resulting from benzene exposure which require further explanation or treatment.

The purpose of requiring the examining physician to supply the employer with a written opinion is to provide the employer with a medical basis to aid in the initial placement of employees and to assess the employee's ability to use protective clothing and equipment. The requirement that an employee be provided with a copy of the

physician's written opinion within 15 days will ensure that the employee is informed of the receipt by the employer of the results of the medical examination in a timely manner. The purpose in requiring that specific findings or diagnoses unrelated to occupational exposure to benzene not be included in the written opinion, paragraph (i)(7)(ii), is to encourage employees to take the medical examinations by removing any concern that the employer will obtain information about their physical condition that is unrelated to occupational exposures.

Editorial changes have been made in paragraph (i)(7)(ii) which stipulates that the physician shall not reveal in the written opinion given to the employer, specific records, findings and diagnoses that have no bearing on an employee's ability to work in a benzene exposed workplace. The purpose of this provision remains protection of the privacy of the employee by not having the physician reveal non-occupational related conditions to the employer. This provision has been included in prior standards.

Union representatives raised the issue of the proper treatment of sensitive personal information that might be gleaned from the medical examinations (Ex. No. 262, p. 49). Both Dr. Parkinson and Dr. Mirer testified that extreme care had to be taken with the information so that the employees would not be arbitrarily fired or transferred (Tr. 3/25/86, pp. 72; 82; Tr. 3/27/86, pp. 159, 160).

OSHA is concerned about privacy. Mindful of these concerns, the Agency has drafted medical surveillance to: (1) limit the amount of information collected to that which a physician would need to determine whether an employee could safely work in an area where benzene exposure exceeds the action level, and (2) limit the information the physician reveals to the employer to only those findings germane to occupational exposure to benzene (paragraph (i)(7)(ii)). The Agency cannot restrict physicians from providing employers with information that bears upon an employee's ability to work in a benzene exposed area, because to do so could easily result in the employee's health or even the health and safety of other employees being compromised. Moreover, the employer may need this information in order to gauge the effectiveness of the company's health and safety program. However, OSHA can and has greatly limited the information from the medical examinations that the physician is allowed to report to the employer. OSHA believes this approach which is consistent with other standards (e.g., EtO), strikes the proper balance between the employer's need to know about conditions related to occupational exposure and employees' privacy rights.

Medical Removal. OSHA proposed that medical removal from further benzene exposure should occur in two circumstances. The first is a temporary removal when the plant physician considers that referral to a hematologist/internist is necessary while waiting for the hematologist/internist report (paragraph (i)(8)(i)). The justification for temporary medical removal by the plant physician while awaiting consultation by the hematologist/internist is based on the fact that, in some cases, blood abnormalities may rapidly progress to serious and possibly life-threatening disease and continued benzene exposure could influence such an event.

The second circumstance where medical removal occurs follows the findings of the hematologist/internist. With this information from the specialist in hand, the physician needs to decide whether the employee can return to work involving benzene exposure or whether the employee shall be kept away from further benzene exposure either permanently or until the blood has returned to normal. If this removal is temporary, an estimate is to be made of the probable removal period and the times of further follow-up examinations. OSHA considers that at a PEL of 1 ppm such removal procedures will be minimal in number.

In the proposal, OSHA posited several reasons for temporarily or permanently removing the employee following consultation with of the hematologist/internist. First, an employee who is removed from benzene exposure at the earliest possible time is given the best chance of enabling his or her blood to return to normal. Second, continued exposure could cause serious progressive and possibly fatal disease, sometimes with rapid onset. The Agency noted that blood conditions can deteriorate rapidly during conditions of continuing exposure. Removal and treatment may prevent death, cure illness or improve the employee's condition.

Most of the commenters supported some form of medical removal. For example, CMA commented that they believed the "provisions for medical removal are appropriate" (Ex. No. 201-33, p. 147). However, commenters, especially physicians, disagreed on the level of health benefits to be gained from medical removal. Dr. Parkinson testified:

> * * * It seems clear from medical evidence that in many cases, blood dyscrasias do precede aplastic anemia and leukemia, and removal from exposure does reduce the risk of progression to leukemia or aplastic anemia (Tr. 3/25/86, p. 83).

Dr. Teitelbaum, in enumerating the appropriate bases of medical surveillance emphasized the necessity of "removing from exposure to benzene those workers with diseases which might predispose them to adverse effects such as pre-existing chronic anemias, leukopenias and thrombocytopenias" (Ex. No. 221, p. 16).

On the other hand, Dr. Bennett testified that, for two diseases, AML and myelodysplasia, once the underlying bone marrow damage has been manifested in the form of abnormal blood counts, the prospects for a return to normal bone marrow are poor (Tr., 3/26/86, p. 124). However, in response to a question about whether a patient with some form of potentially reversible bone marrow damage should be removed from exposure to benzene until the "picture clarified," Dr. Bennett replied, "Yes" (Tr., 3/26/86, p. 136). Moreover, Dr. Bennett testified that removal from benzene exposure would be prudent if a patient has * * *" bone marrow damage that cannot be reversed, or a condition which stimulates the bone marrow on a chronic basis * * * [because] * * * the bone marrow precursor cells may be stimulated enough so that additional insult by an agent such as benzene may be adverse * * *" (Tr., 3/26/86, p. 137).

Dr. Teitelbaum enumerated several instances where removal might be appropriate. He noted that the work of Jandl and others suggested conditions which lead to malignant change might be prevented through early detection followed by removing the exposed worker (Ex. No. 221, pp. 14). Other instances where removal would be appropriate would be for workers who have aplastic anemias or underlying autoimmune diseases that might predispose to aplastic anemias. (Ex. No. 221, pp. 16, 19).

Although physicians may disagree on the criteria and circumstances for removal and the precise advantages to be gained from medical removal, nearly all physicians who evaluated the issue could envision some set of circumstances where removal is appropriate. Therefore, after considering all the evidence in the record on medical removal, OSHA has concluded that medical removal is an integral and

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essential part of medical surveillance in his final standard.

Medical removal of provides an opportunity for blood abnormalities, particularly aplasias and cytopenias, to reverse themselves before they become irreversible. The second basis for removal is to prevent increased benzene exposure for those workers who already show signs of more serious diseases such as leukemia and aplastic anemia. In these cases, most physicians recommend removal from the possible causative agent. If the cause cannot be determined, it is still prudent to remove a worker to avoid a known leukemogen that could increase the adverse effects through a synergistic or additive mechanism with the primary leukemic agent.

After reviewing the evidence, OSHA concludes that the proposal's analysis of the mechanism for removal is correct. The decision is made based on objective evidence of the tests, the recommendations of the specialist and the examing physician's judgment.

Dr. Kenneth B. Miller from OCAW and Dr. Parkinson recommended medically-removed workers be provided extra examinations, preferably by a three doctor review panel (Tr. 3/27/86; 3/25/86). There was concern that the physician and hematologist hired by the company may be overly conservative, inclined to remove an employee who is still capable of working in an area where benzene exceeds the action level (e.g. Tr., 3/25/86, pp. 89–90). Moreover, in noting the gravity of the situation for workers, they pointd out some workers could still lose their livelihoods in that even if MRP is instituted, it is likely to be limited in time and scope. They believed a review panel of physicians would lessen fears of job loss, thus encouraging full participation.

OSHA believes the recommendation for a follow-up examination has merit but the Agency is not persuaded that a three physician review panel is necessary to ensure appropriate care for employees with abnormal hematological findings. The medical surveillance paragraph provides for an initial examination, periodic examinations, additional examinations and referrals, emergency examinations and a follow-up examination for employees who are removed for medical reasons. Referrals are to be made to board certified hematologists or internists, thereby insuring the input of the appropriate medical experts whenever an employee is removed for medical reasons. OSHA does not believe adding more physicians to the plan would improve the medical care provided to the employee.

Medical Removal Protection. In the preamble to the proposal, OSHA raised the issue of medical removal protection. There we said OSHA would expect that employers who were able, would provide employment in areas of no benzene exposure or areas below the action level to those employees temporarily removed from benzene exposure for medical reasons. OSHA suggested that the details of such transfers are best left to collective bargaining and employer personnel policies. However, the Agency specifically sought comment on whether there is a health justification for including such a provision.

Medical removal protection (MRP), has been used in other OSHA standards. OSHA's MRP program for the lead standard was upheld by the United States Court of Appeals for the District of Columbia Circuit in *United Steelworkers of America, AFL-CIO* v. *Marshall, 647 F. 2d 1189 (D.C. Cir. 1980), Cer. denied, Lead Industries Association Inc.* v. *Donovan*, 101 S. Ct. 3148 (1981). Part of the MRP program for lead involved a wage retention provision for workers who transferred to other jobs or were laid off in order to avoid continued exposure to unacceptable levels of lead.

In 1981, the Supreme Court, in *American Textile Manufacturers Institute (ATMI)* v. *Donovan*, 452 U.S. 490 (1981), struck down the MRP of the cotton dust regulation, but left the job transfer provision in effect. The Court held that OSHA did not explain how the provision was related to the achievement of a safe and healthful work environment (*Id.* at 537–538). The Court did not decide the issue of whether OSHA had the underlying authority to promulgate such a provision.

OSHA raised the issue of whether evidence showed health reasons for MRP when it reevaluated the cotton dust standard. OSHA concluded it did, both the industry and union recommended it and MRP was included in this final standard (50 FR 51120; Dec. 13, 1985).

Medical removal provisions are appropriate when they can be shown to provide employee health benefits. This preventative health mechanism is particularly appropriate when a worker's body may be biologically monitored for adverse health effects caused by exposures and when the health effects are reversible. Under these circumstances, temporary medical removal can assist in protecting the worker by limiting further occupational exposure, and by enabling a worker to recover from identified adverse health effects while remaining under the medical surveillance program of the employer. Evidence in the record shows that benzene meets both of these tests, as discussed previously.

In addition, OSHA has received many comments to the benzene record on the role of wage rate retention in encouraging workers to participate in medical surveillance programs.

Mr. Donald Broad, a steelworker, testified:

> Certainly, you must have an earnings provision. We've had a lot of people sign off OSHA physicals in the past. They've been borderline with high blood pressure or trace of sugar, and they're just scared to death of losing their job or their position or whatever, and that's probably the biggest reason people sign off OSHA, as they are scared of losing money. (Tr. 3/25/86, p. 183).

George Cafasso, another steelworker, agreed, stating that workers feared loss of money and also their jobs. (Tr. 3/25/86, p. 183).

Margaret Seminario, Associate Director of Occupational Safety and Health, AFL-CIO, testified that workers refuse medical tests because of fear of losing their jobs. She testified that it is inappropriate for OSHA to include medical removal without a wage maintenance provision similar to that in the lead standard (Tr. 3/25/86, p. 183).

Joseph L. Durst, Jr., Health and Safety Director for the United Brotherhood of Carpenters, testified that his members would not take the medical examination if they thought the consequences would be to lose their jobs (Tr. 3/27/86, p. 108).

Dr. Franklin Mirer, Director of U.A.W. Health and Safety Department, testified that while he did not know of any auto workers exposed to benzene who had refused to take medical examinations, he did know of other workers who had done so, particularly inplant lift truck drivers (Tr. 3/25/86, p. 40).

Several physicians also testified to the importance of a rate retention component of medical removal. Dr. David Parkinson testified that he believed it to be absolutely imperative that benzene workers be provided with a benefit plan like the one in the lead standard. Without this protection, Dr. Parkinson stated, workers would be reluctant to participate in medical removal. He testified that the medical evidence was clear that in many cases blood dyscrasias precede aplastic anemia and leukemia and that removal from exposure does reverse dyscrasias, thereby presumably reducing the risk of progression to aplastic anemia or leukemia (Tr. 3/25/86, p. 83).

Dr. Miller testified that an employee who is removed from a benzene-

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exposed job for medical reasons should have a new job, retaining the employee's wage rate and seniority. If this is not possible, Dr. Miller stated, the employer must maintain wages for some period of time, perhaps 12–18 months (Tr. 3/27/86, p. 98).

Industry representatives were generally opposed to inclusion of a wage rate retention provision. (Ex. Nos. 258; 259; 260). For example, CMA, in their Post-Hearing Brief, supported OSHA's medical removal provisions, but argued that a wage retention provision was "neither legally supportable nor necessary in practice" (Ex. No. 258, p. 157). The trade association questioned OSHA's authority to require MRP, citing section 4(b)(4) of the Act. Additionally, CMA stated that the omission of a wage retention provision in the OSH Act reflected the intent of Congress, since the OSH Act was passed only a year after the Federal Coal Mine Health and Safety Act of 1969, which specifically included a wage retention provision (Ex. No. 258, p. 158).

CMA, having noted that any wage retention provision must have a health justification, argued that not only does no health justification exist, but also that such a provision is not necessary from a practical standpoint (Ex. No. 258, p. 159). In distinguishing the benzene medical removal provisions from the lead standard, which includes a wage retention provision, CMA stated that whereas a significant number of lead workers are removed, with a low 1 ppm standard for benzene, the number of benzene workers removed will be negligible, thereby not likely to lead workers to fear for their jobs or wage rates (Ex. No. 258, pp. 160, 161).

OSHA believes it does have the authority to include such provisions when they are necessary to protect the health of the workers. The Court of Appeals in the lead case found the wage rate retention provision did not violate section 4(b)(4) of the Act since the section 4(b)(4) restriction could only apply to the small group of workers who are removed under MRP pursuant to a final medical determination that they are already disabled, and for whom no low-exposure job of equal salary is available. They rejected the other arguments made by CMA. (*USWA, etc.* v. *Marshall*, 647 F. 2d 1189 at 1235.)

Removal from benzene exposure is clearly needed to protect health when certain conditions are detected by medical surveillance. Yet employees will be reluctant to agree to medical surveillance if they fear it will lead to loss of job. There was much testimony as to this fact in the benzene hearing and this has been the evidence in other OSHA rulemakings. When employees avoid the medical surveillance, there is no way to identify workers who are developing blood abnormalities due to benzene exposure. These same employees will continue to work in a benzene environment to their detriment.

Medical removal benefits are an appropriate area for collective bargaining agreements. But OSHA has become convinced by the evidence presented that there is a health need for these provisions and basic MRP benefits should be incorporated for all workers whether covered by collective bargaining agreements or not or whether another agreement covers it.

The Agency must always ascertain that MRP is needed for health reasons and then tailor the particular components of MRP to the chemical being regulated. OSHA is persuaded that the health of workers exposed to benzene can be improved by requiring employers to provide limited benefits.

There is a particular reason, in the case of benzene, why medical removal protection is especially appropriate. There will be some cases of abnormal blood counts for reasons other than benzene exposure. If some employees are removed without pay until the reason for the abnormal blood count is diagnosed, other employees are likely to start refusing examinations because of this loss of pay.

After a physician determination to remove an employee pursuant to paragraph (i)(6)(ii), the employee is to be transferred to a comparable job with benzene exposures under the action level or, if none is available, receive medical removal benefits for up to 6 months. During this period, the employee's condition may improve. A follow-up examination is required. At that time the physician, in consultation with the hematologist/internist will determine whether the employee may return to the employee's old job or whether the removal is to be made permanent.

OSHA's MRP provision for benzene has been structured to emphasize the desirability of transferring the worker who is medically removed to a job where benzene does not exceed the action level (paragraph (i)(8)(iv)). In effecting such a transfer, the employer is required to maintain the employee's wage rate, seniority and other benefits (paragraph (i)(8)(iv)). OSHA believes most employers will be in a position to do this as discussed in the economic feasibility section. The component of MRP benefits, paying the wage rate and maintaining seniority and other benefits, becomes available to the employee only when there is no comparable job available, paragraph (i)(8)(iv).

After the follow-up examination and a final physician determination that the employee may not return to work in an area where exposures exceed the action level, the employer is to transfer the employee to another job which is available or which becomes available for which the employee is qualified or can be trained in a short period. As relatively few employees will be removed (unlike lead) and such jobs are likely to be available, OSHA believes this provision should carry out the health need of encouraging employees to take medical examinations without substantially interferring with collective bargaining and employer-employee relations. A broader definition of alternative jobs is used to increase the possibility that alternative jobs are available as medical removal benefits are not provided at this stage. The benzene-related condition has been determined at this stage to be permanent.

In paragraph (i)(9)(i), the employer is required to provide up to 6 months of MRP benefits each time an employee is removed because of hematological findings, unless the employee has been transferred to a comparable job. A number of representatives of labor organizations recommended protection continue for up to 18 months as in the lead standard, or for a greater period of time depending on the particulars of each case. (Most industry groups opposed MRP and thus did not comment on specific provisions), OSHA believes that 6 months is the appropriate period of time because, first, it represents the approximate amount of time needed for the hematological examinations and other essential consultations leading to a determination as to whether the employee can return to work in an area where benzene exceeds the action level. Secondly, it is likely that if an abnormal hemoglobin count is due to one of the commoner non-benzene reversable causes such as iron deficiency anemia, menorrhagia or bleeding gastrointestional ulcers, the disorders can be diagnosed and possibly reversed within the six month period.

Paragraph (i)(9)(ii) defines MRP benefits as the maintenance of earnings, seniority and other employment rights as though the employee had not been removed. OSHA believes that inclusion of all of these components of an employee's rights and benefits is essential so that the employees are not prevented from participation in the medical examinations by fear of immediately losing their jobs upon the

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finding of abnormal hematological conditions.

Finally, the employer's obligation to provide MRP is reduced to the extent the employee receives some form of compensation for earnings lost during the period of removal. This provision is necessary in order to ensure the MRP does not result in a "windfall" to the employee who collects other compensation, or earns a salary at another job, while the employee is on medical removal from benzene exposure.

OSHA believes MRP as structured provides appropriate protection to employees without undue intrusion into the area of collective bargaining arrangements.

J. Communication of Benzene Hazards to Employees: Paragraph (j)

In this final benzene standard, OSHA includes a paragraph entitled: "Communication of benzene hazards to employees." This paragraph addresses the issue of transmitting information to employees about the hazards of benzene through the use of: (1) signs and labels, (2) material safety data sheets, and (3) information and training. Previous OSHA health standards generally included separate paragraphs on employee information and training and signs and labels. This final standard incorporates both of those areas into this single paragraph, along with material safety data sheet provisions to be consistent with other recent OSHA rules (e.g., Ethylene Oxide, 49 FR 25734).

On November 25, 1983, the Occupational Safety and Health Administration published its final rule on Hazard Communication at 48 FR 53280 (29 CFR 12919.1200). The Hazard Communication Standard requires all chemical manufacturers and importers to assess the hazards of the chemical which they produce or import, and all manufacturing employers [in SIC codes 20 through 39 (Division D, Standard Industrial Classification Manual)] to provide information concerning the hazards of such chemicals to their employees. The standard provides that:

> This transmittal of information is to be accomplished by means of comprehensive hazard communication programs, which are to include container labeling and other forms of warning, material safety data sheets and employee training [29 CFR 1910.1200 (a)(1)].

Since the Hazard Communication Standard "is intended to address comprehensively the issue of evaluating and communicating chemical hazards to employees" OSHA proposed this paragraph, "Communication of benzene hazards to employees," in an effort to avoid repetition of those requirements now comprehensively laid out in § 1910.1200. In addition, this new paragraph has been developed with the intent of avoiding placement of a duplicate administrative burden on those employers attempting to comply with the requirements of several different applicable OSHA health standards, while at the same time providing the necessary protection afforded employees under the provisions for signs and labels, material safety data sheets, and employee information and training.

The communication of benzene hazards paragraph of the benzene standard has been designed to be substantively as consistent as possible with the Hazard Communication Standard. However, there are some differences. The benzene standard's paragraph on hazard communication covers all industry segments covered by the benzene standard where as the Hazard Communication Standard currently applies only to employers with workplaces in the manufacturing industry sectors (SIC codes 20–39). However, OSHA will be expanding the Hazard Communication Standard to cover a wider segment of industry.

The final rule for benzene requires that regulated areas to be posted with signs stating: "Danger, Benzene, Cancer Hazard, Flammable—No Smoking, Authorized Personnel Only, Respirator Required." The Agency intends the posting of these signs to demarcate regulated areas. Such warning signs are required to be posted whenever a regulated area exists, that is, whenever the permissible exposure limit is likely to be exceeded. For some work sites, regulated areas exist permanently where there is an area where exposures cannot be reduced below the PEL by the use of engineering controls. In those situations the signs are needed to warn employees not to enter the area unless they are wearing respirators and unless there is a need for entering the area.

Regulated areas may also exist on a temporary basis, for example, during maintenance. The use of warning signs in these types of situations is also important, since the temporary high exposures would represent a new or unexpected exposure to employees who are regularly scheduled to work at these sites. The posting of signs at the occurrence of a maintenance situation or during an emergency if there is time, will help to prevent unnecessary exposures to workers who may not otherwise know or expect excessive benzene exposure levels and serves to warn employees of the need to wear respirators.

The wording of the warning signs for regulated areas proposed by OSHA in being carried forth in the final standard in order to assure that the proper warning is given to employees. OSHA feels that the use of the word "Danger" is appropriate, based on the epidemiological evidence of the human carcinogenicity of benzene. "Danger" is used to attract the attention of workers, to alert them to the fact that they are in an area the permissible exposure limit is exceeded, and to emphasize the importance of the message that follows. The use of the word "Danger" is also consistent with other recent OSHA health standards dealing with carcinogens.

One commenter, Amoco, expressed concern about requiring "Flammable—No Smoking" in the signs (Ex. No. 221–22, p. 11). In their operations, Amoco officials stated, any areas that might be designated a regulated area for benzene would be part of a larger area which would already be a no smoking area and employees seeing "No-Smoking" on the sign for the regulated area might think that smoking was forbidden only in the regulated area (Ex. No. 201–22, p. 11). OSHA believes that the need to warn all employees of the fire hazard in a benzene regulated area outweighs possible confusion.

Amoco also commented that the phrase "respirator required" was not instructive since it did not specify what kind of respirator (Ex. No. 201–22). OSHA realizes that the term is not specific, but it does not warn that a respirator is needed, an important notice. It would not be possible to list the types of respirators required and that require further direction by the employer.

While OSHA recognizes that some employees entering the regulated areas for a short time may not be exposed above either the TWA or the STEL, it is still possible that many employees who are assigned to work in these areas may remain in these locations for long enough periods of time to be overexposed to benzene without the use of respirators. To ensure that these employees are adequately protected. It is necessary that the sign alert them to the need to wear respirators.

Paragraph (j)(1)(ii) requires that labels or other appropriate forms of warning be provided for containers (as defined in the "Definitions" paragraph of this section) of benzene within the workplace in accordance with the requirements of the Hazard Communication standard. OSHA is requiring containers be labeled: "Danger, Contains Benzene. Cancer

Hazard." Paragraph (j)(1)(iii) further requires that this same legend be affixed to containers of benzene leaving the workplace. Again, such labeling is to be in accordance with requirements of § 1910.1200(f). As stated in the Scope and Application section of this standard, and, consistent with OSHA's Hazard Communication standard, these labeling requirements do not apply to pipelines.

The requirements for signs and labels are consistent with section 6(b)(7) of the OSH Act, which prescribes the use of labels or other appropriate forms of warning to apprise employees of the hazards to which they are exposed. In addition, the OSHA Hazard Communication standard requires that, if a hazardous chemical is regulated by OSHA in a substance specific health standard. "* * * the chemical manufacturer, importer, distributor or employer shall ensure that the labels or other forms of warning used are in accordance with the requirements of that standard (see 29 CFR 1910.1200 (f)(3)). Therefore, this benzene standard, at paragraph (j)(1) states the specific labeling (and sign) requirements that must be used to warn employees of the hazards to which they are exposed.

OSHA also proposed to require the employer to obtain or develop and to distribute and provide access to a material safety data sheet for benzene in accordance with the requirements of 29 CFR 1910.1200(g). Amoco commented that since their employees are likely to encounter benzene only as a component of another product, any warning for benzene should only be included on the MSDS for the main substance (Ex. No. 201–22, p. 11).

OSHA has considered this recommendation, but has decided not to alter the requirement in the proposal that MSDSs be obtained and developed for benzene. The main reason for this decision is that the hazards of benzene as shown above in the section on health effects are sufficiently great that workers who may be exposed to the chemical need the detailed information that would be present on a MSDS for benzene so the employee would be in a better position to protect oneself.

The material safety data sheet also serves as the central source of information to employees and downstream employers who must be provided with an MSDS if benzene is produced and shipped out of the plant. In addition, the MSDS serves as the basic source of information on the hazards of benzene essential to the training provisions of this and other applicable health standards.

Chemical manufacturers and importers have the primary responsibility, under the Hazard Communication standard, to develop or prepare the material safety data sheet. The manufacturer or importer is most likely to have the best access to information about the product, and is therefore responsible for disseminating this information to downstream users of the material. Therefore, for employers whose employees' exposure to benzene is from products received form outside sources, the information necessary for a complete MSDS or the MSDS itself is to be obtained from the manufacturer and made available to affected employees. The requirements for the information that is to be contained on the material safety data sheet are explained in detail at 29 CFR 1910.1200(g).

Although few commenters addressed the issues in the communication of benzene hazard paragraph, there was one area that drew comment from both union and industry representatives. This was the issue of how much detail should be required on the label, container, or MSDS when benzene is present as a contaminent or as an intergral part of a solution.

As noted above, the Agency proposed to require employers whose employees use solvents containing benzene to label the containers with a specific cautionary phrase and obtain or develop an MSDS for the sovlent and make it available to employees. OSHA intended that these labels and MSDSs be consistent with the Hazard Communication Standard, 29 CFR 1910.1200, which requires carcinogens be identified on a label or MSDS if they make up 0.1% or more of the mixture [29 CFR 1910.1200(f) and (g)]. Identification of the carcinogen need only include the name of the chemical and does not need to specify what percent of the concentration the chemical constitutes.

Union representatives have requested OSHA to require the percentage concentration of benzene be added to the labels, containers and MSDS (Ex. No. 262, p. 55). They argue that merely listing benzene by name on the label is inadequate, since the concentration could be low, as for example 0.1 percent or much higher, perhaps in the range of 10 to 20 percent. These representatives contend that employers, by not knowing the precise percentage of benzene in the mixture, will be unable to determine what protective measures to take (Ex. No. 262, p. 55).

CMA strongly opposes this recommendation. CMA argues that communication issues were considered and resolved in the lengthy rulemaking proceeding for the Hazard Communication Standard (Ex. No. 256, p. 179). They contend the requirements of the Hazard Communication Standard provide employees with all the information they need to minimize risks associated with handling benzene mixtures (Ex. No. 258, pp. 179, 180).

After considering all the evidence, OSHA has decided to carry forth the proposed labeling and MSDS requirements. First, OSHA agrees with CMA that the issue of what is appropriate for labels and MSDSs was considered in the Hazard Communication rulemaking and that the Agency concludes that it is generally appropriate to making the information and labeling requirements of chemical standards consistent with the Hazard Communication standard.

Second, the final standard only exempts from coverage work operations where liquid mixtures, (solvents) containing 0.5 percent or less benzene in the first year following publication, 0.3 percent or less benzene in the second year, and 0.1 percent thereafter, are used. Since mixtures where the percentage of benzene is higher than these limits are subject to full coverage under the standard, employers using the solvents with higher concentration will have to keep employee exposure at or under the PEL regardless of the precise percentage benzene in the solvent. Finally, OSHA believes the provision that exempts mixtures with very low benzene contents will motivate solvent manufacturers to reduce the benzene content of their mixtures so that few, if any, mixtures above the exempt levels will even be available.

Paragraph (j)(3) of this final benzene standard requires employers to provide employees with information and training on benzene at the time of initial assignment and at least annually thereafter. The training program is to be in accordance with the requirements of the Hazard Communication Standard, 29 CFR 1910.1200(h)(1) and (2), including specific information required to be provided by that section. In addition, employees are to be provided with an explanation of the contents of Appendices A and B of this standard. Employees are to be informed where a copy of the final benzene standard is accessible to them, and receive a description of the medical surveillance program required under paragraph (i) of this final standard. Employees are also to receive an explanation of the information contained in Appendix C on the medical surveillance guidelines for benzene.

Training and information requirements are routine components of OSHA health standards and are required by section 6(b)(7) of the Act.

Their inclusion reflects the Agency's experience that informed employees are essential to the operation of any effective occupational health program. Training serves to explain and reinforce the information presented to employees on labels and material safety data sheets. Active employee participation in training sessions results in the more effective communication of hazard information to employees which can further result in workers taking conscientious protective actions at their job duties, thereby decreasing the possibility of occupationally-related illnesses and injuries.

As proposed, the training provisions of this final standard are performance-oriented, rather than specified and detailed language. The standard, in requiring training to be in accordance with the requirements of 29 CFR 1910.1200, lists the categories of information to be transmitted to employees and not the specific ways that this is to be accomplished.

OSHA believes that the employer is in the best position to determine how the training he or she is providing is being received and absorbed by the employees. OSHA has, therefore, described the objectives to be met and the intent of its training to ensure they can help to protect themselves. The specifics of how this is to be accomplished are left up to the employer.

Many comments were received that endorsed this approach. For example, Conoco, Inc. (Ex. No. 142-27) suggested "* * * that OSHA consider that any education and training requirements be in performance language, requiring employers to determine that employees have the necessary health and safety information rather than annual retraining on exactly the same points" Conoco further noted that their "* * * experience with the vinyl chloride standard, which details items to be included in annual training, has shown such-specification language to be counter productive because of the required repetition."

One commenter, Amoco, recommended the benzene training provisions be limited to employees exposed "* * * 30 days or more per year above the action level [or assigned] to work in which respiratory protection is used to protect against exposures above the PEL (Ex. No. 201-22; p. 11). OSHA believes the seriousness of the potential health effects warrants the training provisions be applied to all workers covered by the benzene standard.

Other commenters stated that OSHA's Hazard Communication Standard provides important requirements for training provisions and that separate requirements for training would be redundant. Mindful of their comment, OSHA's training program for this final standard is in accordance with the requirements of 29 CFR 1910.1200. The Agency intends that the use of such performance-oriented requirements will encourage employers to tailor their training needs to their specific workplaces, thereby resulting in the most effective training program suitable for each specific workplace.

K. Recordkeeping: Paragraph (k)

The final benzene standard requires employers to maintain exposure measurement records and medical records. These requirements are in accordance with section 8(c) of the Act which requires employers to keep and make available such records as the Secretary may prescribe as necessary or appropriate for the enforcement of the Act, or for developing information regarding the causes and prevention of occupational accidents and illnesses.

The final rule provides that records be kept to identify the employee monitored and to reflect the employee's exposure accurately. Specifically, exposure records must include the following information: (a) the dates, number, duration and results of each of the samples taken, including, where appropriate, a description of the procedures used to determine representative employee exposures; (b) a description of the sampling and analytical methods used; (c) a description of the type of respiratory protective equipment worn, if applicable; and (d) the name, social security number, job classification and exposure levels of the employee monitored, and all other employees whose exposure the measurement is intended to represent.

In addition to records on employee exposure measurements, the employer is required to establish and maintain an accurate individual record for each employee subject to medical surveillance as required by paragraph (i) of the final standard. OSHA believes that medical records, like exposure monitoring records, are necessary and appropriate to the enforcement of the standard, to the successful treatment of benzene related disease and the development of information regarding the causes and prevention of illness.

The records shall include: (1) The name and social security number of the employee, (2) the employer's copy of all physicians reports on the employee, (3) any employee benzene related medical complaints, (4) a copy of the information provided to the physician as required by paragraph (i)(6) of this section and (5) a copy of the employee's medical and work history related to any hematologic toxins. Abnormal changes of blood elements may be affected by different factors and therefore a good medical history will include specification of known hematologic toxins to which the employee has been exposed. These items constitute information necessary and appropriate for later accurate diagnoses and determinations that the worker is adequately protected under the standard.

It is necessary to keep these records for extended periods because of the long latency period commonly associated with carcinogenesis. Cancer often cannot be detected until 20 or more years after onset of exposure. The extended record retention period is therefore needed for several purposes. First, diagnosis of disease in employees is assisted by having present and past exposure data and the results of prior medical examinations. In addition, retaining records for extended periods also makes it possible at some future date to review effectiveness and the adequacy of the standard.

Two commenters objected to the detailed language of the proposed standard [Ex. Nos. 201-15, 201-35]. Both commenters stated that the recordkeeping provisions were a duplication of the requirements found in § 1910.20, Access to Employee Exposure and Medical Records, and expressed the opinion that only a reference to § 1910.20 was necessary.

The recordkeeping requirements in the standard is not a duplication of § 1910.20 which only requires retention of records the employer chooses to make. The recordkeeping requirements of the benzene standard, mandates the creation of new records or reports, and imposes new obligations on employers to monitor or measure employee exposures, and to provide medical surveillance or examinations relative to occupational exposure to benzene.

The retention and access provisions of the benzene standard are consistent with § 1910.20. Employees and their designated representatives are, in general, allowed unrestricted access to exposure monitoring records. Access to medical records is also provided for employees and, if the employee has given specific written consent, for the employee's designated representative. OSHA retains unrestricted access to both kinds of records, but its access to personally identifiable medical records is made subject to rules of agency practice and procedure concerning

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OSHA access to employee medical records, designed to protect privacy, which have been published at 29 CFR 1913.10 (see 45 FR 35384).

The time period required for retention of exposure of records is thirty years and for medical records duration of employment plus thirty years. These retention periods are consistent with those in the OSHA records access standard.

The transfer of employee exposure monitoring and medical records is to be in accordance with the provisions of paragraph (h) of 29 CFR 1910.20. If an employer ceases to do business and there is no successor employer, the employer is to notify NIOSH and transmit the records to the Director of NIOSH for retention, if requested. An employer may go out of business before notifying NIOSH. However, the records must be retained for at least 90 days after NIOSH is notified.

OSHA believes the collection and retention of these exposure monitoring and medical records is necessary to protect employee health by assisting in diagnosis of conditions and to allow for future assessement of the standard's effectiveness exposure limit and other provisions.

L. Observation of Monitoring: Paragraph (l)

The benzene standard contains provisions for the observation of exposure monitoring. This provision is in accordance with section 8(c) of the OSH Act which requires that employers provide employees and their representatives with the opportunity to observe monitoring of employee exposures to toxic substances or harmful physical agents. Observation procedures are set forth which require the observer, whether it be an employee or a designated representative, to be provided with the personal protective clothing and equipment that is required to be worn by the employees who are working in the area. The employer is required to assure the use of such clothing and equipment or respirators, and is responsible for requiring that the observer complies with all other applicable safety and health procedures.

M. Effective Dates: Paragraph (m)

The standard becomes effective 90 days after date of publication in the Federal Register. The requirements of paragraphs (a) through (m) of the standard are to be completed sixty (60) days after the effective date of the final rule except for paragraph (f)(1), which sets forth the requirements for engineering and work practice controls. Consequently, employers will have 5 months from publication to accomplish those requirements which OSHA believes is adequate time. Implementation dates for the completion of the engineering and work practice requirements are to be no later than 2 years after the effective date of the final rule. This is to allow affected employers sufficient time to design (where necessary), obtain, and install the necessary control equipment. Because of the financial difficulties of the steel industry, and with the agreement of both the United Steel Workers and the American Iron & Steel Institute, the compliance period for coke light oil recovery and byproduct operations is 5 years.

N. Appendices: Paragraph (n)

Five appendices have been included at the end of this standard. Appendices A, B, C, and D have been included primarily for purposes of information. None of the statements contained in Appendices A, B, C, and D should be construed as establishing a mandatory requirement not otherwise imposed by the standard, or as detracting from an obligation which the standard does impose. However, the protocols for respiratory fit testing in Appendix E are binding.

Appendix A contains information on the description and exposure levels of benzene. Also provided in Appendix A is information on the health hazards associated with exposure, descriptions of protective clothing and equipment, emergency and first aid procedures, medical requirements, provisions for the observation of monitoring, access to exposure and medical records, and precautions for the safe use, handling and storage of benzene.

Appendix B contains "substance technical guidelines" for benzene, including physical and chemical data, spill and leak procedures including waste disposal methods, and other miscellaneous precautions for the safe handling of benzene.

Appendix C contains the medical surveillance guidelines for benzene. Included in these guidelines are a description of the routes of entry, the toxicology and symptoms and signs associated with benzene exposure, information on the treatment of acute toxic effects, and surveillance and preventive considerations, including hematology guidelines which may be useful to physicians in conducting the medical surveillance program required by section (i) of this proposed standard.

Appendix D gives details of the OSHA sampling and analytical methods for use in monitoring employee exposures to benzene.

Appendix E gives detailed fit testing procedures that are to be followed for qualitative and quantitative fit testing of negative pressure respirators. Various protocols for qualitative and quantitative fit tests are outlined in detail. These protocols have been simplified from the proposal. Several commenters suggested further simplification. OSHA plans in the near future to propose revisions to section 1910.134, the respirator program standard. In that rulemaking it will consider whether further simplification is appropriate.

All the Appendices are designed to aid the employer in complying with the requirements of the standard. Paragraph (j) of this proposed standard on the "communication of benzene hazards to employees" specifically requires that the contents of the standard and Appendices A and B be made available to affect employees. Information contained in Appendix C on medical surveillance is to be explained to affected employees. The information in Appendix C also provides information needed by the physician to evaluate the results of the medical examination.

Recordkeeping Requirements

The recordkeeping requirements in this standard have been approved by the Office of Management and Budget under the Paperwork Reduction Act of 1980, 44 U.S.C. 3501 *et seq.* The approval number is 1218-0129 and the approval has been granted until August 31, 1990.

Authority

This document was prepared under the direction of John A. Pendergrass, Assistant Secretary of Labor for Occupational Safety and Health, U.S. Department of Labor, Third Street and Constitution Avenue NW., Washington, DC 20210.

Pursuant to sections 6(b) and 8 of the Occupational Safety and Health Act of 1970 (29 U.S.C. 655, 657), 29 CFR Part 1911 and Secretary of Labor's Order No. 9-83 (48 FR 35736), Part 1910 of 29 CFR is hereby amended by adding a new permanent standard for occupational exposure to benzene as section 1910.1028 as set forth below and to make consequential amendments to Table Z-2 of § 1910.1000. In addition, pursuant to section 4(b)(2) of the Act, OSHA has determined that this new standard is more effective than the general standards now in Subpart B of Part 1910, and in Parts 1915, 1917, 1918, and 1926 of Title 29, Code of Federal Regulations. Therefore, these general standards are superseded with respect to benzene by this new § 1910.1028. A new paragraph

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is added to § 1910.19 to reflect this [illegible]

List of Subjects in 29 CFR Part 1910

Benzene, Occupational safety and health, Chemicals, Cancer, Health, Risk assessment.

Signed at Washington, DC, on this 1st day of September 1987.

John A. Pendergrass,

Assistant Secretary of Labor.

XII. The Standard

PART 1910—[AMENDED]

Part 1910 of Title 29 of the Code of Federal Regulations is hereby amended as follows:

1. The authority citation for Subpart B of Part 1910 continues to read as follows:

Authority: Secs. 4, 6, and 8 of the Occupational Safety and Health Act, 29 U.S.C. 653, 655, 657; Walsh-Healey Act, 41 U.S.C. 35 et seq; Service Contract Act of 1965, 41 U.S.C. 351 et seq; Pub. L. 91-54, 40 U.S.C. 333; Pub. L. 85-742, 53 U.S.C. 941; National Foundation on Arts and Humanities Act, 20 U.S.C. 951 et seq; Secretary of Labor's Orders 12-71 (36 FR 8754), 8-76 (41 FR 2506), or 9-83 (48 FR 35736); and 29 CFR Part 1911.

2. A new paragraph (i) is added to § 1910.19 to read as follows:

§ 1910.19 Special provisions for air contaminants.

* * * * *

(i) *Benzene.* Section 1910.1028 shall apply to the exposure of every employee to benzene in every employment and place of employment covered by §§ 1910.12, 1910.13, 1910.14, 1910.15 or 1910.16 in lieu of any different standard on exposures to benzene which would otherwise be applicable by virtue of those sections.

3. The authority citation for Subpart Z of Part 1910 is amended to add an entry for § 1910.1028 as follows:

Authority: Secs. 6, 8 Occupational Safety and Health Act, 29 U.S.C. 655, 657; Secretary of Labor's Orders 12-71 (36 FR 8754), 8-76 (41 FR 25059), or 9-83 (48 FR 35736) as applicable; and 29 CFR Part 1911. Section 1910.1000 Tables Z-1, Z-2, Z-3 also issued under 5 U.S.C. 553. * * * Section 1910.1028 also issued under 29 U.S.C. 653.

* * * * *

4. A footnote "1" is added to the entry "Benzene" in Table Z-2 of Section 1910.1000 to read as follows. The entry for "Benzene" is republished.

§ 1910.1000 [Amended]

TABLE Z-2 [AMENDED]

Material	8-hour time weighted average	Acceptable ceiling concentration	Acceptable maximum average peak above the acceptance ceiling concentration for an 8-hour shift	
			Concentration	Maximum duration
Benzene [1] Z37.40-1969	10 p.p.m	25 p.p.m	50 p.p.m	10 minutes

[1] This standard applies to the industry segments exempt from the 1 ppm 8 hour TWA and 5 ppm STEL of the benzene standard at § 1910.1028. This standard also applies to any industry for which § 1910.1928 is stayed or otherwise not in effect.

5. A new § 1910.1028 and Appendices A, B, C, D, and E are added to Subpart Z to read as follows:

§ 1910.1028 Benzene.

(a) *Scope and application.* (1) This section applies to all occupational exposures to benzene. Chemical Abstracts Service Registry No. 71-43-2, except as provided in paragraphs (a)(2) and (a)(3) of this section.

(2) This section does not apply to:

(i) The storage, transportation, distribution, dispensing, sale or use of gasoline, motor fuels, or other fuels containing benzene subsequent to its final discharge from bulk wholesale storage facilities, except that operations where gasoline or motor fuels are dispensed for more than 4 hours per day in an indoor location are covered by this section.

(ii) Loading and unloading operations at bulk wholesale storage facilities which use vapor control systems for all loading and unloading operations, except for the provisions of 29 CFR 1910.1200 as incorporated into this section and the emergency provisions of paragraphs (g) and (i)(4) of this section.

(iii) The storage, transportation, distribution or sale of benzene or liquid mixtures containing more than 0.1 percent benzene in intact containers or in transportation pipelines while sealed in such a manner as to contain benzene vapors or liquid, except for the provisions of 29 CFR 1910.1200 as incorporated into this section and the emergency provisions of paragraphs (g) and (i)(4) of this section.

(iv) Containers and pipelines carrying mixtures with less than 0.1 percent benzene and natural gas processing plants processing gas with less than 0.1 percent benzene.

(v) Work operations where the only exposure to benzene is from liquid mixtures containing 0.5 percent or less of benzene by volume, or the vapors released from such liquids until September 12, 1988; work operations where the only exposure to benzene is from liquid mixtures containing 0.3 percent or less of benzene by volume or the vapors released from such liquids from September 12, 1988, to September 12, 1989; and work operations where the only exposure to benzene is from liquid mixtures containing 0.1 percent or less of benzene by volume or the vapors released from such liquids after September 12, 1989; except that tire building machine operators using solvents with more than 0.1 percent benzene are covered by paragraph (i) of this section.

(vi) Oil and gas drilling, production and servicing operations.

(vii) Coke oven batteries.

(3) The cleaning and repair of barges and tankers which have contained benzene are excluded from paragraph (f) methods of compliance, paragraph (e)(1) exposure monitoring-general, and paragraph (e)(6) accuracy of monitoring. Engineering and work practice controls shall be used to keep exposures below 10 ppm unless it is proven to be not feasible.

(b) *Definitions.*

"Action level" means an airborne concentration of benzene of 0.5 ppm calculated as an 8-hour time-weighted average.

"Assistant Secretary" means the Assistant Secretary of Labor for Occupational Safety and Health, U.S. Department of Labor, or designee.

"Authorized person" means any person specifically authorized by the employer whose duties require the person to enter a regulated area, or any person entering such an area as a designated representative of employees for the purpose of exercising the right to

observe monitoring and measuring procedures under paragraph (f) of this section, or any other person authorized by the Act or regulations issued under the Act.

"Benzene" (C_6H_6) [CAS Registry No. 71-43-2] means liquefied or gaseous benzene. It includes benzene contained in liquid mixtures and the benzene vapors released by these liquids. It does not include trace amounts of unreacted benzene contained in solid materials.

"Bulk wholesale storage facility" means a bulk terminal or bulk plant where fuel is stored prior to its delivery to wholesale customers.

"Container" means any barrel, bottle, can, cylinder, drum, reaction vessel, storage tank, or the like, but does not include piping systems.

"Day" means any part of a calendar day.

"Director" means the Director of the National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services, or designee.

"Emergency" means any occurrence such as, but not limited to, equipment failure, rupture of containers, or failure of control equipment which may or does result in an unexpected significant release of benzene.

"Employee exposure" means exposure to airborne benzene which would occur if the employee were not using respiratory protective equipment.

"Regulated area" means any area where airborne concentrations of benzene exceed or can reasonably be expected to exceed, the permissible exposure limits, either the 8-hour time weighted average exposure of 1 ppm or the short-term exposure limit of 5 ppm for 15 minutes.

"Vapor control system" means any equipment used for containing the total vapors displaced during the loading of gasoline, motor fuel or other fuel tank trucks and the displacing of these vapors through a vapor processing system or balancing the vapor with the storage tank. This equipment also includes systems containing the vapors displaced from the storage tank during the unloading of the tank truck which balance the vapors back to the tank truck.

(c) *Permissible exposure limits (PELs)*—(1) *Time-weighted average limit (TWA).* The employer shall assure that no employee is exposed to an airborne concentration of benzene in excess of one part of benzene per million parts of air (1 ppm) as an 8-hour time-weighted average.

(2) *Short-term exposure limit (STEL).* The employer shall assure that no employee is exposed to an airborne concentration of benzene in excess of five (5) ppm as averaged over any 15 minute period.

(d) *Regulated areas.* (1) The employer shall establish a regulated area wherever the airborne concentration of benzene exceeds or can reasonably be expected to exceed the permissible exposure limits, either the 8-hour time weighted average exposure of 1 ppm or the short-term exposure limit of 5 ppm for 15 minutes.

(2) Access to regulated areas shall be limited to authorized persons.

(3) Regulated areas shall be determined from the rest of the workplace in any manner that minimizes the number of employees exposed to benzene within the regulated area.

(e) *Exposure monitoring*—(1) *General.* (i) Determinations of employee exposure shall be made from breathing zone air samples that are representative of each employee's average exposure to airborne benzene.

(ii) Representative 8-hour TWA employee exposures shall be determined on the basis of one sample or samples representing the full shift exposure for each job classification in each work area.

(iii) Determinations of compliance with the STEL shall be made from 15 minute employee breathing zone samples measured at operations where there is reason to believe exposures are high, such as where tanks are opened, filled, unloaded or gauged; where containers or process equipment are opened and where benzene is used for cleaning or as a solvent in an uncontrolled situation. The employer may use objective data, such as measurements from brief period measuring devices, to determine where STEL monitoring is needed.

(iv) Except for initial monitoring as required under paragraph (e)(2) of this section, where the employer can document that one shift will consistently have higher employee exposures for an operation, the employer shall only be required to determine representative employee exposure for that operation during the shift on which the highest exposure is expected.

(2) *Initial monitoring.* (i) Each employer who has a place of employment covered under paragraph (a)(1) of this section shall monitor each of these workplaces and work operations to determine accurately the airborne concentrations of benzene to which employees may be exposed.

(ii) The initial monitoring required under paragraph (e)(2)(i) of this section shall be completed by 60 days after the effective date of this standard or within 30 days of the introduction of benzene into the workplace. Where the employer has monitored within one year prior to the effective date of this standard and the monitoring satisfies all other requirements of this section, the employer may rely on such earlier monitoring results to satisfy the requirements of paragraph (e)(2)(i) of this section.

(3) *Periodic monitoring and monitoring frequency.* (i) If the monitoring required by paragraph (e)(2)(i) of this section reveals employee exposure at or above the action level but at or below the TWA, the employer shall repeat such monitoring for each such employee at least every year.

(ii) If the monitoring required by paragraph (e)(2)(i) of this section reveals employee exposure above the TWA, the employer shall repeat such monitoring for each such employee at least every six (6) months.

(iii) The employer may alter the monitoring schedule from every six months to annually for any employee for whom two consecutive measurements taken at least 7 days apart indicate that the employee exposure has decreased to the TWA or below, but is at or above the action level.

(iv) Monitoring for the STEL shall be repeated as necessary to evaluate exposures of employees subject to short term exposures.

(4) *Termination of monitoring.* (i) If the initial monitoring required by paragraph (e)(2)(i) of this section reveals employee exposure to be below the action level the employer may discontinue the monitoring for that employee, except as otherwise required by paragraph (e)(5) of this section.

(ii) If the periodic monitoring required by paragraph (e)(3) of this section reveals that employee exposures, as indicated by at least two consecutive measurements taken at least 7 days apart, are below the action level the employer may discontinue the monitoring for that employee, except as otherwise required by paragraph (e)(5).

(5) *Additional monitoring.* (i) The employer shall institute the exposure monitoring required under paragraphs (e)(2) and (e)(3) of this section when there has been a change in the production, process, control equipment, personnel or work practices which may result in new or additional exposures to benzene, or when the employer has any reason to suspect a change which may result in new or additional exposures.

(ii) Whenever spills, leaks, ruptures or other breakdowns occur that may lead to employee exposure, the employer shall monitor (using area or personal sampling) after the clean-up of the spill

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or repair of the leak, rupture or other breakdown to ensure that exposures have returned to the level that existed prior to the incident.

(6) *Accuracy of monitoring.* Monitoring shall be accurate, to a confidence level of 95 percent, to within plus or minus 25 percent for airborne concentrations of benzene.

(7) *Employee notification of monitoring results.* (i) The employer shall, within 15 working days after the receipt of the results of any monitoring performed under this standard, notify each employee of these results in writing either individually or by posting of results in an appropriate location that is accessible to affected employees.

(ii) Whenever the PELs are exceeded, the written notification required by paragraph (e)(7)(i) of this section shall contain the corrective action being taken by the employer to reduce the employee exposure to or below the PEL, or shall refer to a document available to the employee which states the corrective actions to be taken.

(f) *Methods of compliance*—(1) *Engineering controls and work practices.* (i) The employer shall institute engineering controls and work practices to reduce and maintain employee exposure to benzene at or below the permissible exposure limits, except to the extent that the employer can establish that these controls are not feasible or where the provisions of paragraph (f)(1)(iii) or (g)(1) of this section apply.

(ii) Wherever the feasible engineering controls and work practices which can be instituted are not sufficient to reduce employee exposure to or below the PELs, the employer shall use them to reduce employee exposure to the lowest levels achievable by these controls and shall supplement them by the use of respiratory protection which complies with the requirements of paragraph (g) of this section.

(iii) Where the employer can document that benzene is used in a workplace less than a total of 30 days per year, the employer shall use engineering controls, work practice controls or respiratory protection or any combination of these controls to reduce employee exposure to benzene to or below the PELs, except that employers shall use engineering and work practice controls, if feasible, to reduce exposure to or below 10 ppm as an 8-hour TWA.

(2) *Compliance program.* (i) When any exposures are over the PEL, the employer shall establish and implement a written program to reduce employee exposure to or below the PEL primarily by means of engineering and work practice controls, as required by paragraph (f)(1) of this section.

(ii) The written program shall include a schedule for development and implementation of the engineering and work practice controls. These plans shall be reviewed and revised as appropriate based on the most recent exposure monitoring data, to reflect the current status of the program.

(iii) Written compliance programs shall be furnished upon request for examination and copying to the Assistant Secretary, the Director, affected employees and designated employee representatives.

(g) *Respiratory protection.* (1) *General.* The employer shall provide respirators, and assure that they are used, where required by this section. Respirators shall be used in the following circumstances:

(i) During the time period necessary to install or implement feasible engineering and work practice controls;

(ii) In work operations for which the employer establishes that compliance with either the TWA or STEL through the use of engineering and work practice controls is not feasible, such as some maintenance and repair activities, vessel cleaning, or other operations where engineering and work practice controls are infeasible because exposures are intermittent in nature and limited in duration;

(iii) In work situations where feasible engineering and work practice controls are not yet sufficient or are not required under paragraph (f)(1)(iii) of this section to reduce exposure to or below the PELs; and

(iv) In emergencies.

(2) *Respirator selection.* (i) Where respirators are required or allowed under this section, the employer shall select and provide, at no cost to the employee, the appropriate respirator as specified in Table 1, and shall assure that the employee uses the respirator provided.

(ii) The employer shall select respirators from among those jointly approved by the Mine Safety and Health Administration and the National Institute for Occupational Safety and Health under the provisions of 30 CFR Part 11. Negative pressure respirators shall have filter elements approved by MSHA/NIOSH for organic vapors or benzene.

(iii) Any employee who cannot wear a negative pressure respirator shall be given the option of wearing a respirator with less breathing resistance such as a powered air-purifying respirator or supplied air respirator.

(3) *Respirator program.* The employer shall institute a respiratory protection program in accordance with 29 CFR 1910.134 (b), (d), (e) and (f).

(4) *Respirator use.* (i) Where air-purifying respirators are used, the employer shall replace the air purifying element at the expiration of service life or at the beginning of each shift in which they will be used, whichever comes first.

(ii) If an air purifying element becomes available with an end of useful life indicator for benzene approved by MSHA/NIOSH, the element may be used until such time as the indicator shows no further useful life.

(iii) The employer shall permit employees who wear respirators to leave the regulated area to wash their faces and respirator facepieces as necessary in order to prevent skin irritation associated with respirator use or to change the filter elements of air-purifying respirators whenever they detect a change in breathing resistance or chemical vapor breakthrough.

(5) *Respirator fit testing.* (i) The employer shall perform, and certify the results of, either quantitative or qualitative fit tests at the time of initial fitting and at least annually thereafter for each employee wearing a negative pressure respirator. The test shall be used to select a respirator facepiece which exhibits minimum leakage and provides the required protection as prescribed in Table 1. The employer shall provide and assure that the employee wears a respirator demonstrated by the fit test to provide the required protection.

(ii) The employer shall follow the test protocols outlined in Appendix E of this standard for whichever type of fit testing the employer chooses.

TABLE 1.—RESPIRATORY PROTECTION FOR BENZENE

Airborne concentration of benzene or condition of use	Respirator type
(a) Less than or equal to 10 ppm.	(1) Half-mask air-purifying respirator with organic vapor cartridge.
(b) Less than or equal to 50 ppm.	(1) Full facepiece respirator with organic vapor cartridges. (1) Full facepiece gas mask with chin style canister.[1]
(c) Less than or equal to 100 ppm.	(1) Full facepiece powered air-purifying respirator with organic vapor canister.[1]

TABLE 1.—RESPIRATORY PROTECTION FOR BENZENE—Continued

Airborne concentration of benzene or condition of use	Respirator type
(d) Less than or equal to 1,000 ppm.	(1) Supplied air respirator with full facepiece in positive-pressure mode.
(e) Greater than 1,000 ppm or unknown concentration.	(1) Self-contained breathing apparatus with full facepiece in positive pressure mode. (2) Full facepiece positive- pressure *supplied-air* respirator with auxiliary self-contained air supply.
(f) Escape	(1) Any organic vapor gas mask; or (2) Any self-contained breathing apparatus with full facepiece.
(g) Firefighting	(1) Full facepiece self-contained breathing apparatus in positive pressure mode.

[1] Canisters must have a minimum service life of four (4) hours when tested at 150 ppm benzene, at a flow rate of 64 LPM, 25 °C, and 85% relative humidity for non-powered air purifying respirators. The flow rate shall be 115 LPM and 170 LPM respectively for tight fitting and loose fitting powered air-purifying respirators.

(h) *Protective clothing and equipment.* Personal protective clothing and equipment shall be worn where appropriate to prevent eye contact and limit dermal exposure to liquid benzene. Protective clothing and equipment shall be provided by the employer at no cost to the employee and the employer shall assure its use where appropriate. Eye and face protection shall meet the requirements of 29 CFR 1910.133.

(i) *Medical surveillance*— (1) *General.* (i) The employer shall make available a medical surveillance program for employees who are or may be exposed to benzene at or above the action level 30 or more days per year; for employees who are or may be exposed to benzene at or above the PELs 10 or more days per year; for employees who have been exposed to more than 10 ppm of benzene for 30 or more days in a year prior to the effective date of the standard when employed by their current employer; and for employees involved in the tire building operations called tire building machine operators, who use solvents containing greater than 0.1 percent benzene.

(ii) The employer shall assure that all medical examinations and procedures are performed by or under the supervision of a licensed physician and that all laboratory tests are conducted by an accredited laboratory.

(iii) The employer shall assure that persons other than licensed physicians who administer the pulmonary function testing required by this section shall complete a training course in spirometry sponsored by an appropriate governmental, academic or professional institution.

(iv) The employer shall assure that all examinations and procedures are provided without cost to the employee and at a reasonable time and place.

(2) *Initial examination.* (i) Within 60 days of the effective date of this standard, or before the time of initial assignment, the employer shall provide each employee covered by paragraph (i)(1)(i) of this section with a medical examination including the following elements:

(A) A detailed occupational history which includes:

(*1*) Past work exposure to benzene or any other hematological toxins,

(*2*) A family history of blood dyscrasias including hematological neoplasms;

(*3*) A history of blood dyscrasias including genetic hemoglobin abnormalities, bleeding abnormalities, abnormal function of formed blood elements;

(*4*) A history of renal or liver dysfunction;

(*5*) A history of medicinal drugs routinely taken;

(*6*) A history of previous exposure to ionizing radiation and

(*7*) Exposure to marrow toxins outside of the current work situation.

(B) A complete physical examination.

(C) *Laboratory tests.* A complete blood count including a leukocyte count with differential, a quantitative thrombocyte count, hematocrit, hemoglobin, erythrocyte count and erythrocyte indices (MCV, MCH, MCHC). The results of these tests shall be reviewed by the examining physician.

(D) Additional tests as necessary in the opinion of the examining physician, based on alterations to the components of the blood or other signs which may be related to benzene exposure; and

(E) For all workers required to wear respirators for at least 30 days a year, the physical examination shall pay special attention to the cardiopulmonary system and shall include a pulmonary function test.

(ii) No initial medical examination is required to satisfy the requirements of paragraph (i)(2)(i) of this section if adequate records show that the employee has been examined in accordance with the procedures of paragraph (i)(2)(i) of this section within the twelve months prior to the effective date of this standard.

(3) *Periodic examinations.* (i) The employer shall provide each employee covered under paragraph (i)(1)(i) of this section with a medical examination annually following the previous examination. These periodic examinations shall include at least the following elements:

(A) A brief history regarding any new exposure to potential marrow toxins, changes in medicinal drug use, and the appearance of physical signs relating to blood disorders;

(B) A complete blood count including a leukocyte count with differential, quantitative thrombocyte count, hemoglobin, hematocrit, erythrocyte count and erythrocyte indices (MCV, MCH, MCHC); and

(C) Appropriate additional tests as necessary, in the opinion of the examining physician, in consequence of alterations in the components of the blood or other signs which may be related to benzene exposure.

(ii) Where the employee develops signs and symptoms commonly associated with toxic exposure to benzene, the employer shall provide the employee with an additional medical examination which shall include those elements considered appropriate by the examining physician.

(iii) For persons required to use respirators for at least 30 days a year, a pulmonary function test shall be performed every three (3) years. A specific evaluation of the cardiopulmonary system shall be made at the time of the pulmonary function test.

(4) *Emergency examinations.* (i) In addition to the surveillance required by (i)(1)(i), if an employee is exposed to benzene in an emergency situation, the employer shall have the employee provide a urine sample at the end of the employee's shift and have a urinary phenol test performed on the sample within 72 hours. The urine specific gravity shall be corrected to 1.024.

(ii) If the result of the urinary phenol test is below 75 mg phenol/L of urine, no further testing is required.

(iii) If the result of the urinary phenol test is equal to or greater than 75 mg phenol/L of urine, the employer shall provide the employee with a complete blood count including an erythrocyte count, leukocyte count with differential and thrombocyte count at monthly intervals for a duration of three (3)

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months following the emergency exposure.

(iv) If any of the conditions specified in paragraph (i)(5)(i) of this section exists, then the further requirements of paragraph (i)(5) of this section shall be met and the employer shall, in addition, provide the employees with periodic examinations if directed by the physician.

(5) *Additional examinations and referrals.* (i) Where the results of the complete blood count required for the initial and periodic examinations indicate any of the following abnormal conditions exist, then the blood count shall be repeated within 2 weeks.

(A) The hemoglobin level or the hematocrit falls below the normal limit [outside the 95% confidence interval (C.I.)] as determined by the laboratory for the particular geographic area and/or these indices show a persistent downward trend from the individual's pre-exposure norms; provided these findings cannot be explained by other medical reasons.

(B) The thrombocyte (platelet) count varies more than 20 percent below the employee's most recent values or falls outside the normal limit (95% C.I.) as determined by the laboratory.

(C) The leukocyte count is below 4,000 per mm^3 or there is an abnormal differential count.

(ii) If the abnormality persists, the examining physician shall refer the employee to a hematologist or an internist for further evaluation unless the physician has good reason to believe such referral is unnecessary. (See Appendix C for examples of conditions where a referral may be unnecessary.)

(iii) The employer shall provide the hematologist or internist with the information required to be provided to the physician under paragraph (i)(6) of this section and the medical record required to be maintained by paragraph (k)(2)(ii) of this section.

(iv) The hematologist's or internist's evaluation shall include a determination as to the need for additional tests, and the employer shall assure that these tests are provided.

(6) *Information provided to the physician.* The employer shall provide the following information to the examining physician:

(i) A copy of this regulation and its appendices;

(ii) A description of the affected employee's duties as they relate to the employee's exposure;

(iii) The employee's actual or representative exposure level;

(iv) A description of any personal protective equipment used or to be used; and

(v) Information from previous employment-related medical examinations of the affected employee which is not otherwise available to the examining physician.

(7) *Physician's written opinions.* (i) For each examination under this section, the employer shall obtain and provide the employee with a copy of the examining physician's written opinion within 15 days of the examination. The written opinion shall be limited to the following information:

(A) The occupationally pertinent results of the medical examination and tests;

(B) The physician's opinion concerning whether the employee has any detected medical conditions which would place the employee's health at greater than normal risk of material impairment from exposure to benzene;

(C) The physician's recommended limitations upon the employee's exposure to benzene or upon the employee's use of protective clothing or equipment and respirators.

(D) A statement that the employee has been informed by the physician of the results of the medical examination and any medical conditions resulting from benzene exposure which require further explanation or treatment.

(ii) The written opinion obtained by the employer shall not reveal specific records, findings and diagnoses that have no bearing on the employee's ability to work in a benzene-exposed workplace.

(8) *Medical removal plan.* (i) When a physician makes a referral to a hematologist/internist as required under paragraph (i)(5)(ii) of this section, the employee shall be removed from areas where exposures may exceed the action level until such time as the physician makes a determination under paragraph (i)(8)(ii) of this section.

(ii) Following the examination and evaluation by the hematologist/internist, a decision to remove an employee from areas where benzene exposure is above the action level or to allow the employee to return to areas where benzene exposure is above the action level shall be made by the physician in consultation with the hematologist/internist. This decision shall be communicated in writing to the employer and employee. In the case of removal, the physician shall state the required probable duration of removal from occupational exposure to benzene above the action level and the requirements for future medical examinations to review the decision.

(iii) For any employee who is removed pursuant to paragraph (i)(8)(ii) of this section, the employer shall provide a follow-up examination. The physician in consultation with the hematologist/internist, shall make a decision within 6 months of the date the employee was removed as to whether the employee shall be returned to the usual job or whether the employee should be removed permanently.

(iv) Whenever an employee is temporarily removed from benzene exposure pursuant to paragraph (i)(8)(i) or (i)(8)(ii) of this section, the employer shall transfer the employee to a comparable job for which the employee is qualified (or can be trained for in a short period) and where benzene exposures are as low as possible, but in no event higher than the action level. The employer shall maintain the employee's current wage rate, seniority and other benefits. If there is no such job available, the employer shall provide medical removal protection benefits until such a job becomes available or for 6 months, whichever comes first.

(v) Whenever an employee is removed permanently from benzene exposure based on a physician's recommendation pursuant to paragraph (i)(8)(iii) of this section, the employee shall be given the opportunity to transfer to another position which is available or later becomes available for which the employee is qualified (or can be trained for in a short period) and where benzene exposures are as low as possible but in no event higher than the action level. The employer shall assure that such employee suffers no reduction in current wage rate, seniority or other benefits as a result of the transfer.

(9) *Medical removal protection benefits.* (i) The employer shall provide to an employee 6 months of medical removal protection benefits immediately following each occasion an employee is removed from exposure to benzene because of hematological findings pursuant to paragraphs (i)(8) (i) and (ii) of this section, unless the employee has been transferred to a comparable job where benzene exposures are below the action level.

(ii) For the purposes of this section, the requirement that an employer provide medical removal protection benefits means that the employer shall maintain the current wage rate, seniority and other benefits of an employee as though the employee had not been removed.

(iii) The employer's obligation to provide medical removal protection benefits to a removed employee shall be reduced to the extent that the employee receives compensation for earnings lost during the period of removal either from

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a publicly or employer-funded compensation program, or from voluntary employment with another employer made possible by virtue of the employee's removal.

(j) *Communication of benzene hazards to employees*—(1) *Signs and labels.* (i) The employer shall post signs at entrances to regulated areas. The signs shall bear the following legend:

DANGER
BENZENE
CANCER HAZARD
FLAMMABLE—NO SMOKING
AUTHORIZED PERSONNEL ONLY
RESPIRATOR REQUIRED

(ii) The employer shall ensure that lables or other appropriate forms of warning are provided for containers of benzene within the workplace. There is no requirement to label pipes. The labels shall comply with the requirements of 29 CFR 1910.1200(f) and in addition shall include the following legend:

DANGER
CONTAINS BENZENE
CANCER HAZARD

(2) *Material safety data sheets.* (i) Employers shall obtain or develop, and shall provide access to their employees, to a material safety data sheet (MSDS) which addresses benzene and complies with 29 CFR 1910.1200.

(ii) Employers who are manufacturers or importers shall:

(A) Comply with paragraph (a) of this section, and

(B) Comply with the requirement in OSHA's Hazard Communication Standard, 29 CFR 1910.1200, that they deliver to downstream employers an MSDS which addresses benzene.

(3) *Information and training.* (i) The employer shall provide employees with information and training at the time of their initial assignment to a work area where benzene is present. If exposures are above the action level, employees shall be provided with information and training at least annually thereafter.

(ii) The training program shall be in accordance with the requirements of 29 CFR 1910.1200(h) (1) and (2), and shall include specific information on benzene for each category of information included in that section.

(iii) In addition to the information required under 29 CFR 1910.1200, the employer shall:

(A) Provide employees with an explanation of the contents of this section, including Appendices A and B, and indicate to them where the standard is available; and

(B) Describe the medical surveillance program required under paragraph (i) of this section, and explain the information contained in Appendix C.

(k) *Recordkeeping*—(1) *Exposure measurements.* (i) The employer shall establish and maintain an accurate record of all measurements required by paragraph (e) of this section, in accordance with 29 CFR 1910.20.

(ii) This record shall include:

(A) The dates, number, duration, and results of each of the samples taken, including a description of the procedure used to determine representative employee exposures;

(B) A description of the sampling and analytical methods used;

(C) A description of the type of respiratory protective devices worn, if any; and

(D) The name, social security number, job classification and exposure levels of the employee monitored and all other employees whose exposure the measurement is intended to represent.

(iii) The employer shall maintain this record for at least 30 years, in accordance with 29 CFR 1910.20.

(2) *Medical surveillance.* (i) The employer shall establish and maintain an accurate record for each employee subject to medical surveillance required by paragraph (i) of this section, in accordance with 29 CFR 1910.20.

(ii) This record shall include:

(A) The name and social security number of the employee;

(B) The employer's copy of the physician's written opinion on the initial, periodic and special examinations, including results of medical examinations and all tests, opinions and recommendations;

(C) Any employee medical complaints related to exposure to benzene;

(D) A copy of the information provided to the physician as required by paragraphs (i)(6) (ii) through (v) of this section; and

(E) A copy of the employee's medical and work history related to exposure to benzene or any other hematologic toxins.

(iii) The employer shall maintain this record for at least the duration of employment plus 30 years, in accordance with 29 CFR 1910.20.

(3) *Availability.* (i) The employer shall assure that all records required to be maintained by this section shall be made available upon request to the Assistant Secretary and the Director for examination and copying.

(ii) Employee exposure monitoring records required by this paragraph shall be provided upon request for examination and copying to employees, employee representatives, and the Assistant Secretary in accordance with 29 CFR 1910.20 (a) through (e) and (g) through (i).

(iii) Employee medical records required by this paragraph shall be provided upon request for examination and copying, to the subject employee, to anyone having the specific written consent of the subject employee, and to the Assistant Secretary in accordance with 29 CFR 1910.20.

(4) *Transfer of records.* (i) The employer shall comply with the requirements involving transfer of records set forth in 29 CFR 1019.20(h).

(ii) If the employer ceases to do business and there is no successor employer to receive and retain the records for the prescribed period, the employer shall notify the Director, at least three (3) months prior to disposal and transmit them to the Director if required by the Director within that period.

(l) *Observation of monitoring*—(1) *Employee observation.* The employer shall provide affected employees, or their designated representatives, an opportunity to observe the measuring or monitoring of employee exposure to benzene conducted pursuant to paragraph (e) of this section.

(2) *Observation procedures.* When observation of the measuring or monitoring of employee exposure to benzene requires entry into areas where the use of protective clothing and equipment or respirators is required, the employer shall provide the observer with personal protective clothing and equipment or respirators required to be worn by employees working in the area, assure the use of such clothing and equipment or respirators, and require the observer to comply with all other applicable safety and health procedures.

(m) *Dates*—(1) *Effective date.* The standard shall become effective on December 10, 1987.

(2) *Start-up dates.* (i) The requirements of paragraph (a) through (m) of this section, except the engineering control requirements of paragraph (f)(1) of this section shall be completed within sixty (60) days after the effective date of the standard.

(ii) Engineering and work practice controls required by paragraph (f)(1) of this section shall be implemented no later than 2 years after the effective date of the standard.

(iii) Coke and coal chemical operations may comply with paragraph (m)(2)(ii) of this section or alternately include within the compliance program required by paragraph (f) (2) of this

section, a requirement to phase in engineering controls as equipment is repaired and replaced. For coke and coal chemical operations choosing the latter alternative, compliance with the engineering controls requirements of paragraph (f)(1) of this section shall be achieved no later than 5 years after the effective date of this standard and substantial compliance with the engineering control requirements shall be achieved within 3 years of the effective date of this standard.

(n) *Appendices.* The information contained in Appendices A, B, C, and D is not intended, by itself, to create any additional obligations not otherwise imposed or to detract from any existing obligations. The protocols on respiratory fit testing in Appendix E are mandatory.

Appendix A—Substance Safety Data Sheet, Benzene

I. Substance Identification

A. Substance: Benzene.

B. Permissible Exposure: Except as to the use of gasoline, motor fuels and other fuels subsequent to discharge from bulk terminals and other exemptions specified in § 1910.1028(a)(2):

1. Airborne: The maximum time-weighted average (TWA) exposure limit is 1 part of benzene vapor per million parts of air (1 ppm) for an 8-hour workday and the maximum short-term exposure limit (STEL) is 5 ppm for any 15-minute period.

2. Dermal: Eye contact shall be prevented and skin contact with liquid benzene shall be limited.

C. Appearance and odor: Benzene is a clear, colorless liquid with a pleasant, sweet odor. The odor of benzene does not provide adequate warning of its hazard.

II. Health Hazard Data

A. *Ways in which benzene affects your health.* Benzene can affect your health if you inhale it, or if it comes in contact with your skin or eyes. Benzene is also harmful if you happen to swallow it.

B. *Effects of overexposure.* 1. Short-term (acute) overexposure: If you are overexposed to high concentrations of benzene, well above the levels where its odor is first recognizable, you may feel breathless, irritable, euphoric, or giddy; you may experience irritation in eyes, nose, and respiratory tract. You may develop a headache, feel dizzy, nauseated, or intoxicated. Severe exposures may lead to convulsions and loss of consciousness.

2. Long-term (chronic) exposure. Repeated or prolonged exposure to benzene, even at relatively low concentrations, may result in various blood disorders, ranging from anemia to leukemia, an irreversible, fatal disease. Many blood disorders associated with benzene exposure may occur without symptoms.

III. Protective Clothing and Equipment

A. *Respirators.* Respirators are required for those operations in which engineering controls or work practice controls are not feasible to reduce exposure to the permissible level. However, where employers can document that benzene is present in the workplace less than 30 days a year, respirators may be used in lieu of engineering controls. If respirators are worn, they must have joint Mine Safety and Health Administration and the National Institute for Occupational Safety and Health (NIOSH) seal of approval, and cartridge or canisters must be replaced before the end of their service life, or the end of the shift, whichever occurs first. If you experience difficulty breathing while wearing a respirator, you may request a positive pressure respirator from your employer. You must be thoroughly trained to use the assigned respirator, and the training will be provided by your employer.

B. *Protective Clothing.* You must wear appropriate protective clothing (such as boots, gloves, sleeves, aprons, etc.) over any parts of your body that could be exposed to liquid benzene.

C. *Eye and Face Protection.* You must wear splash-proof safety goggles if it is possible that benzene may get into your eyes. In addition, you must wear a face shield if your face could be splashed with benzene liquid.

IV. Emergency and First Aid Procedures

A. *Eye and face exposure.* If benzene is splashed in your eyes, wash it out immediately with large amounts of water. If irritation persists or vision appears to be affected see a doctor as soon as possible.

B. *Skin exposure.* If benzene is spilled on your clothing or skin, remove the contaminated clothing and wash the exposed skin with large amounts of water and soap immediately. Wash contaminated clothing before you wear it again.

C. *Breathing.* If you or any other person breathes in large amounts of benzene, get the exposed person to fresh air at once. Apply artificial respiration if breathing has stopped. Call for medical assistance or a doctor as soon as possible. Never enter any vessel or confined space where the benzene concentration might be high without proper safety equipment and at least one other person present who will stay outside. A life line should be used.

D. *Swallowing.* If benzene has been swallowed and the patient is conscious, do not induce vomiting. Call for medical assistance or a doctor immediately.

V. Medical Requirements

If you are exposed to benzene at a concentration at or above 0.5 ppm as an 8-hour time-weighted average, or have been exposed at or above 10 ppm in the past while employed by your current employer, your employer is required to provide a medical examination and history and laboratory tests within 60 days of the effective date of this standard and annually thereafter. These tests shall be provided without cost to you. In addition, if you are accidentally exposed to benzene (either by ingestion, inhalation, or skin/eye contact) under emergency conditions known or suspected to constitute toxic exposure to benzene, your employer is required to make special laboratory tests available to you.

VI. Observation of Monitoring

Your employer is required to perform measurements that are representative of your exposure to benzene and you or your designated representative are entitled to observe the monitoring procedure. You are entitled to observe the steps taken in the measurement procedure, and to record the results obtained. When the monitoring procedure is taking place in an area where respirators or personal protective clothing and equipment are required to be worn, you or your representative must also be provided with, and must wear the protective clothing and equipment.

VII. Access to Records

You or your representative are entitled to see the records of measurements of your exposure to benzene upon written request to your employer. Your medical examination records can be furnished to yourself, your physician or designated representative upon request by you to your employer.

VIII. Precautions for Safe Use, Handling and Storage

Benzene liquid is highly flammable. It should be stored in tightly closed containers in a cool, well ventilated area. Benzene vapor may form explosive mixtures in air. All sources of ignition must be controlled. Use nonsparking tools when opening or closing benzene containers. Fire extinguishers, where provided, must be readily available.

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Know where they are located and how to operate them. Smoking is prohibited in areas where benzene is used or stored. Ask your supervisor where benzene is used in your area and for additional plant safety rules.

Appendix B—Substance Technical Guidlines, Benzene

I. Physical and Chemical Data

A. Substance Identification.

1. *Synonyms:* Benzol, benzole, coal naphtha, cyclohexatriene, phene, phenyl hydride, pyrobenzol. (Benzin, petroleum benzin and Benzine do not contain benzene).

2. *Formula:* C_6H_6 (CAS Registry Number: 71–43–2)

B. Physical data.

1. Boiling Point (760 mm Hg): 80.1 °C (176 °F)

2. Specific Gravity (water=1): 0.879

3. Vapor Density (air=1): 2.7

4. Melting Point: 5.5 °C (42 °F)

5. Vapor Pressure at 20 °C (68 °F): 75 mm Hg

6. Solubility in Water: .06%

7. Evaporation Rate (ether=1): 2.8

8. Appearance and Odor: Clear, colorless liquid with a distinctive sweet odor.

II. Fire, Explosion, and Reactivity Hazard Data

A. Fire.

1. Flash Point (closed cup): −11 °C (12 °F)

2. Autoignition Temperature: 580 °C (1076 °F)

3. Flammable limits in Air. % by Volume: Lower: 1.3%, Upper: 7.5%

4. Extinguishing Media: Carbon dioxide, dry chemical, or foam.

5. Special Fire-Fighting procedures: Do not use solid stream of water, since stream will scatter and spread fire. Fine water spray can be used to keep fire-exposed containers cool.

6. Unusual fire and explosion hazards: Benzene is a flammable liquid. Its vapors can form explosive mixtures. All ignition sources must be controlled when benzene is used, handled, or stored. Where liquid or vapor may be released, such areas shall be considered as hazardous locations. Benzene vapors are heavier than air; thus the vapors may travel along the ground and be ignited by open flames or sparks at locations remote from the site at which benzene is handled.

7. Benzene is classified as a 1 B flammable liquid for the purpose of conforming to the requirements of 29 CFR 1910.106. A concentration exceeding 3,250 ppm is considered a potential fire explosion hazard. Locations where benzene may be present in quantities sufficient to produce explosive or ignitable mixtures are considered Class I Group D for the purposes of conforming to the requirements of 29 CFR 1910.309.

B. Reactivity.

1. Conditions contributing to instability: Heat.

2. Incompatibility: Heat and oxidizing materials.

3. Hazardous decomposition products: Toxic gases and vapors (such as carbon monoxide).

III. Spill and Leak Procedures

A. Steps to be taken if the material is released or spilled. As much benzene as possible should be absorbed with suitable materials, such as dry sand or earth. That remaining must be flushed with large amounts of water. Do not flush benzene into a confined space, such as a sewer, because of explosion danger. Remove all ignition sources. Ventilate enclosed places.

B. Waste disposal method. Disposal methods must conform to other jurisdictional regulations. If allowed, benzene may be disposed of: (a) By absorbing it in dry sand or earth and disposing in a sanitary landfill; (b) if small quantities, by removing it to a safe location from buildings or other combustible sources, pouring it in dry sand or earth and cautiously igniting it; and (c) if large quantities, by atomizing it in a suitable combustion chamber.

IV. Miscellaneous Precautions

A. High exposure to benzene can occur when transferring the liquid from one container to another. Such operations should be well ventilated and good work practices must be established to avoid spills.

B. Use non-sparking tools to open benzene containers which are effectively grounded and bonded prior to opening and pouring.

C. Employers must advise employees of all plant areas and operations where exposure to benzene could occur. Common operations in which high exposures to benzene may be encountered are: the primary production and utilization of benzene, and transfer of benzene.

Appendix C—Medical Surveillance Guidelines for Benzene

I. Route of Entry

Inhalation; skin absorption.

II. Toxicology

Benzene is primarily an inhalation hazard. Systemic absorption may cause depression of the hematopoietic system, pancytopenia, aplastic anemia, and leukemia. Inhalation of high concentrations can affect central nervous system function. Aspiration of small amounts of liquid benzene immediately causes pulmonary edema and hemorrhage of pulmonary tissue. There is some absorption through the skin. Absorption may be more rapid in the case of abraded skin, and benzene may be more readily absorbed if it is present in a mixture or as a contaminant in solvents which are readily absorbed. The defatting action of benzene may produce primary irritation due to repeated or prolonged contact with the skin. High concentration are irritating to the eyes and the mucuous membranes of the nose, and respiratory tract.

III. Signs and Symptoms

Direct skin contact with benzene may cause erythema. Repeated or prolonged contact may result in drying, scaling dermatitis, or development of secondary skin infections. In addition, there is benzene absorption through the skin. Local effects of benzene vapor or liquid on the eye are slight. Only at very high concentrations is there any smarting sensation in the eye. Inhalation of high concentrations of benzene may have an initial stimulatory effect on the central nervous system characterized by exhilaration, nervous excitation, and/or giddiness, followed by a period of depression, drowsiness, or fatigue. A sensation of tightness in the chest accompanied by breathlessness may occur and ultimately the victim may lose consciousness. Tremors, convulsions and death may follow from respiratory paralysis or circulatory collapse in a few minutes to several hours following severe exposures.

The detrimental effect on the blood-forming system of prolonged exposure to small quantities of benzene vapor is of extreme importance. The hematopoietic system is the chief target for benzene's toxic effects which are manifested by alterations in the levels of formed elements in the peripheral blood. These effects have occurred at concentrations of benzene which may not cause irritation of mucous membranes, or any unpleasant sensory effects. Early signs and symptoms of benzene morbidity are varied, often not readily noticed and non-specific. Subjective complaints of headache, dizziness, and loss of appetite may precede or follow clinical signs. Rapid pulse and low blood pressure, in addition to a physical appearance of anemia, may accompany a subjective complaint of shortness of breath and excessive tiredness. Bleeding from the nose, gums, or mucous membranes, and the development of purpuric spots (small bruises) may occur as the condition

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progresses. Clinical evidence of leukopenia, anemia, and thrombocytopenia, singly or in combination, has been frequently reported among the first signs.

Bone marrow may appear normal, aplastic, or hyperplastic, and may not, in all situations, correlate with peripheral blood forming tissues. Because of variations in the susceptibility to benzene morbidity, there is no "typical" blood picture. The onset of effects of prolonged benzene exposure may be delayed for many months or years after the actual exposure has ceased and identification or correlation with benzene exposure must be sought out in the occupational history.

IV. Treatment of Acute Toxic Effects

Remove from exposure immediately. Make sure you are adequately protected and do not risk being overcome by fumes. Give oxygen or artificial resuscitation if indicated. Flush eyes, wash skin if contaminated and remove all contaminated clothing. Symptoms of intoxication may persist following severe exposures. Recovery from mild exposures is usually rapid and complete.

V. Surveillance and Preventive Considerations

A. General

The principal effects of benzene exposure which form the basis for this regulation are pathological changes in the hematopoietic system, reflected by changes in the peripheral blood and manifesting clinically as pancytopenia, aplastic anemia, and leukemia. Consequently, the medical surveillance program is designed to observe, on a regular basis, blood indices for early signs of these effects, and although early signs of leukemia are not usually available, emerging diagnostic technology and innovative regimes make consistent surveillance for leukemia, as well as other hematopoietic effects, essential.

Initial examinations are to be provided within 60 days of the effective date of this standard, or at the time of initial assignment, and periodic examinations annually thereafter. There are special provisions for medical tests in the event of hematologic abnormalities or for emergency situations.

The blood values which require referral to a hematologist or internist are noted in the standard in paragraph (i)(5). The standard specifies that blood abnormalities that persist must be referred "unless the physician has good reason to believe such referral is unnecessary" (paragraph (i)(5)). Examples of conditions that could make a referral unnecessary despite abnormal blood limits are iron or folate deficiency, menorrhagia, or blood loss due to some unrelated medical abnormality.

Symptoms and signs of benzene toxicity can be non-specific. Only a detailed history and appropriate investigative procedures will enable a physician to rule out or confirm conditions that place the employee at increased risk. To assist the examining physician with regard to which laboratory tests are necessary and when to refer an employee to the specialist, OSHA has established the following guidelines.

B. Hematology Guidelines

A minimum battery of tests is to be performed by strictly standardized methods.

1. Red cell, white cell, platelet counts, white blood cell differential, hematocrit and red cell indices must be performed by an accredited laboratory. The normal ranges for the red cell and white cell counts are influenced by altitude, race, and sex, and therefore should be determined by the accredited laboratory in the specific area where the tests are performed.

Either a decline from an absolute normal or an individual's base line to a subnormal value or a rise to a supra-normal value, are indicative of potential toxicity, particularly if all blood parameters decline. The normal total white blood count is approximately 7,200/mm ^{3} plus or minus 3,000. For cigarette smokers the white count may be higher and the upper range may be 2,000 cells higher than normal for the laboratory. In addition, infection, allergies and some drugs may raise the white cell count. The normal platelet count is approximately 250,000 with a range of 140,000 to 400,000. Counts outside this range should be regarded as possible evidence of benzene toxicity.

Certain abnormalities found through routine screening are of greater significance in the benzene-exposed worker and require prompt consultation with a specialist, namely:

a. Thrombocytopenia.

b. A trend of decreasing white cell, red cell, or platelet indices in an individual over time is more worrisome than an isolated abnormal finding at one test time. The importance of trend highlights the need to compare an individual's test results to baseline and/or previous periodic tests.

c. A constellation or pattern of abnormalities in the different blood indices is of more significance than a single abnormality. A low white count not associated with any abnormalities in other cell indices may be a normal statistical variation, whereas if the low white count is accompanied by decreases in the platelet and/or red cell indices, such a pattern is more likely to be associated with benzene toxicity and merits thorough investigation.

Anemia, leukopenia, macrocytosis or an abnormal differential white blood cell count should alert the physician to further investigate and/or refer the patient if repeat tests confirm the abnormalities. If routine screening detects an abnormality, follow-up tests which may be helpful in establishing the etiology of the abnormality are the peripheral blood smear and the reticulocyte count.

The extreme range of normal for reticulocytes is 0.4 to 2.5 percent of the red cells, the usual range being 0.5 to 1.2 percent of the red cells, but the typical value is in the range of 0.8 to 1.0 percent. A decline in reticulocytes to levels of less than 0.4 percent is to be regarded as possible evidence (unless another specific cause is found) of benzene toxicity requiring accelerated surveillance. An increase in reticulocyte levels to about 2.5 percent may also be consistent with (but is not as characteristic of) benzene toxicity.

2. An important diagnostic test is a careful examination of the peripheral blood smear. As with reticulocyte count the smear should be with fresh uncoagulated blood obtained from a needle tip following venipuncture or from a drop of earlobe blood (capillary blood). If necessary, the smear may, under certain limited conditions, be made from a blood sample anticoagulated with EDTA (but never with oxalate or heparin). When the smear is to be prepared from a specimen of venous blood which has been collected by a commercial Vacutainer® type tube containing neutral EDTA, the smear should be made as soon as possible after the venesection. A delay of up to 12 hours is permissible between the drawing of the blood specimen into EDTA and the preparation of the smear if the blood is stored at refrigerator (not freezing) temperature.

3. The minimum mandatory observations to be made from the smear are:

a. The differential white blood cell count.

b. Description of abnormalities in the appearance of red cells.

c. Description of any abnormalities in the platelets.

d. A careful search must be made throughout of every blood smear for immature white cells such as band forms (in more than normal proportion,

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i.e., over 10 percent of the total differential count), any number of metamyelocytes, myelocytes or myeloblasts. Any nucleate or multinucleated red blood cells should be reported. Large "giant" platelets or fragments of megakaryocytes must be recognized.

An increase in the proportion of band forms among the neutrophilic granulocytes is an abnormality deserving special mention, for it may represent a change which should be considered as an early warning of benzene toxicity in the absence of other causative factors (most commonly infection). Likewise, the appearance of metamyelocytes, in the absence of another probable cause, is to be considered a possible indication of benzene-induced toxicity.

An upward trend in the number of basophils, which normally do not exceed about 2.0 percent of the total white cells, is to be regarded as possible evidence of benzene toxicity. A rise in the eosinophil count is less specific but also may be suspicious of toxicity if the rises above 6.0 percent of the total white count.

The normal range of monocytes is from 2.0 to 8.0 percent of the total white count with an average of about 5.0 percent. About 20 percent of individuals reported to have mild but persisting abnormalities caused by exposure to benzene show a persistent monocytosis. The findings of a monocyte count which persists at more than 10 to 12 percent of the normal white cell count (when the total count is normal) or persistence of an absolute monocyte count in excess of 800/mm ^{3} should be regarded as a possible sign of benzene-induced toxicity.

A less frequent but more serious indication of benzene toxicity is the finding in the peripheral blood of the so-called "pseudo" (or acquired) Pelger-Huet anomaly. In this anomaly many, or sometimes the majority, of the neutrophilic granulocytes possess two round nuclear segements—less often one or three round segments—rather than three normally elongated segments. When this anomaly is not hereditary, it is often but not invariably predictive of subsequent leukemia. However, only about two percent of patients who ultimately develop acute myelogenous leukemia show the acquired Pelger-Huet anomaly. Other tests that can be administered to investigate blood abnormalities are discussed below; however, such procedures should be undertaken by the hematologist.

An uncommon sign, which cannot be detected from the smear, but can be elicited by a "sucrose water test" of peripheral blood, is transient paroxysmal nocturnal hemoglobinuria (PNH), which may first occur insidiously during a period of established aplastic anemia, and may be followed within one to a few years by the appearance of rapidly fatal acute myelogenous leukemia. Clinical detection of PNH, which occurs in only one or two percent of those destined to have acute myelogenous leukemia, may be difficult; if the "sucrose water test" is positive, the somewhat more definitive Ham test, also known as the acid-serum hemolysis test, may provide confirmation.

e. Individuals documented to have developed acute myelogenous leukemia years after initial exposure to benzene may have progressed through a preliminary phase of hematologic abnormality. In some instances pancytopenia (i.e., a lowering in the counts of all circulating blood cells of bone marrow origin, but not to the extent implied by the term "aplastic anemia") preceded leukemia for many years. Depression of a single blood cell type or platelets may represent a harbinger of aplasia or leukemia. The finding of two or more cytopenias, or pancytopenia in a benzene-exposed individual, must be regarded as highly suspicious of more advanced although still reversible, toxicity. "Pancytopenia" coupled with the appearance of immature cells (myelocytes, myeloblasts, erythroblasts, etc.), with abnormal cells (pseudo Pelger-Huet anomaly, atypical nuclear heterochromatin, etc.), or unexplained elevations of white blood cells must be regarded as evidence of benzene overexposure unless proved otherwise. Many severely aplastic patients manifested the ominous finding of 5–10 percent myeloblasts in the marrow, occasional myeloblasts and myelocytes in the blood and 20–30% monocytes. It is evident that isolated cytopenias, pancytopenias, and even aplastic anemias induced by benzene may be reversible and complete recovery has been reported on cessation of exposure. However, since any of these abnormalities is serious, the employee must immediately be removed from any possible exposure to benzene vapor. Certain tests may substantiate the employee's prospects for progression or regression. One such test would be an examination of the bone marrow, but the decision to perform a bone marrow aspiration or needle biopsy is made by the hematologist.

The findings of basophilic stippling in circulating red blood cells (usually found in 1 to 5% of red cells following marrow injury), and detection in the bone marrow of what are termed "ringed sideroblasts" must be taken seriously as they have been noted in recent years to be premonitory signs of subsequent leukemia.

Recently peroxidase staining of circulating or marrow neutrophil granulocytes, employing benzidine dihydrochloride, have revealed the disappearance of, or diminution in, peroxidase in a sizable proportion of the granulocytes, and this has been reported as an early sign of leukemia. However, relatively few patients have been studied to date. Granulocyte granules are normally strongly peroxidase positive. A steady decline in leukocyte alkaline phosphatase has also been reported as suggestive of early acute leukemia. Exposure to benzene may cause an early rise in serum iron, often but not always associated with a fall in the reticulocyte count. Thus, serial measurements of serum iron levels may provide a means of determining whether or not there is a trend representing sustained suppression of erythropoiesis.

Measurement of serum iron, determination of peroxidase and of alkaline phosphatase activity in peripheral granulocytes can be performed in most pathology laboratories. Peroxidase and alkaline phosphatase staining are usually undertaken when the index of suspicion for leukemia is high.

Appendix D—Sampling and Analytical Methods for Benzene Monitoring and Measurement Procedures

Measurements taken for the purpose of determining employee exposure to benzene are best taken so that the representative average 8-hour exposure may be determined from a single 8-hour sample or two (2) 4-hour samples. Short-time interval samples (or grab samples) may also be used to determine average exposure level if a minimum of five measurements are taken in a random manner over the 8-hour work shift. Random sampling means that any portion of the work shift has the same change of being sampled as any other. The arithmetic average of all such random samples taken on one work shift is an estimate of an employee's average level of exposure for that work shift. Air samples should be taken in the employee's breathing zone (air that would most nearly represent that inhaled by the employee). Sampling and analysis must be performed with procedures meeting the requirements of the standard.

There are a number of methods available for monitoring employee exposures to benzene. The sampling and analysis may be performed by collection

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of the benzene vaptor or charcoal absorption tubes, with subsequent chemical analysis by gas chromatography. Sampling and analysis may also be performed by portable direct reading instruments, real-time continuous monitoring systems, passive dosimeters or other suitable methods. The employer has the obligation of selecting a monitoring method which meets the accuracy and precision requirements of the standard under his unique field conditions. The standard requires that the method of monitoring must have an accuracy, to a 95 percent confidence level, of not less than plus or minus 25 percent for concentrations of benzene greater than or equal to 0.5 ppm.

The OSHA Laboratory modified NIOSH Method S311 and evaluated it at a benzene air concentration of 1 ppm. A procedure for determining the benzene concentration in bulk material samples was also evalauted. This work, reported in OSHA Laboratory Method No. 12, includes the following two analytical procedures:

I. OSHA Method 12 for Air Samples

Analyte: Benzene
Matrix: Air
Procedure: Adsorption on charcoal, desorption with carbon disulfide, analysis by GC.
Detection limit: 0.04 ppm
Recommended air volume and sampling rate: 10L to 0.2 L/min.

1. Principle of the Method.

1.1 A known volume of air is drawn through a charcoal tube to trap the organic vapors present.

1.2. The charcoal in the tube is transferred to a small, stoppered vial, and the anlyte is desorbed with carbon disulfide.

1.3. An aliquot of the desorbed sample is injected into a gas chromatograph.

1.4 The area of the resulting peak is determined and compared with areas obtained from standards.

2. Advantages and disadvantages of the method.

2.1 The sampling device is small, portable, and involved no liquids. Interferences are minimal, and most of those which do occur can be eliminated by altering chromatographic conditions. The samples are analyzed by means of a quick, instrumental method.

2.2 The amount of sample which can be taken is limited by the number of milligrams that the tube will hold before overloading. When the sample value obtained for the backup section of the charcoal tube exceeds 25 percent of that found on the front section, the possibility of sample loss exists.

3. Apparatus.

3.1 A calibrated personal sampling pump whose flow can be determined within ±5 percent at the recommended flow rate.

3.2. Charcoal tubes: Glass with both ends flame sealed, 7 cm long with a 6-mm O.D. and a 4-mm I.D., containing 2 sections of 20/40 mesh activated charcoal separated by a 2-mm portion of urethane foam. The activated charcoal is prepared from coconut shells and is fired at 600 °C prior to packing. The adsorbing section contains 100 mg of charcoal, the back-up section 50 mg. A 3-mm portion of urethane foam is placed between the outlet end of the tube and the back-up section. A plug of silanized glass wool is placed in front of the adsorbing section. The pressure drop across the tube must be less than one inch of mercury at a flow rate of 1 liter per minute.

3.3. Gas chromatograph equipped with a flame ionization detector.

3.4. Column (10-ft × ⅛-in stainless steel) packed with 80/100 Supelcoport coated with 20 percent SP 2100, 0.1 percent CW 1500.

3.5. An electronic integrator or some other suitable method for measuring peak area.

3.6. Two-milliliter sample vials with Teflon-lined caps.

3.7. Microliter syringes: 10-microliter (10-μL syringe, and other convenient sizes for making standards, 1-μL syringe for sample injections.

3.8. Pipets: 1.0 mL delivery pipets

3.9. Volumetric flasks: convenient sizes for making standard solutions.

4. Reagents.

4.1. Chromatographic quality carbon disulfide (CS_2). Most commercially available carbon disulfide contains a trace of benzene which must be removed. It can be removed with the following procedure:

Heat under reflux for 2 to 3 hours, 500 mL of carbon disulfide, 10 mL concentrated sulfuric acid, and 5 drops of concentrated nitric acid. The benzene is converted to nitrobenzene. The carbon disulfide layer is removed, dried with anhydrous sodium sulfate, and distilled. The recovered carbon disulfide should be benzene free. (It has recently been determined that benzene can also be removed by passing the carbon disulfide through 13x molecular sieve).

4.2. Benzene, reagent grade.

4.3. p-Cymene, reagent grade, (internal standard).

4.4. Desorbing reagent. The desorbing reagent is prepared by adding 0.05 mL of p-cymene per milliliter of carbon disulfide. (The internal standard offers a convenient means correcting analytical response for slight inconsistencies in the size of sample injections. If the external standard technique is preferred, the internal standard can be eliminated).

4.5. Purified GC grade helium, hydrogen and air.

5. Procedure.

5.1. Cleaning of equipment. All glassware used for the laboratory analysis should be properly cleaned and free of organics which could interfere in the analysis.

5.2. Calibration of personal pumps. Each pump must be calibrated with a representative charcoal tube in the line.

5.3. Collection and shipping of samples.

5.3.1. Immediately before sampling, break the ends of the tube to provide an opening at least one-half the internal diameter of the tube (2 mm).

5.3.2. The smaller section of the charcoal is used as the backup and should be placed nearest the sampling pump.

5.3.3. The charcoal tube should be placed in a vertical position during sampling to minimize channeling through the charcoal.

5.3.4 Air being sampled should not be passed through any hose or tubing before entering the charcoal tube.

5.3.5. A sample size of 10 liters is recommended. Sample at a flow rate of approximately 0.2 liters per minute. The flow rate should be known with an accuracy of at least ±5 percent.

5.3.6. The charcoal tubes should be capped with the supplied plastic caps immediately after sampling.

5.3.7. Submit at least one blank tube (a charcoal tube subjected to the same handling procedures, without having any air drawn through it) with each set of samples.

5.3.8. Take necessary shipping and packing precautions to minimize breakage of samples.

5.4. Analysis of samples.

5.4.1. Preparation of samples. In preparation for analysis, each charcoal tube is scored with a file in front of the first section of charcoal and broken open. The glass wool is removed and discarded. The charcoal in the first (larger) section is transferred to a 2-ml vial. The separating section of foam is removed and discarded; the second section is transferred to another capped vial. These two sections are analyzed separately.

5.4.2. Desorption of samples. Prior to analysis, 1.0 mL of desorbing solution is pipetted into each sample container. The desorbing solution consists of 0.05 μL internal standard per mL of carbon disulfide. The sample vials are capped as soon as the solvent is added. Desorption should be done for 30 minutes with occasional shaking.

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5.4.3. GC conditions. Typical operating conditions for the gas chromatograph are:

1.30 mL/min (60 psig) helium carrier gas flow.

2.30 mL/min (40 psig) hydrogen gas flow to detector.

3.240 mL/min (40 psig) air flow to detector.

4.150 °C injector temperature.

5.250 °C detector temperature.

6.100 °C column temperature.

5.4.4. Injection size. 1 µL.

5.4.5. Measurement of area. The peak areas are measured by an electronic integrator or some other suitable form of area measurement.

5.4.6. An internal standard procedure is used. The integrator is calibrated to report results in ppm for a 10 liter air sample after correction for desorption efficiency.

5.5. Determination of desorption efficiency.

5.5.1. Importance of determination. The desorption efficiency of a particular compound can vary from one laboratory to another and from one lot of chemical to another. Thus, it is necessary to determine, at least once, the percentage of the specific compound that is removed in the desorption process, provided the same batch of charcoal is used.

5.5.2. Procedure for determining desorption efficiency. The reference portion of the charcoal tube is removed. To the remaining portion, aliquots of (3) representing 0.5X, 1X, and 2X amt (X = represents target concentration) based on a 10 L air sample are injected into several tubes at each level. Dilutions of benzene with carbon disulfide are made to allow injection of measurable quantities. These tubes are then allowed to equilibrate at least overnight. Following equilibration they are analyzed following the same procedure as the samples. Desorption efficiency is determined by dividing the amount of benzene found by amount spiked on the tube.

6. Calibration and standards. A series of standards varying in concentration over the range of interest is prepared and analyzed under the same GC conditions that will be used on the samples. A calibration curve is prepared by plotting concentration (µg/mL) versus peak area.

7. Calculations. Benzene air concentration can be calculated from the following equation:

$mg/m^3 = (A)(B)/(C)(D)$

Where: A = µg/mL benzene, obtained from the calibration curve

B = desorption volume (1 mL)

C = Liters of air sampled

D = desorption efficiency

The concentration in mg/m^3 can be converted to ppm (at 25° and 760 mm) with following equation:

$ppm = (mg/m^3)(24.46)/(78.11)$

Where: 24.46 = molar volume of an ideal gas at 25 °C and 760 mm

78.11 = molecular weight of benzene

8. Backup Data.

8.1 Detection limit—Air Samples.

The detection limit for the analytical procedure is 1.26 ng with a coefficient of variation of 0.023 at this level. This would be equivalent to an air concentration of 0.04 ppm for a 10 L air sample. This amount provided a chromatographic peak that could be identifiable in the presence of possible interferences. The detection limit data were obtained by making 1 µL injections of a 1.263 µg/mL standard.

Injection	Area Count	
1	655.4	
2	617.5	
3	662.0	X = 640.2
4	641.1	SD = 14.9
5	636.4	CV = 0.023
6	629.2	

8.2. Pooled coefficient of variation—Air Samples. The pooled coefficient of variation for the analytical procedure was determined by 1 µL replicate injections of analytical standards. The standards were 16.04, 32.08, and 64.16 µg/mL, which are equivalent to 0.5, 1.0, and 2.0 ppm for a 10 L air sample respectively.

Injection	Area Counts		
	0.5 ppm	1.0 ppm	2.0 ppm
1	3996.5	8130.2	16481
2	4059.4	8235.6	16493
3	4052.0	8307.9	16535
4	4027.2	8263.2	16609
5	4046.8	8291.1	16552
6	4137.9	8288.8	16618
X =	4053.3	8254.0	16548.3
SD =	47.2	62.5	57.1
CV =	0.0116	0.0076	0.0034
CV = 0.008			

8.3. Storage data—Air Samples

Samples were generated at 1.03 ppm benzene at 80% relative humidity, 22 °C, and 643 mm. All samples were taken for 50 minutes at 0.2 L/min. Six samples were analyzed immediately and the rest of the samples were divided into two groups by fifteen samples each. One group was stored at refrigerated temperature of −25 °C, and the other group was stored at ambient temperature (approximately 23 °C). These samples were analyzed over a period of fifteen days. The results are tabulated below.

PERCENT RECOVERY

Day analyzed	Refrigerated			Ambient		
0	97.4	98.7	98.9	97.4	98.7	98.9
0	97.1	100.6	100.9	97.1	100.6	100.9
2	95.8	96.4	95.4	95.4	96.6	96.9
5	93.9	93.7	92.4	92.4	94.3	94.1
9	93.6	95.5	94.6	95.2	95.6	96.6
13	94.3	95.3	93.7	91.0	95.0	94.6

PERCENT RECOVERY—Continued

Day analyzed	Refrigerated			Ambient		
15	96.8	95.8	94.2	92.9	96.3	95.9

8.4. Desorption data.

Samples were prepared by injecting liquid benzene onto the A section of charcoal tubes. Samples were prepared that would be equivalent to 0.5, 1.0, and

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2.0 ppm for a 10 L air sample.

PERCENT RECOVERY (DOT)

Sample	0.5 ppm	1.0 ppm	2.0 ppm
1	99.4	98.8	99.5
2	99.5	98.7	99.7
3	99.2	98.6	99.8
4	99.4	99.1	100.0
5	99.2	99.0	99.7
6	99.8	99.1	99.9
X=	99.4	98.9	99.8
SD=	0.22	0.21	0.19
CV=	0.0022	0.0021	0.0018
X=99.4			

8.5. Carbon disulfide

Carbon disulfide from a number of sources was analyzed for benzene contamination. The results are given in the following table. The benzene contamiant can be removed with the procedures given in section 4.1.

Sample	µg Benzene/mL	ppm equivalent (for 10 L air sample)
Aldrich Lot 83017	4.20	0.13
Baker Lot 720364	1.01	0.03
Baker Lot 822351	1.01	0.03
Malinkrodt Lot WEMP	1.74	0.05
Malinkrodt Lot WDSJ	5.85	0.18
Malinkrodt Lot WHGA	2.90	0.09
Treated CS_2		

II. OSHA Laboratory Method No. 12 for Bulk Samples

Analyte: Benzene.

Matrix: Bulk Samples.

Procedure: Bulk Samples are analyzed directly by high performance liquid chromatography (HPLC).

Detection limits: 0.01% by volume.

1. Principle of the method.

1.1. An aliquot of the bulk sample to be analyzed is injected into a liquid chromatograph.

1.2. The peak area for benzene is determined and compared to areas obtained from standards.

2. Advantages and disadvantages of the method.

2.1. The analytical procedure is quick, sensitive, and reproducible.

2.2. Reanalysis of samples is possible.

2.3. Interferences can be circumvented by proper selection of HPLC parameters.

2.4. Samples must be free of any particulates that may clog the capillary tubing in the liquid chromatograph. This may require distilling the sample or clarifying with a clarification kit.

3. Apparatus.

3.1. Liquid chromatograph equipped with a UV detector.

3.2. HPLC Column that will separate benzene from other components in the bulk sample being analyzed. The column used for validation studies was a Waters uBondapack C18, 30 cm x 3.9 mm.

3.3. A clarification kit to remove any particulates in the bulk if necessary.

3.4. A micro-distillation apparatus to distill any samples if necessary.

3.5. An electronic integrator or some other suitable method of measuring peak areas.

3.6. Microliter syringes—10 µL syringe and other convenient sizes for making standards. 10 µL syringe for sample injections.

3.7 Volumetric flasks, 5 mL and other convenient sizes for preparing standards and making dilutions.

4. Reagents.

4.1. Benzene, reagent grade.

4.2. HPLC grade water, methyl alcohol, and isopropyl alcohol.

5. Collection and shipment of samples.

5.1. Samples should be transported in glass containers with Teflon-lined caps.

5.2. Samples should not be put in the same container used for air samples.

6. Analysis of samples.

6.1. Sample preparation.

If necessary, the samples are distilled or clarified. Samples are analyzed undiluted. If the benzene concentration is out of the working range, suitable dilutions are made with isopropyl alcohol.

6.2. HPLC conditions.

The typical operating conditions for the high performance liquid chromatograph are:

1. Mobile phase—Methyl alcohol/water, 50/50

1. Analytical wavelength—254 nm

3. Injection size—10 µL

6.3. Measurement of peak area and calibration.

Peak areas are measured by an integrator or other suitable means. The integrator is calibrated to report results in % in benzene by volume.

7. Calculations.

Since the integrator is programmed to report results in % benzene by volume in an undiluted sample, the following equation is used:

% Benzene by Volume = A x B

Where: A = % by volume on report
B = Dilution Factor
(B = 1 for undiluted sample)

8. Backup Data.

8.1. Detection limit—Bulk Samples.

The detection limit for the analytical procedure for bulk samples is 0.88 µg, with a coefficient of variation of 0.019 at this level. This amount provided a chromatographic peak that could be identifiable in the presence of possible interferences. The detection limit date were obtained by making 10 µL injections of a 0.10% by volume standard.

1	45386	
2	44214	
3	43822	X=44040.1
4	44062	SD=852.5
6	42724	CV=0.019

8.2. Pooled coefficient of variation—Bulk Samples.

The pooled coefficient of variation for analytical procedure was determined by 50 µL replicate injections of analytical standards. The standards were 0.01, 0.02, 0.04, 0.10, 1.0, and 2.0% benzene by volume.

AREA COUNT (PERCENT)

Injection No.	0.01	0.02	0.04	0.10	1.0	2.0
1	45386	84737	166097	448497	4395380	9339150
2	44241	84300	170832	441299	4590800	9484900
3	43822	83835	164160	443719	4593200	9557580
4	44062	84381	164445	444842	4642350	9677060
5	44006	83012	168398	442564	4646430	9766240
6	42724	81957	173002	443975	4646260	
X =	44040.1	83703.8	167872	444149	4585767	9564986
SD =	852.5	1042.2	3589.8	2459.1	96839.3	166233
CV =	0.0194	0.0125	0.0213	0.0055	0.0211	0.0174
CV =	0.017					

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Appendix E: Qualitative and Quantitative Fit Testing Procedures

I. Fit Test Protocols

A. The employer shall include the following provisions in the fit test procedures. These provisions apply to both qualitative fit testing (QLFT) and quantitative fit testing (QNFT).

1. The test subject shall be allowed to pick the most comfortable respirator from a selection including respirators of various sizes from different manufacturers. The selection shall include at least three sizes of elastomeric facepieces of the type of respirator that is to be tested, i.e., three sizes of half mask; or three sizes of full facepiece; and units from at least two manufacturers.

2. Prior to the selection process, the test subject shall be shown how to put on a respirator, how it should be positioned on the face, how to set strap tension and how to determine a comfortable fit. A mirror shall be available to assist the subject in evaluating the fit and positioning the respirator. This instruction may not constitute the subject's formal training on respirator use, at it is only a review.

3. The test subject shall be informed that he/she is being asked to select the respirator which provides the most comfortable fit. Each respirator represents a different size and shape, and if fitted and used properly, will provide adequate protection.

4. The test subject shall be instructed to hold each facepiece up to the face and eliminate those which obviously do not give a comfortable fit.

5. The more comfortable facepieces are noted; the most comfortable mask is donned and worn at least five minutes to assess comfort. Assistance in assessing comfort can be given by discussing the points in item 6 below. If the test subject is not familiar with using a particular respirator, the test subject shall be directed to don the mask several times and to ajust the straps each time to become adept at setting proper tension on the straps.

6. Assessment of comfort shall include reviewing the following points with the test subject and allowing the test subject adequate time to determine the comfort of the respirator:

(a) Position of the mask on the nose.

(b) Room for eye protection.

(c) Room to talk.

(d) Position of mask on face and cheeks.

7. The following criteria shall be used to help determine the adequacy of the respirator fit:

(a) Chin properly placed;

(b) Adequate strap tension, not overly tightened;

(c) Fit across nose bridge;

(d) Respirator of proper size to span distance from nose to chin;

(e) Tendency of respirator to slip;

(f) Self-observation in mirror to evaluate fit and respirator position.

8. The test subject shall conduct the negative and positive pressure fit checks as described below or ANSI Z88.2–1980. Before conducting the negative or positive pressure test, the subject shall be told to seat the mask on the face by moving the head from side-to-side and up and down slowly while taking in a few slow deep breaths. Another facepiece shall be selected and retested if the test subject fails the fit check tests.

(a) *Positive pressure test.* Close off the exhalation value and exhale gently onto the facepiece. The face fit is considered satisfactory if a slight positive pressure can be built up inside the facepiece without any evidence of outward leakage of air at the seal. For most respirators this method of leak testing requires the wearer to first remove the exhalation value cover before closing off the exhalation value and then carefully replacing it after the test.

(b) *Negative pressure test.* Close off the inlet opening of the canister or cartridge(s) by covering with the palm of the hand(s) or by replacing the filter seal(s), inhale gently so that the facepiece collapses slightly, and hold the breath for ten seconds. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the tightness of the respirator is considered satisfactory.

9. The test shall not be conducted if there is any hair growth between the skin and the facepiece sealing surface, such as stubble beard growth, beard, or long sideburns which cross the respirator sealing surface. Any type of apparel which interferes with a satisfactory fit shall be altered or removed.

10. If a test subject exhibits difficulty in breathing during the tests, she or he shall be referred to a physician trained in respiratory disease or pulmonary medicine to determine whether the test subject can wear a respirator while performing her or his duties.

11. The test subject shall be given the opportunity to wear the successfully fitted respirator for a period of two weeks. If at any time during this period the respirator becomes uncomfortable, the test subject shall be given the opportunity to select a different facepiece and to be retested.

12. The employer shall certify that a successful fit test has been administered to the employee. The certification shall include the following information:

(a) Name of employee;

(b) Type, brand and size of respirator; and

(c) Date of test.

Where QNFT is used, the fit factor, strip chart, or other recording of the results of the test, shall be retained with the certification. The certification shall be maintained until the next fit test is administered.

13. Exercise regimen. Prior to the commencement of the fit test, the test subject shall be given a description of the fit test and the test subject's responsibilities during the test procedure. The description of the process shall include a description of the test exercises that the subject will be performing. The respirator to be tested shall be worn for at least 5 minutes before the start of the fit test.

14. Test Exercises. The test subject shall perform exercises, in the test environment, in the manner described below:

(a) Normal breathing. In a normal standing position, without talking, the subject shall breathe normally.

(b) Deep breathing. In a normal standing position, the subject shall breathe slowly and deeply, taking caution so as to not hyperventilate.

(c) Turning head side to side. Standing in place, the subject shall slowly turn his/her head from side to side between the extreme positions on each side. The head shall be held at each extreme momentarily so the subject can inhale at each side.

(d) Moving head up and down. Standing in place, the subject shall slowly move his/her head up and down. The subject shall be instructed to inhale in the up position (i.e., when looking toward the ceiling).

(e) Talking. The subject shall talk out loud slowly and loud enough so as to be heard clearly by the test conductor. The subject can read from a prepared text such as the Rainbow Passage, count backward from 100, or recite a memorized poem or song.

(f) Grimace. The test subject shall grimace by smiling or frowning.

(g) Bending over. The test subject shall bend at the waist as if he/she were to touch his/her toes. Jogging in place shall be substituted for this exercise in those test environments such as shroud type QNFT units which prohibit bending at the waist.

(h) Normal breathing. Same as exercise 1.

Each test exercise shall be performed for one minute except for the grimace

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exercise which shall be performed for 15 seconds.

The test subject shall be questioned by the test conductor regarding the comfort of the respirator upon completion of the protocol. If it has become uncomfortable, another model of respirator shall be tried.

B. Qualitative Fit Test (QLFT) Protocols.

1. General.

(a) The employer shall assign specific individuals who shall assume full responsibility for implementing the respirator qualitative fit test program.

(b) The employer shall ensure that persons administering QLFT are able to prepare test solutions, calibrate equipment and perform tests properly, recognize invalid tests, and assure that test equipment is in proper working order.

(c) The employer shall assure that QLFT equipment is kept clean and well maintained so as to operate at the parameters for which it was designed.

2. *Isoamyl Acetate Protocol.*

(a) Odor threshold screening.

The odor threshold screening test, performed without wearing a respirator, is intended to determine if the individual tested can detect the odor of isoamyl acetate.

(1) Three 1-liter glass jars with metal lids are required.

(2) Odor free water (e.g. distilled or spring water) at approximately 25 degrees C shall be used for the solutions.

(3) The isoamyl acetate (IAA) (also known as isopentyl acetate) stock solution is prepared by adding 1 cc of pure IAA to 800 cc of odor free water in a 1 liter jar and shaking for 30 seconds. A new solution shall be prepared at least weekly.

(4) The screening test shall be conducted in a room separate from the room used for actual fit testing. The two rooms shall be well ventilated but shall not be connected to the same recirculating ventilation system.

(5) The odor test solution is prepared in a second jar by placing 0.4 cc of the stock solution into 500 cc of odor free water using a clean dropper or pipette. The solution shall be shaken for 30 seconds and allowed to stand for two to three minutes so that the IAA concentration above the liquid may reach equilibrium. This solution shall be used for only one day.

(6) A test blank shall be prepared in a third jar by adding 500 cc of odor free water.

(7) The odor test and test blank jars shall be labeled 1 and 2 for jar identification. Labels shall be placed on the lids so they can be periodically peeled, dried off and switched to maintain the integrity of the test protocol.

(8) The following instruction shall be typed on a card and placed on the table in front of the two test jars (i.e., 1 and 2): "The purpose of this test is to determine if you can smell banana oil at a low concentration. The two bottles in front of you contain water. One of these bottles also contains a small amount of banana oil. Be sure the covers are on tight, then shake each bottle for two seconds. Unscrew the lid of each bottle, one at a time, and sniff at the mouth of the bottle. Indicate to the test conductor which bottle contains banana oil."

(9) The mixtures used in the IAA odor detection test shall be prepared in an area separate from where the test is performed, in order to prevent olfactory fatigue in the subject.

(10) If the test subject is unable to correctly identify the jar containing the odor test solution, the IAA qualitative fit test shall not be performed.

(11) If the test subject correctly identifies the jar containing the odor test solution, the test subject may proceed to respirator selection and fit testing.

(b) Isoamyl acetate fit test.

(1) The fit test chamber shall be similar to a clear 55-gallon drum liner suspended inverted over a 2-foot diameter frame so that the top of the chamber is about 6 inches above the test subject's head. The inside top center of the chamber shall have a small hook attached.

(2) Each respirator used for the fitting and fit testing shall be equipped with organic vapor cartridges or offer protection against organic vapors. The cartridges or masks shall be changed at least weekly.

(3) After selecting, donning, and properly adjusting a respirator, the test subject shall wear it to the fit testing room. This room shall be separate from the room used for odor threshold screening and respirator selection, and shall be well ventilated, as by an exhaust fan or lab hood, to prevent general room contamination.

(4) A copy of the test exercises and any prepared text from which the subject is to read shall be taped to the inside of the test chamber.

(5) Upon entering the test chamber, the test subject shall be given a 6-inch by 5-inch piece of paper towel, or other porous, absorbent, single-ply material, folded in half and wetted with 0.75 cc of pure IAA. The test subject shall hand the wet towel on the hook at the top of the chamber.

(6) Allow two minutes for the IAA test concentration to stabilize before starting the fit test exercises. This would be an appropriate time to talk with the test subject; to explain the fit test, the importance of his/her cooperation, and the purpose for the head exercises; or to demonstrate some of the exercises.

(7) If at any time during the test, the subject detects the banana like odor of IAA, the test has failed. The subject shall quickly exit from the test chamber and leave the test area to avoid olfactory fatigue.

(8) If the test has failed, the subject shall return to the selection room and remove the respirator, repeat the odor sensitivity test, select and put on another respirator, return to the test chamber and again begin the procedure described in (1) through (7) above. The process continues until a respirator that fits well has been found. Should the odor sensitivity test be failed, the subject shall wait about 5 minutes before retesting. Odor sensitivity will usually have returned by this time.

(9) When a respirator is found that passes the test, its efficiency shall be demonstrated for the subject by having the subject break the face seal and take a breath before existing the chamber.

(10) When the test subject leaves the chamber, the subject shall remove the saturated towel and return it to the person conducting the test. To keep the test area from becoming contaminated, the used towels shall be kept in a self sealing bag so there is no significant IAA concentration build-up in the test chamber during subsequent tests.

3. *Saccharin Solution Aerosol Protocol.*

The saccharin solution aerosol QLFT protocol is the only currently available, validated test protocol for use with particulate disposable dust respirators not equipped with high-efficiency filters. The entire screening and testing procedure shall be explained to the test subject prior to the conduct of the screening test.

(a) Taste threshold screening.

The saccharin taste threshold screening, performed without wearing a respirator, is intended to determine whether the individual being tested can detect the taste of saccharin.

(1) Threshold screening as well as fit testing subjects shall wear an enclosure about the head and shoulders that is approximately 12 inches in diameter by 14 inches tall with at least the front portion clear and that allows free movements of the head when a respirator is worn. An enclosure substantially similar to the 3M hood assembly, parts # FT 14 and # FT 15 combined, is adequate.

(2) The test enclosure shall have a ¾ inch hole in front of the test subject's

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nose and mouth area to accommodate the nebulizer nozzle.

(3) The test subject shall don the test enclosure. Throughout the threshold screening test, the test subject shall breathe through his/her wide open mouth with tongue extended.

(4) Using a DeVilbiss Model 40 Inhalation Medication Nebulizer the test conductor shall spray the *threshold check solution* into the enclosure. This nebulizer shall be clearly marked to distinguish it from the fit test solution nebulizer.

(5) The *threshold check solution* consists of 0.83 grams of sodium saccharin USP in 1 cc of warm water. It can be prepared by putting 1 cc of the fit test solution (see (b)(5) below) in 100 cc of distilled water.

(6) To produce the aerosol, the nebulizer bulb is firmly squeezed so that it collapses completely, then released and allowed to fully expand.

(7) Ten squeezes are repeated rapidly and then the test subject is asked whether the saccharin can be tasted.

(8) If the first response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the saccharin is tasted.

(9) If the second response is negative, ten more squeezes are repeated rapidly and the test subject is again asked whether the saccharin is tasted.

(10) The test conductor will take note of the number of squeezes required to solicit a taste response.

(11) If the saccharin is not tasted after 30 squeezes (step 10), the test subject may not perform the saccharin fit test.

(12) If a taste response is elicited, the test subject shall be asked to take note of the taste for reference in the fit test.

(13) Correct use of the nebulizer means that approximately 1 cc of liquid is used at a time in the nebulizer body.

(14) The nebulizer shall be thoroughly rinsed in water, shaken dry, and refilled at least each morning and afternoon or at least every four hours.

(b) Saccharin solution aerosol fit test procedure.

(1) The test subject may not eat, drink (except plain water), or chew gum for 15 minutes before the test.

(2) The fit test uses the same enclosure described in (a) above.

(3) The test subject shall don the enclosure while wearing the respirator selected in section (a) above. The respirator shall be properly adjusted and equipped with a particulate filter(s).

(4) A second DeVilbiss Model 40 Inhalation Medication Nebulizer is used to spray the fit test solution into the enclosure. This nebulizer shall be clearly marked to distinguish it from the screening test solution nebulizer.

(5) The fit test solution is prepared by adding 83 grams of sodium saccharin to 100 cc of warm water.

(6) As before, the test subject shall breathe through the open mouth with tongue extended.

(7) The nebulizer is inserted into the hole in the front of the enclosure and the fit test solution is sprayed into the enclosure using the same number of squeezes required to elicit a taste response in the screening test.

(8) After generating the aerosol the test subject shall be instructed to perform the exercises in section I. A. 14 above.

(9) Every 30 seconds the aerosol concentration shall be replenished using one half the number of squeezes as initially.

(10) The test subject shall indicate to the test conductor if at any time during the fit test the taste of saccharin is detected.

(11) If the taste of saccharin is detected, the fit is deemed unsatisfactory and a different respirator shall be tried.

4. *Irritant Fume Protocol.*

(a) The respirator to be tested shall be equipped with high-efficiency particulate air (HEPA) filters.

(b) The test subject shall be allowed to smell a weak concentration of the irritant smoke before the respirator is donned to become familiar with its characteristic odor.

(c) Break both ends of a ventilation smoke tube containing stannic oxychloride, such as the MSA part No. 5645, or equivalent. Attach one end of the smoke tube to a low flow air pump set to deliver 200 milliliters per minute.

(d) Advise the test subject that the smoke can be irritating to the eyes and instruct the subject to keep his/her eyes closed while the test is performed.

(e) The test conductor shall direct the stream of irritant smoke from the smoke tube towards the face seal area of the test subject. He/She shall begin at least 12 inches from the facepiece and gradually move to within one inch, moving around the whole perimeter of the mask.

(f) The exercises identified in section I. A. 14 above shall be performed by the test subject while the respirator seal is being challenged by the smoke.

(g) Each test subject passing the smoke test without evidence of a response shall be given a sensitivity check of the smoke from the same tube once the respirator has been removed to determine whether he/she reacts to the smoke. Failure to evoke a response shall void the fit test.

(h) The fit test shall be performed in a location with exhaust ventilation sufficient to prevent general contamination of the testing area by the test agent.

C. Quantitative Fit Test (QNFT) Protocol.

1. General.

(a) The employer shall assign specific individuals who shall assume full responsibility for implementing the respirator quantitative fit test program.

(b) The employer shall ensure that persons administering QNFT are able to calibrate equipment and perform tests properly, recognize invalid tests, calculate fit factors properly and assure that test equipment is in proper working order.

(c) The employer shall assure that QNFT equipment is kept clean and well maintained so as to operate at the parameters for which it was designed.

2. Definitions.

(a) Quantitative fit test. The test is performed in a test chamber. The normal air-purifying element of the respirator is replaced by a high-efficiency particulate air (HEPA) filter in the case of particulate QNFT aerosols or a sorbent offering contaminant penetration protection equivalent to high-efficiency filters where the QNFT test agent is a gas or vapor.

(b) Challenge agent means the aerosol, gas or vapor introduced into a test chamber so that its concentration inside and outside the respirator may be measured.

(c) Test subject means the person wearing the respirator for quantitative fit testing.

(d) Normal standing position means standing erect and straight with arms down along the sides and looking straight ahead.

(e) Maximum peak penetration method means the method of determining test agent penetration in the respirator as determined by strip chart recordings of the test. The highest peak penetration for a given exercise is taken to be representative of average penetration into the respirator for that exercise.

(f) Average peak penetration method means the method of determining test agent penetration into the respirator utilizing a strip chart recorder, integrator, or computer. The agent penetration is determined by an average of the peak heights on the graph or by computer integration, for each exercise except the grimace exercise. Integrators or computers which calculate the actual test agent penetration in to the respirator for each exercise will also be considered to meet the requirements of the average peak penetration method.

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(g) "Fit Factor" means the ration of challenge agent concentration outside with respect to the inside of a respirator inlet covering (facepiece or enclosure).

3. Apparatus.

(a) Instrumentation. Aerosol generation, dilution, and measurement systems using corn oil or sodium chloride as test aerosols shall be used for quantitatives fit testing.

(b) Test chamber. The test chamber shall be large enough to permit all test subjects to perform freely all required exercises without distrubing the challenge agent concentration or the measurement apparatus. The test chamber shall be equipped and constructed so that the challenge agent is effectively isolated from the ambient air, yet uniform in concentration throughout the chamber.

(c) When testing air-purifying respirators, the normal filter or cartridge element shall be replaced with a high-efficiency particulate filter supplied by the same manufacturer.

(d) The sampling instrument shall be selected so that a strip chart record may be made of the test showing the rise and fall of the challenge agent concentration with each inspiration and expiration at fit factors of at least 2,000. Integrators or computers which integrate the amount of test agent penetration leakage into the respirator for each exercise may be used provided a record of the readings is made.

(e) The combination of substitute air-purifying elements, challenge agent and challenge agent concentration in the test chamber shall be such that the test subject is not exposed in excess of an established exposure limit for the challenge agent at any time during the testing process.

(f) The sampling port on the test specimen respirator shall be placed and constructed so that no leakage occurs around the port (e.g. where the respirator is probed), a free air flow is allowed into the sampling line at all times and so that there is no interference with the fit or performance of the respirator.

(g) The test chamber and test set up shall permit the person administering the test to observe the test subject inside the chamber during the test.

(h) The equipment generating the challenge atmosphere shall maintain the concentration of challenge agent inside the test chamber constant to within a 10 percent variation for the duration of the test.

(i) The time lag (interval between an event and the recording of the event on the strip chart or computer or integrator) shall be kept to a minimum. There shall be a clear association between the occurrence of an event inside the test chamber and its being recorded.

(j) The sampling line tubing for the test chamber atmosphere and for the respirator sampling port shall be of equal diameter and of the same material. The length of the two lines shall be equal.

(k) The exhaust flow from the test chamber shall pass through a high-efficiency filter before release.

(l) When sodium chloride aerosol is used, the relative humidity inside the test chamber shall not exceed 50 percent.

(m) The limitations of instrument detection shall be taken into account when determining the fit factor.

(n) Test respirators shall be maintained in proper working order and inspected for deficiencies such as cracks, missing valves and gaskets, etc.

4. Procedural Requirements.

(a) When performing the initial positive or negative pressure test the sampling line shall be crimped closed in order to avoid air pressure leakage during either of these tests.

(b) An abbreviated screening isoamyl acetate test or irritant fume test may be utilized in order to quickly identify poor fitting respirators which passed the positive and/or negative pressure test and thus reduce the amount of QNFT time. When performing a screening isoamyl acetate test, combination high-efficiency organic vapor cartridges/canisters shall be used.

(c) A reasonably stable challenge agent concentration shall be measured in the test chamber prior to testing. For canopy or shower curtain type of test units the determination of the challenge agent stability may be established after the test subject has entered the test environment.

(d) Immediately after the subject enters the test chamber, the challenge agent concentration inside the respirator shall be measured to ensure that the peak penetration does not exceed 5 percent for a half mask or 1 percent for a full facepiece respirator.

(e) A stable challenge concentration shall be obtained prior to the actual start of testing.

(f) Respirator restraining straps shall not be overtightened for testing. The straps shall be adjusted by the wearer without assistance from other persons to give a reasonable comfortable fit typical of normal use.

(g) The test shall be terminated whenever any single peak penetration exceeds 5 percent for half masks and 1 percent for full facepiece respirators. The test subject shall be refitted and retested. If two of the three required tests are terminated, the fit shall be deemed inadequate.

(h) In order to successfully complete a QNFT, three successful fit tests are required. The results of each of the three independent fit tests must exceed the minimum fit factor needed for the class of respirator (e.g. half mask respirator, full facepiece respirator).

(i) Calculation of fit factors.

(1) The fit factor shall be determined for the quantitative fit test by taking the ratio of the average chamber concentration to the concentration inside the respirator.

(2) The average test chamber concentration is the arithmetic average of the test chamber concentration at the beginning and of the end of the test.

(3) The concentration of the challenge agent inside the respirator shall be determined by one of the following methods:

(i) Average peak concentration.

(ii) Maximum peak concentration.

(iii) Integration by calculation of the area under the individual peak for each exercise. This includes computerized integration.

(j) Interpretation of test results. The fit factor established by the quantitative fit testing shall be the lowest of the three fit factor values calculated from the three required fit tests.

(k) The test subject shall not be permitted to wear a half mask, or full facepiece respirator unless a minimum fit factor equivalent to at least 10 times the hazardous exposure level is obtained.

(l) Filters used for quantitative fit testing shall be replaced at least weekly, or whenever increased breathing resistance is encountered, or when the test agent has altered the integrity of the filter media. Organic vapor cartridges/canisters shall be replaced daily (when used) or sooner if there is any indication of breakthrough by a test agent.

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