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General Summary*

An International Workshop/Conference under the joint chairmanship of Drs. Lars Friberg of the Karolinska Institute and Norton Nelson of New York University Medical Center, jointly sponsored by the National Institute for Occupational Safety and Health, National Cancer Institute, and the National Institute of Environmental Health Sciences, and planned in consultation with the Scientific Committee on the Toxicology of Metals of the Permanent Commission and International Association on Occupational Health, was held March 24-28, 1980, in Atlanta, Georgia, to evaluate the present state of scientific knowledge concerning metal carcinogenicity and to seek underlying principles for mechanisms of metal carcinogen action in relation to public health. Metal carcinogenesis is considered an important area of health research due to the ubiquity of human exposure under occupational and/or environmental circumstances, and the persistence of metallic carcinogenic compounds in the environment.

The Workshop was attended by 54 experts from 11 countries, including Belgium, Canada, Denmark, Finland, France, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States, who formulated recommendations for future research on compounds of arsenic, beryllium, cadmium, chromium, nickel, and other metals and their compounds. During the course of the meeting, the group considered the history of cancer related to metals as well as reviews of data from epidemiological, animal bioassay, and *in vitro* studies. Data from these studies were evaluated in relation to the

known chemistry and biochemical effects of metal compounds. Participants were divided into five working subgroups concerned with: Introduction and General Findings, Epidemiology, Animal Bioassays, Chemistry, and Cellular Mechanisms. Reports generated by these groups formed the basis for general conclusions on metals of carcinogenic concern.

The carcinogenicities of arsenic, chromium, and nickel compounds were again reviewed and agreed upon. In addition, the aggregate of consistently positive findings from several epidemiological studies on workers exposed to cadmium or beryllium compounds combined with experimental observations led meeting participants to conclude that acceptable evidence now exists to regard some of these compounds as contributing to the development of cancer in man.

The participants concluded that evaluation of carcinogenic effects for metallic carcinogens were greatly hindered by the lack of data on exposure to these substances in both the occupational and general environment and it was therefore strongly recommended that monitoring programs be planned and implemented to assess human exposure.

The participants also recognized that human exposure situations in both the work and general environment are frequently complex and that studies of single metal compounds are frequently insufficient for cancer risk assessment since concomitant exposure to other carcinogenic or cocarcinogenic substances, as well as their specific chemical forms, must also be evaluated.

Detailed recommendations for future studies were developed in each of the Workshop Groups.

*The Chief Editor was Sidney Belman (New York University Medical Center), with the assistance of Gunnar Nordberg, under the general guidance of an editorial committee composed of: Sidney Belman, Maths Berlin, Thomas Clarkson, Sir Richard Doll, Lars Friberg, Robert A. Goyer, Trent Lewis, Arthur E. Martell, Norton Nelson, Gunnar F. Nordberg, and Umberto Saffioti.

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Introduction, General Findings and General Recommendations"

Objectives

The Workshop/Conference, the deliberations of which are reported here, has sought to assess the present state of knowledge in metal carcinogenicity as the basis for seeking unifying principles and making recommendations for research needed to fill gaps in our present understanding of metal carcinogenicity relevant to public health.

Although the ultimate aim of the recommendations put forward concerns knowledge which will be applicable to the prevention of human cancer, it is recognized that this requires an understanding of the mechanisms of action ranging from the molecular level to organ response, as well as methods for the epidemiological study of human disease. Accordingly, the Workshop/Conference brought together a multidisciplinary group in order to undertake a conceptually linked examination of the progression of tumors from their initiation to malignancy. In this examination, specific attention was given to the role of potential interaction with other agents.

Attention has also been given to predictive testing for carcinogenic metallic compounds by both whole animal and *in vitro* methods.

Although the Workshop was not charged with a formal evaluation as to whether a specific metallic compound is or is not carcinogenic, as, for example, in the IARC Monographs, it was felt that the data at hand made it possible to reach conclusions for a number of the metals. In addition, the Workshop took as one of its major objectives the development of recommendations to improve our understanding of metal carcinogenicity. There has been no attempt to review safety standards for human expo-

sure or techniques involving quantitative extrapolation to man from high to low doses whether based on human data or laboratory tests. On the other hand, the qualitative meaning of laboratory tests for man, both short-term and long-term, has been examined.

Historical Review

The chronology of observations of the carcinogenicity of some metallic compounds is illustrated in Figure 1. In most but not all instances, a clinical report of a cluster of cancer cases was the signal for subsequent epidemiologic and animal studies. Thus, cancer from arsenic was reported in 1888 (1) in a group of persons treated with Fowler's solution. The first systematic epidemiologic study was not undertaken until 1948 (2). Despite many attempts to reproduce cancer in animals with arsenic compounds, failure has been the rule. Recently, however, suggestive evidence of carcinogenicity in rats was reported. They were dosed with a Bordeaux mixture containing arsenic (3).

It may be noted that in the earlier instances (Fig. 1) the first suspicion came from case reports. In two more recent cases, the first signal came from animal studies (Fig. 1). As for beryllium and cadmium, the most reasonable interpretation of available data is that compounds of these metals have contributed to the development of lung cancer in the case of beryllium and prostatic cancer in the case of cadmium in exposed workers.

In general, systematic epidemiologic investigation is required to validate an association of one or several possible etiologic factors. Normally such studies are weak in, or even incapable of, identifying specific causal agents. At this level, animal studies are of particular value; it may be that *in vitro* tests can increasingly aid in such identification.

Workgroup I recognized the prudence of the approach taken by IARC in suggesting that substances for which there is sufficient evidence of

*This section was prepared by a Workgroup co-chaired by Lars Friberg (Karolinska Institute, Stockholm, Sweden) and Norton Nelson (NYU Medical Center, New York, N.Y. 10016). Other members of the Workgroup were: Jay Beaumont, Bruce A. Fowler, Robert Lauwerys, Gunnar Nordberg, Jaroslav Vostal, and Reiner Zielhuis.

- carcinogenicity in animal studies should be regarded as if they were carcinogenic in man.

Importance of Metals in Carcinogenesis

Of about 80 metals there are at least 20 which have compounds that have been reported to give rise to well-defined toxic effects in man. Only a few of these metals have been shown or are suspected to be carcinogenic. The importance of metal carcinogenesis does not so much concern the number of carcinogenic compounds, but rather the ubiquity of exposure, their wide industrial use, and their persistence in the environment. Thus, implementation of appropriate protective measures for metallic compounds proven to be carcinogenic may be difficult in comparison with organic carcinogens which are likely to be less persistent. Thus, arsenic (a recognized carcinogen) is found to occur in high concentrations in drinking water in some parts of the world. In these areas, skin cancer has been associated with the drinking of such water. Only drastic measures will reduce the exposure substantially.

In industry, exposure is often not to a single metal only, but instead to mixtures. Significant amounts of a large number of metals have been found at autopsy in the lungs of workers with a high risk for lung cancer who retired from their work in

a smelter several years before their death. The difficulties in evaluating causal relationships are obvious; in such instances the interactions must be considered. Furthermore, whenever a metal is classified as carcinogenic or noncarcinogenic, such a statement should only apply to specific forms of the metal. There is ample evidence that metabolism, toxicity in general, and also carcinogenicity are dependent on the chemical and physical forms of a metal.

Metal compounds may cause alteration or interfere with a number of intracellular biochemical mechanisms and may also induce toxic effects not related to carcinogenesis. Some metals, e.g., lead, exert toxic effects on the nervous system, which, at the present, determine accepted exposure levels to a large extent. On the other hand, other metals, e.g., Cr(VI) and Ni compounds, induce predominantly carcinogenic effects. In evaluation of health risk and in setting priorities for epidemiological and experimental cancer studies, these considerations should be taken into account.

Methods of Evaluation

Epidemiological Studies

Epidemiological studies identify the incidence of cancer in groups of humans who experience different environmental conditions. If different groups

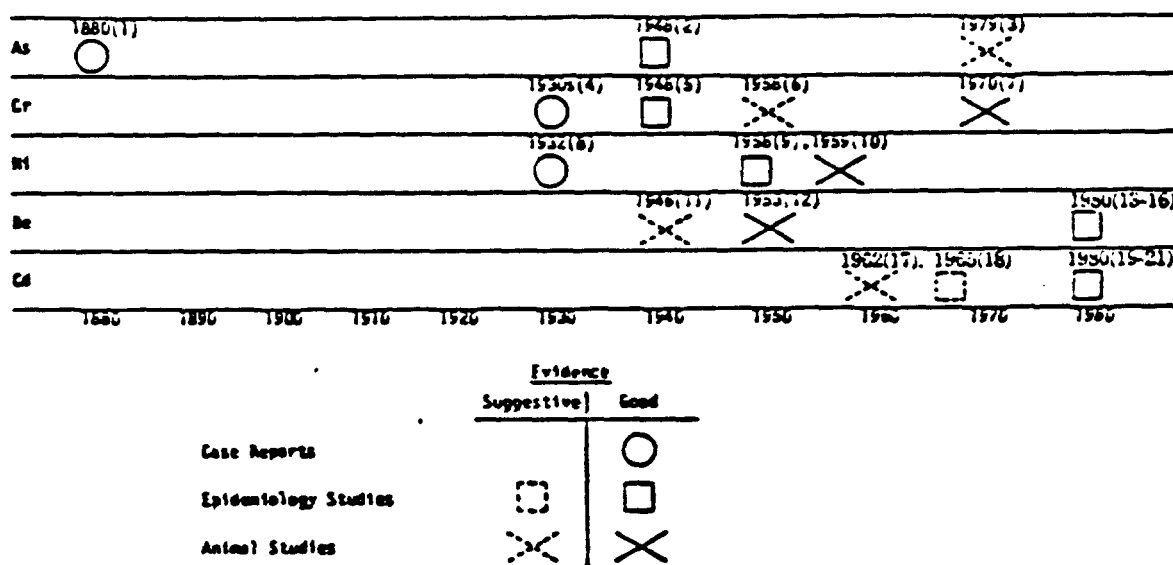


FIGURE 1. Chronology of observations on the carcinogenicity of metallic compounds judged by this workshop as contributing to human cancer. The suspected metallic compounds are not specified in the figure but listed as the element. As pointed out elsewhere, however, specific metallic compounds are usually the carcinogenic entity and not the element as such. References are shown in parentheses.

are exposed to different amounts of a carcinogenic agent, it may be possible to determine the relationship between the amount of exposure and the resulting cancer incidence and thence to make quantitative estimates of the risk involved. Because the studies are always carried out in real life situations, it is seldom, if ever, possible to design them in such a way as to satisfy the strict requirements of experimental design that are normal in the laboratory; and there may be some doubt about the interpretation that should be attached to their results. Nevertheless, epidemiological studies have the overwhelming advantage that they refer directly to humans and they provide the only *ce-&* means for designating a metal compound as a human carcinogen.

Clinical case reports have served as useful warning signals of the existence of risk on a number of occasions in the past, and they may still do so occasionally in the future. It ought to be possible, however, to organize the collection of observations on humans in such a way that any risk that have inadvertently been caused are picked up more quickly and more certainly by planned inquiry. One form of inquiry is the case-control study. Such studies have proved valuable in establishing the reality of a risk, but the method that is most generally applicable to the detection of occupational hazards is the cohort study, in which groups of exposed workers are followed up to determine their experience of disease. The problems involved in using cohort studies to obtain evidence about the carcinogenic effect of metals on humans, or the lack of any such effect, are discussed in the introduction to the report of Workgroup IB.

Whole Animal Experiments

Several in vivo experimental models have been used to evaluate the potential carcinogenicity of pure metals or some of their inorganic and organic compounds and to investigate the factors modifying their activity.

Several endpoints may be considered, such as the development of a tumor at the site of contact or at a distance in the treated animals or their offspring (transplacental carcinogenesis) and chromosomal damage in germinal or somatic cells. The last two types of effects (transplacental carcinogenesis and chromosomal aberrations) have rarely been looked for in animals treated with metallic compounds.

One important advantage of animal experiments is the fact that the chemical and physical properties of the administered metallic compounds can be well defined. The investigation of the carcinogenic potential of well characterized complex mixtures, the

comparison of the carcinogenic potency by various routes, and different compounds of the same metal administered is possible. Animal studies simulating the usual route of human exposure may be particularly useful in an evaluation of the physical and chemical forms most hazardous for humans. For example, animal studies have shown that the most active chromium compounds for the development of lung cancer are the hexavalent salts of intermediate solubility.

Those animal studies which use routes of administration different from those by which man is usually exposed have limitations for extrapolating the results to man; nevertheless, such studies may provide useful information on internal factors (absorption, distribution, immunological status, etc.) and external factors (e.g., interaction with other metallic compounds or organic chemicals) influencing the carcinogenic or cocarcinogenic potency of metallic compounds. For example, it has been demonstrated that the combined injection of Mn and Ni_3S_2 reduced the numbers of local sarcomas relative to IM injection of Ni_3S_2 alone.

Unfortunately, whole animal carcinogenesis studies with metals and their compounds are still very limited. Data on species variation and dose-response relationships are lacking for the majority of metals. One important disadvantage of animal experiments is that they can be time and space consuming. In some cases whole animal models are less useful than in vitro systems for investigating the molecular mechanisms of action of carcinogens.

In Vitro Mutation Test Systems

In vitro bacterial mutation test systems have proven highly useful for studying a number of metallational mechanisms involving direct effects of metals on DNA metabolism. Alteration of DNA structure, infidelity of DNA synthesis, and excision repair processes have all been reported following in vitro incubation with metals of carcinogenic concern. Studies using metals with mammalian cells in vitro have demonstrated in some instances increased viral or morphologic transformation of some cell lines following incubation with a number of metals. One potential problem with such tests is the fact that at present each system measures only those types of mutational events to which it is specifically sensitive and, hence, comparative studies of different mutational mechanisms in one system are lacking. Another area of concern involves the question as to what extent the mutational mechanisms observed in these test systems may be expected to operate in normal mammalian cells in vivo. The degree to which potentially toxic metals

are sequestered from direct interaction with DSA in vivo by binding to high affinity intracellular ligands or traps is also presently unknown.

Other studies involving effects of metals on subcellular systems of essential importance to cellular viability or metabolism of organic carcinogens showed that these systems were also highly susceptible to metal toxicity.

Potential ramifications of these observations are that metals may act as promoters of the carcinogenic response by stimulating cell turnover and/or altering cellular susceptibility to organic carcinogens or their metabolic derivatives. The effects of metal alteration of microsomal or S_0 fraction on activation of *in vitro* mutation test systems are also presently unknown. Studies of metal effects on subcellular systems which metabolize organic carcinogens are also currently largely lacking and hence the potential cocarcinogenic effects of these metals on the carcinogenic response from organic carcinogens are unknown.

General Findings and Recommendations

General Finding 1

There exists a serious lack of quantitative data that can be used for dose-response evaluations on occupational exposure to potentially carcinogenic metal compounds.

Recommendations

Monitoring programs should be planned and implemented to measure exposures in the work environment. In addition to measurements of total exposure levels to metal compounds, means should be sought to develop and apply procedures for the characterization of the biologically important physical and chemical characteristics of metal compounds in the work environment. Whenever appropriate, possible cocarcinogenic agents should also be measured.

Assessment of exposure to suspected metal compounds in workroom air should take into account intake by (1) inhalation, including, where practicable, estimated mucociliary transport with subsequent ingestion, (2) direct ingestion, e.g., direct contact with fingers, cigarettes, etc., or (3) skin contact.

Where possible, exposure to suspected metal compounds should be estimated through analysis of biological samples of blood, urine, saliva, hair and feces, and autopsy specimens.

General Finding 2

For several potentially carcinogenic metal compounds there are also inadequate data on exposure levels of the general population.

Recommendations

Monitoring programs should be planned to estimate exposure of the general population to carcinogenic metals. Due attention should be given to all routes of exposure and to measurement through biological monitoring and measurement in biopsy and autopsy specimens wherever feasible.

In instances of probable exposure of the general population to compounds of carcinogenic concern, identification of specific chemical species, in addition to the total metal concentration, should be undertaken.

General Finding 3

Several reports indicate gross analytical errors of importance for evaluation of exposure to metals.

Recommendation

Internationally accepted analytical methods and standard reference material should be developed for measurements of carcinogenic metals in environmental and biological samples. These can serve for validation of routine analytical procedures. International programs for analytical harmonization should be promoted, and reference materials should be made available.

General Finding 4

Environmental exposure to carcinogenic metals results generally in cancer in a small fraction of exposed individuals. This indicates that factors determining the susceptibility to cancer induction play a decisive role.

Recommendation

Efforts should be made to identify factors determining susceptibility and to identify susceptible groups.

General Finding 5

For both occupationally exposed groups and the general population very few studies are available on the relationship between tissue concentration of the carcinogenic metal compound and the carcinogenic

response. **Data** are also lacking for experimental animals.

Recommendation

Concentrations of metals or, whenever possible, their suspected active species should be measured in biological samples (blood, urine, biopsy or autopsy material) from exposed populations and experimental animals in order to detect possible correlations between such concentrations and effects in terms of precancerous lesions or fully developed carcinogenic effects. Such studies would also aid in reaching quantitative estimates of relationships between tissue concentrations and carcinogenic response.

General Finding 6

Metals are elements and, as such, they have been an intrinsic component of the environment to which man is adapted. Specific compounds of some metals are required for human life, and some metals are thus designated "essential metals."

With several metals a distinct possibility exists that metals essential at one level or route of intake might be carcinogenic at another level or route. At different levels it is necessary to consider changes in chemical speciation and whether or not the levels exceed the capacity of the normal homeostatic mechanisms.

Recommendation

Systematic investigations are necessary to identify the carcinogenic chemical species or, for the same chemical species, the role of the physical state—particle size and surface properties, as well as concentration. Attention should be given to their biochemical interconversions in solution and biotransformations, and to compare these forms with their nutritionally essential states. These investigations should be explored on a quantitative basis.

General Finding 7

It has been suggested that chromosomal aberrations, sister chromatid exchange, and DNA repair are of predictive value in relation to cancer development.

Recommendation

Further studies should be conducted at the epidemiological and laboratory levels to evaluate the reliability of these approaches.

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General Finding 8

There are examples of biological interactions involving metals that lead to alteration of tumor response, e.g., dietary zinc intake in laboratory animals or a number of organic carcinogens. Also, exposure situations are often complex. In environments which have been demonstrated to cause an excess risk of cancer, a number of possible interactions may be operating (e.g., SO₂-arsenic interactions in smelter environments).

Recommendation

Possible enhancing or inhibitory effects of exposure to various metal compounds in combination with other carcinogens or cocarcinogenic compounds should be examined in appropriate animal, cellular, *in vitro*, and epidemiological studies. The mechanisms by which metals cause such effects should be elucidated.

General Finding 9

Lifetime studies in animals have been found to be predictive of probable carcinogenicity in man, especially when the routes of exposure and the sites of the tumors are the same. However, a positive outcome, even with different routes of exposure or differences in the tumor site, yields suggestive evidence of possible carcinogenicity for man.

Recommendation

When used for predictive testing, whole animal studies should, as a rule, employ a similar route of exposure as the one encountered in humans. Other routes of administration may be usefully employed especially in the investigation of mechanisms of action.

General Finding 10

Negative epidemiological studies should be evaluated in the same way as positive studies and their results taken fully into account when assessing the human evidence. The acquisition of sufficient and adequate data with which to evaluate the carcinogenicity or lack of carcinogenicity of metals in humans requires a study period at least comparable to the induction time for carcinogenesis.

Recommendation

Negative epidemiological studies of adequate duration should be published and the confidence limits of risk estimates included when relevant.

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Problems of Epidemiological Evidence*

Problems associated with the use of epidemiological evidence to evaluate the carcinogenicity of metals are, in the main, those associated with epidemiological enquiry in general. There are, however, some additional difficulties that arise from the variety of ways in which exposure to metals can occur, the variety of metal species and compounds, and the frequency of mixed exposure. We shall, therefore, review some of these problems, and the ways in which they can be overcome, before reviewing the evidence relating to individual elements.

One of the greatest difficulties is to obtain a population for study that is large enough to distinguish the effects of a specific hazard from the effects of the random variation of small numbers or alternatively to be confident that no material risk exists, when negative results are obtained (the problem of statistical power and its relation to sample size). These cannot always be overcome by increasing the size of the population, as the number of people exposed to high concentrations of the agent may be small and extension of the study to include larger numbers will only dilute the results. If the additional subjects have not been intensively exposed. In studies of cancer, there is also the problem that the first ten years after exposure to a carcinogen seldom provide much evidence of risk. Longer periods, even 30 years or more, may be required before the existence of a risk can be properly assessed, and the inclusion of large numbers of subjects who have been observed for only a short period will serve to dilute the results still further. The analysis should, therefore, be identified whenever possible, both by intensity of exposure and by length of time since exposure began.

The exact nature of past exposure at the workplace is often difficult to determine and, in the case of exposure to metals, may be quite complex. Little

information may be available on the previous exposure of individual workers, and comparisons may be practicable only between groups of workers employed in particular occupations or on specific processes. Sometimes, when measurements of the intensity of past exposures are not available, these may have to be estimated from the intensity of current exposure in the same occupation or the length of employment may have to be used as a substitute for measurement on the assumption that exposure has been constant over time. Exceptionally, however, if exposure was particularly heavy at a time when labor turnover was high, duration of employment can be dissociated from intensity of exposure and paradoxical results may appear to be obtained.

A special problem in the study of metals is that mixed exposures to more than one metal and to different valencies or oxidation states of the metal under investigation are frequent, and precise specifications of individual components of the ambient pollution may not be available because of limitations in the analytic method. Changes in the nature of the process and in the consequent exposure patterns may also have occurred over time without being recognized.

Two other considerations which have to be taken into account are the adequacy of the measure of risk and the possible existence of confounding factors. The endpoint that has most commonly been used in studies of metal carcinogenesis is cancer mortality; this is adequate for types of cancer with a high fatality rate (e.g., cancer of the lung) but is a poor measure for assessing the risk of developing tumors with low fatality rates (e.g., cancer of the larynx). Potential confounding factors such as personal habits, socioeconomic status, and other occupational exposure are seldom taken adequately into account due to lack of information. Smoking habits constitute one important confounding factor when the hazard of lung cancer is being considered. Differences in smoking habits are unlikely to be large enough to account for a relative risk of lung cancer more than twice that of the general population. In the absence of detailed information, it is a matter of judgment as to how far smaller relative

* This section was prepared by a Workgroup chaired by Sir Richard Doll (University of Oxford, England). Other members of the workgroup were: Lawrence Fishbein, Peter Infante, Philip Landrigan, J. William Lloyd, Thomas J. Maron, Ernest Mastromatteo, Tor Norseth, Goran Pershagen, Umberto Saffioti, and Rodolfo Saracci.

risks that are not due to chance can be attributed to excess smoking, exposure to the metal, or a combined effect of both.

As with all other epidemiological studies, the most important criterion for the evaluation of those relating to metal carcinogenesis is the consistency of the results between studies (i.e., do they all point in the same direction), within each individual study (i.e., does the risk vary with the degree of exposure), and with the results of laboratory tests concerning carcinogenicity in animals and the absorption, distribution, metabolism and mechanism of action of the metal under investigation. It must, however, be borne in mind that there are many ways in which apparent inconsistency can be produced, and it may be difficult to sort out how far it can be due to differences in the design, method of investigation, or analysis of the studies, or to differences in the exposure of the subjects, or biological variation. Positive results in one set of circumstances are not necessarily contradicted by negative results in another, nor vice versa. When major inconsistencies prevent an unequivocal interpretation of the totality of the data, this should be regarded as constituting urgent grounds for further research.

In the rest of our report we have considered in detail the evidence relating to eight metals (in alphabetical order) and follow this with a brief note on other metals. Specific recommendations concerning individual metals and recommendations concerning the detection of occupational hazards of cancer in general are brought together at the end.

Arsenic

There is conclusive epidemiological evidence of an increased risk of lung cancer in the manufacture of arsenic containing pesticides (1-3). The exposure has been mainly to inorganic arsenic compounds. No conclusions can be drawn with regard to the carcinogenicity of trivalent versus pentavalent compounds as both forms have occurred in the circumstances in which individuals have been occupationally exposed. The use of arsenic-containing pesticides, often as arsenates of low solubility, has been associated with lung cancer among vintners in Germany (4) and in France (5), but the data are not conclusive.

The carcinogenicity of inorganic, mainly trivalent arsenic is also evident from many epidemiological studies of men employed in smelters (6-11). As a rule, an increase in lung cancer mortality with increasing dose of arsenic has been observed (6, 8, 10). It should be recognized that the smelter environment is very complex, and the interaction

between arsenic and other environmental pollutants (SO₂, heavy metals, etc.) as well as with tobacco smoking is poorly understood.

Some studies have indicated an increased mortality from lung cancer in populations living near point emission sources of arsenic to air (11), but the role of arsenic cannot be assessed because of lack of measurements of exposure and effects of confounding factors.

Exposure to inorganic arsenic can cause non-melanotic skin cancer. This has been observed following the ingestion of arsenic in drinking water and in arsenical medications in doses amounting to several grams (12-15). The form of arsenic in the drinking water has yet to be determined, but in medication the evidence definitely relates to the inorganic trivalent form (14).

Cases of hemangioendothelioma of the liver have been reported following exposure to inorganic arsenic from medicinal preparations (16-29), contaminated drinking water (20), and wine (21). The evidence that arsenic was a causative factor in these cases is thought to be conclusive.

A possible association between arsenic and cancer of other sites, most notably of the lymphatic and hematopoietic systems (2, 10), needs further investigation. No epidemiological data are available relating to the carcinogenicity of organic arsenic compounds.

Beryllium

Although numerous experimental studies had indicated that a number of beryllium compounds were carcinogenic in experimental animals by several routes of administration (22), the results of epidemiologic study up to the end of 1970 (23-26) had not demonstrated any consistent evidence of carcinogenicity in men and women employed in primary beryllium production works, or among subjects enrolled in the U.S. Beryllium Case Registry (BCR). Results of follow-up studies of these populations through the mid-1970s have been recently reported (27-30). The study populations somewhat overlap, as three reports concern the workers in two factories (27-29), while the fourth concerns the mortality of individuals in the Registry (30), many of whom were employed in the same factories. Each study demonstrates a significant excess of lung cancer.

The lung cancer mortality observed in the beryllium exposed workers was excessive compared with the mortality recorded for the U.S. general population (27) and that in a second industrial population located in the same geographic region (29).

The studies demonstrate an excess lung cancer

risk following short-term but heavy exposure to beryllium (28). This same phenomenon was observed for individuals who died from beryllium disease, a clinical endpoint previously demonstrated to be associated with occupational/environmental exposure to beryllium (31). Our interpretation of the total evidence is that beryllium is the cause of the excess cancer mortality in these groups of employees.

Cadmium

Occupational exposure to cadmium oxide fumes occurs in the smelting and refining of the metal and in the production of copper-cadmium and brazing alloys. Exposure to cadmium oxide dust occurs in cadmium-nickel battery manufacture and in the production and use of cadmium oxide for plating, chemical and plastics industries. Exposure to cadmium sulfide occurs in pigment manufacture. Lesser exposures to cadmium stearates and other compounds also occur. While cadmium has been used increasingly in industry over the past 50 to 60 years, the total number of workers exposed to the compounds of this metal has not been large. In the earlier years of cadmium usage, occupational exposure was often heavy and prolonged, for neither the fume nor the dust are highly irritant unless exposure is massive. With the recognition of chronic cadmium poisoning, many processes were redesigned in the 1960's with enclosure and the installation of exhaust ventilation. As a result, occupational exposure over the past 10-15 years has been greatly reduced from concentrations measured in milligrams per cubic meter to levels measured in micrograms per cubic meter.

The first intimation that cadmium might be a human carcinogen came from a small study in Britain of men exposed to cadmium oxide dust for a minimum period of one year in cadmium-nickel battery manufacture (32, 33), where there were four deaths from carcinoma of the prostate when less than one was expected. Exposure to cadmium oxide dust had been heavy and had given rise to chronic poisoning in the work force. In a similar-sized group engaged for a minimum period of two years on the refining of cadmium in the U.S., also under heavy exposure conditions, four deaths from prostate cancer were again observed, all of which occurred more than 20 years after first exposure (34). This number is significantly greater than that expected (0.88) from national mortality statistics. In this cohort there was also a significant excess of lung cancer. However, smoking habits were not determined, and there was concurrent exposure to

other compounds, in particular to arsenic. Concentrations of arsenic were low when measured at the time of the survey, but there is no information on arsenic levels in the earlier years. In a Swedish cadmium-nickel battery factory, where again heavy exposure to cadmium oxide and nickel hydroxide dusts had occurred in earlier years giving rise to the first reported cases of chronic cadmium poisoning, all workers with more than five years exposure who developed cancer between 1959 and 1975 (35) were identified. No significant excess of prostatic or lung cancer was found. Finally, in a Swedish copper-cadmium alloy plant, a small increase in prostatic cancer mortality, but not reaching a significant level, was found in a group of workers with at least five years heavy exposure to cadmium oxide fume (35). In each of these studies the number of workers investigated was small, with, in all, 14 cases of prostatic cancer against 5.4 expected.

The most reasonable interpretation of these results is that exposure to cadmium had contributed to the development of prostatic cancer in the exposed workers?

Injection site sarcoma and interstitial cell tumor of the testis have followed the injection of several cadmium compounds (36-43). Prostatic tumors have not been observed, but it is questionable whether the animals studied provide adequate models (44).

Chromium

An increased risk of lung cancer has been established for workers in the primary chromate production industry (45, 46). This increased risk has been attributed to exposure to an incompletely defined mixture of chromates. An excess risk of lung cancer has also been observed in workers in the chrome pigment production industry (47, 48).

Secondary users of chromates other than the chrome pigment industry and secondary users of chrome pigments must be regarded as possibly being at risk, but the epidemiological evidence (46, 49-51) is not conclusive.

Both results from the primary chromate production industry and from chrome pigment production are not inconsistent with the concept that slightly soluble chromates are more carcinogenic than the soluble compounds. Increased risk of lung cancer has been reported in platers exposed to soluble compounds (52), but the results in two studies

† One member of the Working Group dissociated himself from this statement on the grounds that he considered the data inadequate at the present time to reach such a conclusion.

(53-55) are inconclusive.† Animal experiments also support the assumption that the slightly soluble compounds are the more active (56), but soluble and slightly soluble compounds are equally potent mutagens *in vitro* (57, 58).

There is very little epidemiological evidence relating to workers exposed to trivalent chromium, but such as there is does not suggest an increased risk. A suggestion of an increased risk of lung cancer in ferrochromium production can be attributed to exposure to hexavalent chromium in the process (50). The assumption that exposure to trivalent chromium does not constitute an increased risk of cancer is indirectly supported by *in vitro* tests for mutagenicity (59, 60) and by the observation that only hexavalent chromium passes the cell membrane (61), although the trivalent form may be the active agent at the site of action (61-65).

No relation between dose and response can yet be determined for the cancer causing effect of hexavalent chromium in men. This is partly because the active agent in the actual circumstances of exposure is unknown, and partly because only limited and unreliable dose estimates can be obtained for workers who have been found at risk for the last 20-30 years. The importance of the chromium that is found in tobacco for the development of lung cancer is not known, nor is it known whether there are synergistic effects between chromate exposure and smoking. Some published data suggest an increased risk of gastrointestinal cancer (52, 53, 66-69), but the results are inconclusive.

Cobalt

Occupational exposure to cobalt occurs in the tungsten carbide hard metal industry, in mining and refining of cobalt, in the production of cobalt alloys, and in the handling of cobalt salts. Pulmonary fibrosis has been reported in workers from the hard metal industry (70, 71). Despite these excessive exposures, there have been few reports of cancer mortality occurring in these workers. One epidemiological study of cobalt refinery workers has reported an excess of deaths from lung cancer (72). However, interpretation is complicated by the fact that there was also heavy exposure to arsenic, mainly as arsenic trioxide, and probably also to nickel. There are no convincing reports of cancer arising from the use of cobalt-containing prosthetic devices in patients.

Finely divided cobalt metal powder, cobalt oxide, and cobalt sulfide have produced fibrosarcoma (73)

and rhabdomyosarcoma (74) at injection sites in the rat.

Cobalt, as the divalent ion, has been shown to substitute for Mg^{2+} as an activator for **DS.4** polymerase (75). Cobalt chloride has decreased the fidelity of DNA synthesis *in vitro* (75, 76).

Iron

This most abundant metal in the earth's crust is present in its natural state in the form of oxides and carbonate. Occupational exposure, dating back to prehistoric times, is both common and heavy in iron ore mining, iron refining, steel production and welding.

The injection of certain iron carbohydrate complexes in large doses has been followed by local sarcoma production in several animal species (77-82) with evidence of a dose response relationship. Millions of doses of such complexes have been given parenterally over the past 30 years in the treatment of iron deficiency anemia, but no more than a handful of tumors at the site of injection (where tumors are also known to occur spontaneously) have been reported (83). In one study of all soft tissue sarcomas which occurred over a defined interval, no history of parenteral iron therapy could be obtained (84). In another study covering all cases of sarcoma of the buttock notified to U.K. cancer registries over a two-year period, four cases were discovered (85), but only one of them is considered acceptable as a sarcoma that could have arisen in response to iron injection (86). The possibility that iron dextran injection may give rise to sarcoma cannot be entirely discounted, but the risk (if any) appears to be extremely small.

The administration of iron oxide to the respiratory tract of hamsters by intratracheal instillation together with benzo(a)pyrene or by inhalation following systemic administration of diethyl nitrosamine has resulted in an increased yield of tumors, while tumors were not obtained with iron oxide alone. This effect is considered to be nonspecific.

An excess mortality from lung cancer has been observed in iron ore miners from a number of countries. The original observations were reported from Cumberland, England (87), and confirmed in a later study in 1970, in which the miners of haematite showed a clear excess mortality from lung cancer compared with national and regional figures (88). An excess lung cancer mortality has also been reported amongst iron ore miners from some other countries (89-93).

The increased lung cancer risk in haematite miners may be attributed to a number of possible factors. Although a carcinogenic effect of iron oxide

† Some members of the Working Group felt that the results were conclusive evidence of an increased risk in platers.

particles alone, possibly acting in a nonspecific way, cannot be entirely discounted. The totality of the evidence strongly suggests that the excess lung cancer risk could be attributed to ionizing radiation from the radon and radon daughters present in the atmosphere of the mine. The relationship between the excess mortality from lung cancer and the level of radiation in the Cumberland haematite mines was comparable to that found in other mining situations where radioactivity is held to be responsible for an occupational lung cancer risk (88). However, radioactivity levels have not been determined in all other mines where an increased lung Cancer risk has been shown to exist.

Two early studies in Britain showed an increased lung cancer mortality in foundry workers (94, 95), but this cannot necessarily be attributed to iron oxide, as exposure to polycyclic hydrocarbons also occurred.

Lead

Inorganic lead has been shown to produce renal tumors in a number of experimental studies, at least six in rats (96-100) and one in mice (103). Dosage was by several routes including oral. Levels of exposure in all of the studies far exceeded the maximum doses tolerated by man and caused gross morphological damage to the kidney. Lead is reported to have produced lung tumors in hamsters (104) and cerebral gliomas in rats (101). *In vitro*, lead oxide has been found to induce dose-related transformation in Syrian hamster embryo cells (105). Lead oxide also enhanced the transformation produced in Syrian hamster cells by SA7 virus (106).

In an early epidemiological study, an excess proportionate mortality ratio was noted for malignant neoplasms (all sites combined) in battery workers with so-called 'negligible exposure with lead in urine values within the normal range' (25 deaths observed vs. 14.2 expected; $p < 0.05$), but no excess mortality was noted among workers with "heavy" exposure to lead (107). No comment was made in that study as to any site-specific occurrence of excess malignancy.

In a more recent study of lead smelter and battery workers (108, 109), a significant excess of malignancies at all sites combined was found in smelter workers but not in battery workers. In both groups, mortality from digestive and respiratory cancer was greater than national RKS predicted. A five-year follow-up study leaves the interpretation of these findings in doubt. This pattern was not maintained, malignant neoplasms showing a slight deficiency in smelters and slight excess in battery workers (109, 110).

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From the data it may be concluded that there is evidence that lead in high dose can produce cancer in experimental animals. However, insufficient observations on man have been reported to enable a definite conclusion to be reached as to whether lead causes human cancer.

Nickel

Nickel is used chiefly in the production of alloys including stainless steels. Other uses include: electroplating, catalysts, coinage, and pigments. Nickel alloys are also used in jewelry and in dental and surgical prostheses.

Occupational exposure occurs in mining, refining, alloy production and use, electroplating, welding, and in the handling of nickel salts. Increased risk of lung and nasal sinus cancer in nickel refining workers was first noted in 1926 from Clydach, Wales (111), a refinery using the Mond process which began operation in 1902. The Mond process made use of nickel carbonyl in the refining of nickel. Because of this, it has often been believed that nickel carbonyl was the sole carcinogen. Subsequent epidemiological studies from Canada (112, 113), Norway (114, 115), the U.S.S.R. (72), and New Caledonia (116) have shown that the increased risk also occurred in refineries where the Mond process was not used. In addition, continuing studies have shown that the increased risk at the Clydach refinery has dropped markedly in workers entering employment after 1932 despite continuing use of the carbonyl process (111). Studies in Canada (102, 119) and in Wales (111, 117) suggest that exposure to furnace fumes and dust, from the high temperature sintering or calcining of impure nickel sulfide mattes was the source of the increased risk. These same operations were carried out in the Norwegian refinery (118) and, although some risk appeared to be associated in the electrolytic workers, mixed exposures of these workers cannot be ruled out. The Norwegian studies also demonstrated an increase in the observed incidence of laryngeal cancer, as well as an increase in incidence of lung and nasal sinus cancer.

Mining, smelting, and refining of laterite (nickel oxide) ores have been carried out for about 100 years. It was believed that the increased risk of respiratory cancer did not occur in laterite operations. A single case-control study, however, reported an increase among workers and residents living near a nickel smelter in New Caledonia (116). It was also assumed that increased risk of respiratory cancer did not occur among nickel users, e.g., in nickel alloy manufacture and use, use of nickel powder, nickel plating, nickel welding, etc., but

definitive studies on this have been lacking. A recent study did not indicate an increase in respiratory cancer among a cohort exposed to nickel powder and followed for a minimum of 19 years (119). Another recent case control study did not indicate an increase of risk in workers engaged in grinding and welding operations with nickel alloys (120).

Studies with experimental animals have demonstrated that nickel subsulfide (Ni_3S_2) produced local tumors at a wide variety of injection sites and by inhalation in rats (121). Ni_3S_2 also enhanced the carcinogenic effects of benzo(a)pyrene (122) and 20-methylcholanthrene in experimental animals (123). In vitro mammalian cell tests demonstrate that Ni_3S_2 and NiSO_4 compounds give rise to mammalian cell transformation (124-130).

Other Metals

Epidemiological evidence relating to exposure to a variety of other metals should be sought if at all possible, either because large numbers of workers are involved or because laboratory tests suggest the possibility that a cancer hazard might exist. These metals include copper, manganese, mercury, platinum, selenium, titanium, vanadium, and zinc.

Studies of copper refiners are particularly desirable, but it may be difficult to define groups who have not also had material exposure to arsenic.

In view of the small numbers of workers exposed, it will be necessary to obtain the collaboration of industry on an international scene if any worthwhile human evidence is to be obtained relating to platinum, selenium, and vanadium. The possibility of establishing specialized registers of men who have worked with these metals should be considered.

Recommendations

Specific

The epidemiological evidence strongly implicates inorganic trivalent arsenic as the responsible agent when an excess of lung cancer is attributed to exposure to arsenic. There is, however, no reason to exonerate pentavalent arsenic, and workers exposed solely to other forms of arsenic should be investigated further.

Experimental work should be undertaken on the effect of exposure of the respiratory tract to arsenic compounds of low solubility.

The incidence of lung cancer in areas where there are unusually high concentrations of arsenic in the air should be studied in order to assess possible

risks to the general public. Airborne levels and personal excretion patterns should be monitored in such areas.

There is a need to study dose-response relationships for arsenic in water and skin cancer. Particular emphasis should be given to differences in relation to valence state.

The conclusion that beryllium and cadmium contribute to the development of some cancers in man was reached because this seemed to be the most reasonable interpretation of the available facts. The numbers of observations on man are small, however, in both cases, and it is important to check that the conclusion is correct by continued observation of the cohorts of workers exposed to beryllium in the U.S. and by collecting observations on larger numbers of men who have been exposed to substantial amounts of cadmium whenever they can be found.

Further studies are required to determine which compounds of chromium are carcinogenic to man and, particularly, to determine if there is any hazard associated with exposure to soluble compounds in the plating industry.

Cohorts of workers exposed to airborne respirable cobalt and its inorganic compounds should be identified and followed up to determine their cancer mortality rates.

Long-term exposure of experimental animals to both insoluble and soluble forms of cobalt (such as cobalt oxide or cobalt sulfide and cobalt chloride or cobalt nitrate) via the respiratory tract should be included.

Further epidemiological studies of iron miners, steel workers, foundry workers, and welders are required in which attempts are made to characterize the extent to which the men are exposed to ionizing radiation and possible carcinogens as well as to iron and iron compounds.

More studies are needed of men who have had long term occupational exposures to lead. Case-control studies of adults with kidney tumors and follow-up studies of people who suffered from lead poisoning in childhood could also help to clarify the extent to which lead may contribute to the development of cancer in man.

Further epidemiological studies of workers exposed to soluble and slightly soluble forms of nickel and nickel alloys in the nickel processing and mining industries are needed. These should in-

* A larger epidemiological study of cadmium workers is currently being carried out in Britain, the results of which should be available in 1982.

* Many such studies are currently underway, the results of which should become available in 1981.

clude industries involving mixed exposure to nickel and other metals, e.g., nickel and cadmium in battery manufactures and nickel and chromium in stainless steel manufactures, welding, nickel plating, and chrome plating.

Additional long-term inhalation studies in experimental animals are needed to determine the potential carcinogenicity of nickel metal and nickel compounds. Priority should be given to testing nickel metal, nickel sulfate, and nickel oxide, because of the large number of workers exposed and the lack of conclusive information concerning these substances.

General

The possibility of interactions between metals (particularly arsenic), other industrial pollutants and tobacco smoke in the production of lung cancer should be further investigated.

Epidemiological studies should, whenever practical, include comparison of the risk of cancer in groups of industrial workers exposed to a particular agent with that in unexposed workers in the same industry or in residence in the same geographical area as well as with those in the country as a whole.

In epidemiological studies, identification of cohorts with past exposure is often difficult or impossible because: (a) employment records are often destroyed after a minimal time interval, and (b) job descriptions in company or medical records may be nonexistent or inadequate. Employment records adequate for the identification of workers for the determination of their vital studies should be retained by companies and medical or industrial hygiene departments where these exist for a minimum of 30 years. Because of the long period that may elapse between initial exposure and the development of cancer, these records should include job description, with qualitative and quantitative information on exposure. Whenever possible, information on other potential exposures, e.g., cigarette smoking, should be recorded.

In the interest of public health, facilities should be provided in all industrialized countries to allow bona fide research workers to link records maintained in industry with national records of birth (when practicable), sickness, and causes of death, subject to appropriate safeguards to insure that personal records are never used to the detriment of the individual.

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