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Chemical Sessions

TOTAL JOB ANALYSIS

By DR. KEITH E. BARENKLAU
Associate Director, International Safety Academy,
Houston, TX

Total Job Analysis is a tool that enables the supervisor to teach and to direct his employees systematically in order to obtain maximum job efficiency. While there is little new in the concept of job analysis, the application described here is unique and has benefits far exceeding those of the more widely used job safety analysis technique.

All of the principles of job safety analysis can be found in total job analysis. In fact, in doing a total job analysis you will find you are doing a job safety analysis as well, but you will also be doing much more. The "much more" includes pinpointing of key quality and production factors rather than just the key safety factors.

Basis for the Total Job Analysis Method

Total job analysis is based on the new consideration of safety as one of many inseparable parts of the supervisor's job. In this concept of the supervisor's job, safety is not considered as a separate and distinct responsibility, but rather as an integral part of many other responsibilities such as maintaining productivity, quality, and morale. To illustrate this point, consider our definition of total job analysis—"A tool for systematically obtaining maximum job efficiency." How would you separate safety from efficiency? A job performed without regard to the prevention of property damage or personal injury could hardly be termed efficient. Efficiency demands maximum use and control of the men, equipment, machines, and environment involved in any job. By the same token, a job done safely but incorrectly is of little use.

For a job to be done properly, all factors concerning production, quality, and safety must be considered as well as the sequence of the steps involved in performing the total job. Total job analysis is the way these factors are determined, considered, and used to fullest advantage. An ever increasing number of safety leaders throughout the world today agree that the direction should be toward the broader concept of total job analysis, rather than the narrower and more restricted job safety analysis.

The "Job" in Total Job Analysis

The word "job" is used in two major ways. At times it is used to refer to an occupation title such as carpenter, pipefitter, or electrician. For example, "John has a job as a pipefitter." At other times it is used to describe the tasks or activities a man does within his job description or occupational title, such as unloading a truck, lighting up a furnace, or replacing a light bulb. In total job analysis we will use this last definition.

A job, for our purposes, is a number of steps or operations performed in a definite sequence to complete a work assignment. Under this definition unloading a truck, lighting up a furnace, or replacing a light bulb are all jobs, even though they may be done by persons with various occupational titles or job descriptions. It is the job and not the occupational title with which we are concerned.

Cornerstones of Total Job Analysis

Keeping in mind our definition of a job, let's look at the two major assumptions upon which the total job analysis

technique is based. The first is that every job has key factors of production, quality, and safety involved in it and that these three concerns are generally so closely related and intertwined that it is impossible to affect one without affecting the others. This assumption then requires that any analysis of a job identify and consider all key factors related to any of these three things.

The second assumption is that job efficiency demands maximum use and control of the men, equipment, machinery, and environment involved. Maximum use and control of these factors naturally requires that they be known or determined. The only way this can be done is through total analysis of the job.

Anatomy of a Total Job Analysis

A natural question at this point then is what is a total job analysis and how is it done. There are four basic steps in a T.J.A.: (1) determine the job to be analyzed; (2) break the job down into a sequence of steps; (3) determine key factors related to production, quality and safety; and (4) perform "efficiency check."

Determine the job to be analyzed. Doing T.J.A. on all jobs done in his area might be a fine long range goal for the supervisor, but establishing shorter range goals would seem more practical. There are hundreds of things a supervisor would like to do, but under the reality of day-to-day pressures, he must give priority to those that are most urgent and important. Total job analysis will normally have to be approached in the same way. The selection of which jobs should be analyzed will normally be guided by some central agency within the company (such as the safety department or a supervisors' committee). This will eliminate any duplication of effort which might occur if several supervisors in different departments decided to analyze the same job.

How can you determine the critical or more important jobs which should be given priority for T.J.A.? There are four considerations to make in selection of a job for analysis and in deciding priorities:

1. *Past Loss Record.* Past experience may clearly indicate jobs with a history of severe and/or frequent production, quality, and safety losses. The degree of loss severity and frequency will serve as a guide in assigning priority for analysis. Production and accident records will provide the necessary data to prove the need for analysis of these jobs. They can also provide additional insights, as the next two points will illustrate.

2. *Loss Severity Potential.* The key here is "there's always a first time." The fact that a job has never been involved with a significant loss doesn't mean it won't be and may reflect only the laws of chance. You don't have to wait for production, quality, or safety to be affected negatively before doing something to avoid it.

Where they are available, Incident Recall reports are invaluable for this purpose. An incident recall program analyzes occurrences which were "near-miss" accidents. This permits hazardous conditions or practices to be corrected before losses occur. It will quickly indicate losses that almost, or could have, happened. Quality and accident investigation reports can provide similar information. The potential loss of a particular accident may have been major, though the actual loss experienced was quite minor. Again, this may have been a function of pure chance.

If you are not fortunate enough to have such records available, consider those experiences you have had in light of their potential loss. In setting priorities based on loss severity potential, you should also consider the next standard—probable recurrence rate.

3. *Probable Recurrence Rate.* Both actual and potential losses should be considered in terms of how often they can be expected to happen. This probable recurrence rate should have a definite bearing on the priority given a job for analysis. If the loss (or potential loss) associated with a job is severe and the probable recurrence rate high (might happen frequently), that job should naturally be given high priority. If the actual or potential loss is minor and the probable recurrence rate low (might happen rarely), the job would probably be given a much lower priority. There are, of course, many variations possible between these two extremes. Just remember to consider these three questions concerning any job: (a) What can be lost? (There is no price on a human life.) (b) How much can be lost? and (c) How often can it be expected to happen?

4. *The Unknown or Unfamiliar.* Whenever a new job is created or changes are made in an old one, there will be unknown or unfamiliar risks to be considered. There may be no past experience as a guide, no accident investigations or incident recalls to indicate possible losses. Such a situation requires close study and consideration to determine the key factors involving production, quality, and safety. This can be an ideal case for T.J.A. since it can reveal these key points and allow them to be stressed in instruction for the job. This, in turn, will allow you to avoid even the first loss. You don't have to learn from experience. One last reminder, don't overlook jobs which may have been changed after T.J.A. was done for them.

Break the Job Down into Steps. Any job consists of a number of steps or operations performed in a certain order. To analyze a job you must break it down into these basic steps in the sequence in which they are done. Then these steps can be examined individually to determine the key production, quality, and safety factors necessary to insure maximum efficiency.

A job step can be defined as "a logical segment of the operation when something happens to advance the work." Steps should not be too fine nor too general. As an example, here is a breakdown of a fairly common job—painting a chair.

Step 1. Select work area.
Step 2. Bring painting tools and supplies to work area.
Step 3. Prepare work area.
Step 4. Remove old paint from chair.
Step 5. Sand chair.
Step 6. Apply first coat of paint.
Step 7. Apply second coat of paint.
Step 8. Clean up area and tools.
Step 9. Store tools and supplies.

There are several things you may notice about the steps in this job breakdown. For one thing they tell only what is done, now how it is done. For another, no mention is made of how to do the operation in the least time (productivity), how to do it so the result wil be acceptable (quality), or how to do it without damage to the person, chair, or work area (safety). These things will come later from a careful analysis of each step.

This example of a job breakdown can be deceptive. It is not quite as easy to develop as it might appear. The two greatest dangers in development of a step-by-step breakdown are that the steps may become too fine (narrow) or too general (broad). For comparison, let's look at examples of such steps so you can see how they differ from our original example. A too fine breakdown would be:

Step 1. Remove lid from paint can.
Step 2. Dip brush into paint.
Step 3. Place brush against chair.
Step 4. Move brush back and forth over surface.
Step 5. . . . . .

This breakdown goes too far. You ean imagine the number of steps that would be involved if you continued in this manner. Besides, this sounds like instructions you might give a preschool age child!

At the other extreme you find the too general breakdown, such as:

Step 1. Remove old paint from chair.
Step 2. Paint the chair.

This is quite different from the last example, but equally bad. Instead of going too far, it doesn't go far enough. The steps are much too broad and general. Several steps are missed which have a direct effect on production, quality, and safety. This leaves the door

wide open for wasting time doing the job, producing poor quality results, and causing damage or personal injury. The entire purpose of the T.J.A. would be destroyed by doing this.

The majority of jobs will probably break down into ten to 15 basic steps. Naturally some will have fewer steps and some more, but the average will usually fall in the ten to 15 range. Simply keep this rule of thumb in mind—the breakdown of the job should have enough steps to describe accurately the work being done, but no more than are actually needed. Experience and common sense will usually enable you to determine just when this point is reached.

Once a job has been broken down into its basic steps, you are ready for the next operation in T.J.A.

Determine Key Factors Related to Production, Quality, and Safety. With the basic steps of the job determined, you are ready to examine the breakdown for those factors essential to maximum production, quality, and safety. A properly done job analysis used as an instructional outline is one of the best tools available to a supervisor to be sure production, quality, and safety standards are maintained. For this reason alone, it is extremely important none of these key factors be omitted, overlooked, or slighted.

Though key factors can be determined in several ways, one of the best methods is job observation, actually watching the steps being done. In this method you view each step or operation from the standpoint of what is being done and why it is being done. A clear picture of the "what" and "why" of a step will easily identify key factors and their purposes. As an example of this, consider the job step of "Select proper grinding wheel" from a job breakdown of a grinding operation. Watching this step being done and asking yourself, "What is being done here?" might produce an answer like, "Check label for grit size and maximum operating speed." Questioning the "why" for this would reveal that only a certain abrasive grit size can produce the desired finish on the material being ground (quality key factor) and that exceeding the recommended speed for the wheel could cause serious injury (safety key factor).

Determining key factors requires close attention and observation; therefore, no effort should be made to develop any problem solutions simultaneously. Thoroughness requires that you do one thing at a time when conducting a T.J.A.

When you are sure all key factors in all steps of the job breakdown have been determined, you are ready for the final procedure.

Perform Efficiency Check. Many will feel this procedure could be equally well described as a "deficiency check" since it involves checking each job step and key factor for deficiencies and developing solutions for these potential hazards to efficiency. It is a procedure to guarantee maximum job efficiency by eliminating any conditions conducive to error or potential losses.

One way to conduct this check is to take each job step and key factor and examine it by applying the following questions:

1. Is this the best way this can be done? If not, how can it be improved?
2. Could anything occur here to endanger production, quality, or safety?
3. If the step is done exactly as described, will it always result in meeting the standards of production, quality, and safety?
4. Are additional measures needed to assure the desired result?

If deficiencies or hazards are found, the next step in the procedure is to develop a solution to eliminate or to minimize them. These solutions may be in any one of the following categories:

1. *A job procedure solution.* This type of solution is one that involves outlining exactly what a worker is to do, or not to do, to insure the desired result or to avoid a potential loss. It is a specific measure aimed at achieving a specific result or avoiding a specific potential loss. As an example, the job step may require the worker to make some machine adjustment where there is a potential hazard of electrical shock. The job procedure solution might be to tag and lock-out the main power switch for the machine before making the adjustment.

2. *A job environment solution.* This type of solution involves changing some part of the total job environment to insure efficiency and/or to avoid potential loss. It may concern materials, equipment, lighting, building or work area layout—anything that is included in the total job environment. As an example, the job step might require the worker to mix chemicals which produce noxious fumes that could pose a hazard if allowed to accumulate. The environment solution could then be to install exhaust fans over the work area to remove the fumes as they are generated.

3. *A method change solution.* This tpe of solution usually changes the entire way of performing the job. Most of the time it results in improving job efficiency by decreasing risk of loss, saving time and effort, or reducing cost. An example of this type of solution follows below. This particular example is from a specialized industry, but the principles involved could be applied to many other types of work, including, for example, the food-processing industry. A job in an electroplating department consisted of removing and replacing nickel anode bars in the plating tank when they eroded to a certain width and posed a hazard of falling and puncturing the tank liner. The method of replacement was not only a time-consuming and hazardous procedure, but also involved considerable waste of nickel since the bars removed could not be used further. The new method involved replacing the bar anodes with anode baskets which were filled with nickel chips. This method change not only eliminated the entire job of removal and replacement of anode bars, but also resulted in a significant cost savings since all nickel chips placed in the baskets could be completely consumed with no material waste.

4. *A reduced recurrence solution.* This type of solution involves reducing the number of times a job must be done, thereby reducing the cost, effort, and potential for loss. Some of the best examples are found in the area of maintenance or service jobs where periodic repairs are required when something wears out and must be replaced or some material such as dust or dirt accumulates and must be removed. A prime example can be seen, again, in an electroplating department where dirt and impurities collected in a cleaning tank, requiring the tank to be taken out of operation every three months while it was drained, cleaned, and a new solution made up. The operation was time-consuming, costly, and hazardous because of the chemicals used. The solution involved installation of a filtration system which resulted in the tank being drained and cleaned only once every two years. This not only reduced operating costs, but also greatly decreased the frequency with which the worker had to be subjected to the hazards involved in cleaning the tank.

These four categories of solutions and the examples given should provide you with a better understanding of all that is involved in the efficiency check procedure. They should also point out that a Total Job Analysis is a tool for increasing operating efficiency, lowering costs, and reducing hazards.

Benefits of Total Job Analysis

The first benefits of a T.J.A. will be noticed while the analysis is still being developed. The supervisor will find he is learning more about the jobs he supervises. Workers will take more interest and pride in a job when they are asked to help in its analysis. With these comes an increase in ideas and suggestions for ways of increasing productivity, improving quality, eliminating waste, and improving safety. As a consequence, costs are usually reduced.

One of the most valuable uses of a job

analysis, however, is in job instruction. A completed analysis is an ideal instructional outline. It enables anyone to learn how to do the job in the best way and in the shortest time. It also standardizes the job procedure so everyone learns to do it in the same way. Having all the key factors listed greatly reduces the chance of one or more being missed or overlooked. All these things help make the new employee more productive in less time and prevent or lessen the drop in quality that might normally be expected. Naturally damage and injury will be less likely when an employee is properly trained.

Another use for the job analysis is in methods improvement. Since it is a step-by-step picture of how the particular job is done, T.J.A. is the ideal starting point for methods and cost improvement studies. Enabling someone to become closely familiar with a particular job in the shortest possible time also means that the savings from these studies can be obtained more quickly.

You can see that several of the uses to which a job analysis can be put have measurable dollar savings associated with them. For the supervisor this is a very desirable characteristic. Being able to show results in dollars is always an advantage, especially if it is a new program you have instituted.

There are many other uses for a total job analysis besides those we have discussed. They can be used in safety contacts and for spot checks to be sure standard practices are being followed. But no matter how many uses we might list, a supervisor will probably find more once he starts his own program. Once T.J.A. is done, there is never a problem in finding uses for it.

The supervisor will use a total job analysis more readily than a job safety analysis since it includes all elements of his responsibility and not just the safety aspects. By covering all facets of his work, it will seem a more realistic tool.

With this general description of T.J.A. and its uses in mind, let's take a closer look at some of the mechanics and methods involved in doing an actual analysis.

The Mechanics and Methods of Total Job Analysis

Once a job to be analyzed has been selected, you are ready to begin the actual analysis itself. To take the mystery out of how this is done, simply ask yourself this question: "If I wanted to find out how a job is done, what would I do?" The two most natural answers are, "Watch someone do it" or, "Ask someone who does it." It should not be surprising then that these are the two best methods to use—observation and discussion. Each has its advantages and disadvantages, however, and the nature of the job to be analyzed will dictate which should be used.

To enable you to decide for yourself which method to use for any given job, let's go through the mechanics of each. As we discuss each method, we will point out, in detail, how it is done and the reasoning involved.

Total Job Analysis by Observation

The observation method is preferred whenever possible since it tends to be the more direct and quicker of the two. Unfortunately, there are several situations where it is not practical. For example, when a job is performed infrequently with long intervals in between, it might take months or even years to complete an analysis. Such a delay is inadvisable for any job worthy of analysis. Another example might be jobs that are performed in the field or in another plant at a considerable distance from the supervisor's normal work place. Here it might not be realistic to expect the supervisor to take extended travel time just for this purpose. But, as we have said, whenever it is possible, observation should be used. Now let's consider how the job is broken down.

Briefly, there are five steps in doing a job breakdown by the observation method:

1. *Select the proper worker to observe.* This should be done carefully and based on more concrete evidence than simply your personal opinion. A thorough check of production records, inspection sheets, and accident reports will give tangible, measurable evidence of which workers have the best records of productivity, quality, and safety. In addition, where a certain worker is much higher in one particular category, it might be advisable to observe him. Workers selected should also be cooperative, but how they are approached on the subject will have considerable bearing on this.

2. *Explain the purpose of the analysis.* Be completely open and honest with the worker. Explain that it is the job, and not him, that you want to study. Show him a completed T.J.A., so he can get a better idea of what you want to do. Discuss it with him as you develop it.

3. *Observe the job and write the breakdown.* Observe the job and write down the basic steps. Don't get in the worker's way or distract him in any way! Making him nervous will only defeat your purpose. As you write the basic steps, keep in mind the points already discussed. Don't make them too fine or too general. This may require observing the job being done several times. Be sure the steps are recorded in the order in which they are done.

4. *Check the breakdown with the worker.* When your breakdown is written, show it to the worker you observed and discuss it with him. See if he agrees that it is an accurate description. If he disagrees on certain points, talk them out, even if it requires observing those steps again. Don't get sidetracked on the "why" aspects at this point. That comes later.

5. *Record the basic steps of the job breakdown.* When agreement is reached on the accuracy of breakdown, record it. Use brief, four- or five-word descriptions starting with action words such as place, set, position, remove, etc.

The second operation in the analysis is to determine the key factors related to production, quality, and safety. Armed with your completed breakdown, observe the job again, this time questioning (in your own mind first) why each step is done, what its purpose is, and what relationship it has to maintaining standards of productivity, quality, or safety. Then review and discuss each step in the same way with the worker to be sure all factors have been noted and considered. Make certain you clearly describe what is done and why. Each key factor should include a complete description of why it is important and what aspect of production, quality, or safety it is meant to insure. Explaining fully the purpose of this procedure will aid considerably in winning the employees' full cooperation in this critical operation.

The last operation, performing the efficiency check, has already been discussed at length. One of the best ways to do it is to observe the job a third time, concentrating on each step and key factor you have listed and applying the questions recommended in the earlier section on these checks. It is then a matter of determining the type of solution to be used for problems that exist.

It is extremely important that all key factors in your final analysis be written as clearly and definitely as possible. Don't use generalized terms such as too much, too heavy, etc. Spell out as exactly as you can just how much is "too much" and how heavy something must be to be "too heavy."

Worker involvement is another critical area. Generally speaking, the more you can involve the worker and allow him to contribute, the more successful your analysis will be. Just remember, however, that you will bear full responsibility for the accuracy and completeness of the analysis, so nothing can be permitted to compromise this final goal. The more jobs you observe, the more accurate your analysis will be.

Total Job Analysis by Discussion

There will be times, as mentioned before, when for one reason or another, it

is not practical to do a job analysis by actual observation. When this is the case, the discussion method is a useful alternative. You will notice that several of the operations involved are similar to those used with the observation method, while others are quite different.

The first thing to do is to select group participants for the discussion. Wherever possible, this group should definitely include experienced workers who perform the job, selected along the lines given in the discussion on observation. The group can include supervisors experienced with the job, but every effort should be made to have workers represented. After all, they know how the job is done, while all too often supervisors know how it was done at some point in the past. Where criticality is based on quality, scheduling, or the function or responsibility of some particular department, a representative of that department (quality control, production control, etc.) should be included in the group. Certainly the analysis should be reviewed with everyone concerned. In the discussion to follow, we will assume you, as the supervisor doing the analysis, are serving as discussion leader for the group.

The purpose of the job analysis should be reviewed completely with the group, telling them how and what they will be expected to contribute. It will help if copies of a completed analysis are available for them to refer to. As soon as everyone understands the reason for the group being called together, you can begin the first operation—breaking the job down into its basic steps.

1. *Breaking Down a Job by the Discussion Method.* This is done in much the same manner as by observation, except rather than watch the job as it is done, you listen while it is described. As a group describes each job step, it should be written down on a newsprint pad or chalkboard so all participants can see and discuss it. When the group agrees that the description of a step is accurate and in the proper sequence, you can move on to the next. Be sure, however, any disagreement is talked over and ironed out as much as possible before proceeding. Don't let the group get bogged down in discussions of why or how something is done. Stick strictly to what is done at this point.

2. *Determining Key Factors.* When the job breakdown has been completed and reviewed by the group, it is then used to determine the key factors influencing producton, quality, and safety. Cover each step, one at a time, asking the group what key factors can be associated with that step. Write these down for all to see just as you did with the job step, remembering it is better to have a large number than to risk missing one.

3. *Performing the Efficiency Check.* When all job steps and key factors have been recorded, the entire group should review them, questioning each step for ways it might be improved, made more foolproof, or safeguarded to insure attaining the desired result. In effect, this is a minor "brainstorming" session for methods improvement.

When done properly, the discussion method can provide an accurate and useful analysis of a job. Several meetings will probably be required to complete the process, but the time will be well spent. Just remember, your role as discussion leader is to keep the process moving and on the track. Don't let your meetings become bull sessions!

Both observation and discussion can produce effective T.J.A.s if done skillfully and conscientiously. Some may suggest a third method, "memory," but the feeling here is that this method relies too heavily on a supervisor's memory of how a particular job is done. No one is perfect, and too often this system leads to an analysis based on equal parts of memory, opinion, and conjecture—all of which should be minimized or totally absent in a total job analysis.

Using the methods and outlines provided here will provide a very workable framework for an effective total job analysis program. The key is to try it. Always keep in mind the fact that even a poor analysis will be of considerably more value and benefit than none at all.

Management Involvement in Total Job Analysis

For a total job analysis plan to be accepted and operated properly, the involvement of higher management is an absolute necessity. Unless top management expresses a genuine interest in the program, it will become a sporadic and tedious chore, little used and even less useful.

At all important meetings where serious problems or losses are discussed. T.J.A.s should be suggested or considered as a possible way of attacking the situation. Objectives should be set by top management relative to the T.J.A. program and then followed up religiously. The "worst first" principle should be applied by management to give individual departments the initial impetus required to do a T.J.A. on the worst (from the standpoints of quality, production, and safety) job in its area first.

Even after the program is successfully launched, top management should still conduct spot checks to be sure T.J.A.s are being done—and used. In many ways the success of a total job analysis program will be a direct reflection of the degree of involvement from top management.

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EFFECTIVE SOFTWARE IN A HARDWARE ORIENTED SOCIETY

By HERBERT J. KOLODNER
Dir., Safety, Security & Fire Protection,
Celanese Corp., Charlotte, NC

Starting with the turn of the twentieth century, the need for safety took on new meaning and impetus. Machines had taken the place of handwork, hardware of all kinds was proliferating as increased production became the order of the day. It was soon realized that much of this equipment was poorly designed from the worker protection standpoint. Variations in reaction time, individual idiosyncrasies, distractions, and unfamiliarity with the equipment took their toll of fingers, toes, eyes, and other body parts. The need soon became obvious; hardware guarding and better designed equipment were needed if the carnage was to be controlled. And thus, into the 1920s, through the 30s and 40s, the main thrust of accident prevention was in the area of engineering—better guards, better marking and lighting, better new equipment. As was to be expected, the frequency and severity rates of injuries dropped significantly. However, after a number of years of gradually diminishing rates, a general plateauing effect set in. This has now held true for the past 10-15 years, even rising in some isolated industries. This plateauing of rates has forced loss prevention personnel to broaden their scope in order to further increase the effectiveness of their overall accident prevention programs.

In retrospect then, why has the main emphasis of loss control programs in many organizations been centered around a hardware orientation? This was true primarily because: it was easier psychologically for workers to accept; it was easier to "enforce" if directed against machinery, and the results could be seen immediately.

As discussed previously, there are many limitations to the "hardware" approach. The main ones are:

1. It is very costly in dollars and engineering effort.
2. Statistical analysis has shown that unsafe conditions cause only ten per cent of accidents; unsafe acts cause 87 per cent; and acts of God, three per cent.
3. Most companies expend 90 per cent or more of their efforts, dollars, and energies on hardware, even though it is an area where only ten per cent of accidents occur.
4. There is a plateauing effect beyond which hardware guarding or modifications produce negligible results.
5. The best hardware can be negated or rendered ineffective by misuse or neglect on the part of employees.
6. Above all, it must always be kept in mind that the controlling factor for all hardware is the operator of that machine. Numerous studies have indicated that even under the most ideal environmental conditions, with the most carefully designed equipment and most thoroughly trained operator, the probability of error is at least one in one thousand (10^{-3}). This was shown in studies done by Dr. Powers at M.I.T. in which he researched the probability of error in such key functions as astronaut and airline pilot. Using that failure ratio as base line data, if one factors in all the environmental detractants, personality deviations, lack of motivation, production schedule pressures, minimal training, and the countless other idiosyncrasies that constitute human individual differences, the probability of failure rises dangerously close to a "one in one" situation. We therefore must do more than merely design safe equipment and processes, we must also establish and enforce the necessary procedures for the proper use of that equipment.

Software (procedures) deals with people, their methods of operation and sequencing of events. They must be: logical and well planned; designed to follow the natural flow of operation and be enforceable; understood by all employees; enforced; reviewed periodically and changed to reflect changes in methodology; and reinforced and reemphasized periodically.

Effective procedures do not come about on their own. They take hard work and concentrated effort. The key steps are:

1. Analyzing the operation thoroughly, step by step.
2. Using "worst case" or failure mode and effect analysis, determining all possible failure conditions, paths, or modes.
3. Studying the individual problems and possible synergistic effects of one or more failures.
4. Using the "critical incident" technique, behavior sampling or other accepted method, determining the way the employees are currently doing the job.
5. Discussing the methods with the foreman and employees, asking for their suggestions and contributions. If it is "their idea," acceptance and implementation is greatly eased.
6. Reviewing similar operations in other departments of the plant and in other plant locations. Try to adopt the safest, most efficient, most effective, and most-widely-in-use system wherever possible. Improve upon the system without feeling you must "re-invent the wheel."
7. Writing the procedures and having them reviewed by plant management to include the first line supervisor involved. Accepting suggested modifications—don't feel that first draft must be final issue.
8. Publishing procedures, instructing supervisors and employees, assuring complete understanding of "intent of the law" as well as "letter of the law."
9. Making supervisor responsible for enforcement and follow-up.
10. Auditing periodically to assure adherence to procedures and not hesitating to invoke penalties for infractions. Without enforcement the best procedure or rule is useless.

The bond that runs through this entire chain that makes it successful and productive versus another "paper exercise" is management involvement, acceptance, and enforcement. Participation by management is essential for ultimate success. It is not always easy to reorient hardware conscious managers. Often it must be a step-by-step process integrating statistical data, training programs, and a strong communications pattern. However, once company management has been convinced of the true value of effective software, it will take its proper place in the prevention of losses. The best raw material, the most efficient hardware and years of technological development in process design are all only as effective as the human mind or hand that guides them. Effective software provides the continuity which makes safety programs successful over the long run.

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SUPERVISORY SAFETY TRAINING — DISPELLING THE MYTH

By THOMAS A. McWILLIE
Industrial Resources, Houston, TX

A myth is an imaginary thing, like the old folklore about trolls and goblins. These myths, even though imaginary, will sometimes play little tricks on us. They trick our emotions and sometimes become so real that in certain situations they scare us. We know the situation isn't real, but . . . .

How many times have we in industry developed a supervisory safety program that really is an imaginary thing? It fills our needs as we see them, but doesn't fill the needs of our supervisors. We develop a complete program for our supervisors that doesn't acomplish the true goal we set out to accomplish, that of good safety training directed at the supervisor to sharpen their job skills (give them something they can take with them to improve their job performance).

Ideally, every supervisor should be trained to supervise with special emphasis on safety. This training must be understood and related to the supervisor in his own world, but too often the overall pressure on our supervisors is to get the job done.

Too many times, management diretly tells the supervisor in an autocratic way, "Work safely." We then attempt to put on a program to train him in safety that really tends to be short lived in their mind because of the external pressures from management to get the job done. I'm sure some of you have been involved in some of these programs directed at our supervisors. I find myself wondering how many supervisors go through a training course and really understand or relate to the overall objective of giving them tools to work with in their everyday job of directing the work activities of people.

How do we dispell this myth so the supervisor understands and relates to the safety training? One way is to make sure that in your supervisory training assignments of responsibility are clearly defined. In other words, supervisors must have implanted in their minds "safety values clarification" with management's declaration that is clearly understood. This then gives the supervisor support by way of authority. This should clear up any myths in the supervisor's mind about performing his job with special emphasis on total safety. The clarification of safety values will convert attitudes into action.

Second, the safety training program must show good organization. The trainer should be—must be—skilled in his role to present a program that will demonstrate the organization.

Third, insure everyone participates in the training program. This falls on the shoulders of the instructor. The personal magnetism of the instructor tends to draw out participation from a group. I once read, "You influence people only through an appeal to their emotions," and this is certainly true in safety training.

Last, relate the basic elements of a safety training program so that the supervisors will build into everyday actions emphasis on total safety for their employees. Develop the examples in the training that relate to the individual supervisors for a particular work group. Use real life examples that will turn the group on (you're again appealing to the emotions).

Don't overlook the need for follow-up training. "Your value is established entirely by your ability to render useful service or your capacity to induce others to render such service." — Napoleon Hill

78 1942

EMERGENCY PLANNING

By R. E. SOURWINE
Manager, Safety & Loss Prevention, Chemical Div.
PPG Industries, Pittsburgh PA

Within a corporation such as PPG there is a wide diversity of products; we have many different types of plants and each plant has to plan for emergencies that are likely to occur at that location.

From a corporate viewpoint, it is necessary that each manufacturing location have a well trained and efficient emergency crew. There is no known federal legislation that requires any industrial manufacturer to maintain an emergency control program; however, the company has an implied moral obligation, as well as responsibilities toward the company's investors to maintain a facility that is operating and profitable. Also, in this day when industry is under close scrutiny from the public sector, it is necessary that a plan be developed that can be implemented to protect the public in the area surrounding the plant.

It is the corporate policy of PPG to provide a safe work and living environment for its employees and neighbors. Planning, engineering, maintenance, and work procedures are all directed toward routine attainment of this goal. Moreover, means and methods of limiting and containing situations are provided in the establishment of emergency control programs.

Establishing an emergency control program is not an easy task. The first hurdle is to convince local management that there is a need for such a program. Then copies of sample programs must be obtained. Many earlier programs were patterned after Civil Defense programs. It may be necessary to send members of local plant management to other industrial locations to observe and evaluate their programs. Training sessions will be necessary and drills must be conducted to make the program effective.

An effective emergency control program requires the same planning and organization as does any other business undertaking. Management is responsible for developing and operating an emergency control program designed to meet all anticipated eventualities. Before beginning extensive planning, it is well to determine just what type of disasters are most likely to occur.

Disasters are subject to change with the times. Programs have to include procedures for handling such problems as bomb threats and power failures. A manufacturing plant located in this area is subject to hurricanes, where one located in the Midwest is more likely to encounter tornadoes, and, of course, many locations could be subject to flooding. Therefore, emergency control programs must be geared to handle today's problems and adverse weather conditions as well as operational difficulties.

Organizing an emergency control program requires that a company review and analyze the needs of its own particular location. This includes the geographical location, exposures, security, types of construction of the various facilities, use of automatic detection and extinguishing equipment, types of operation and processes used, and consideration of the various materials handled, such as toxic chemicals, flammable liquids, and combustibles.

Emergency control planning should also take into account such items as: plant alarm system; communications procedures; the responsibilities of each member of the emergency control organizational chart; evacuation plans; a list of available emergency equipment and where it is located; gas detection teams; department's emergency plans;

bomb threat procedures; emergency situations outside the plant; mutual aid; phone numbers of key personnel; traffic control and other pertinent information. An Emergency Control Manual containing the relevant information should be prepared and distributed to those responsible for the execution of the plan. The manual should be reviewed at least annually and updated as needed.

There must be training of emergency crews for an emergency program to be effective. We must recognize that the frequency of response to actual emergencies in the majority of industrial and commercial facilities is limited. Infrequent need for action has a deterring effect on the ability of the organization to respond to a real emergency.

For the programs to be effective, emergency crews must be provided for all shifts. The crews need to be trained to handle all types of emergencies: fire, toxic gas releases, chemical spills, serious injury, and personnel rescue. Management must recognize this need and provide the necessary time and materials to complete an effective training program or the emergency control program will not meet the established objectives.

To meet the needs of the four major divisions, the corporate policy sets general guidelines: controls and specific solutions to local problems are to be developed by the individual facility. Thus, PPG has opted for localized plans developed at operating locations by individuals who ultimately would be responsible for handling an emergency. The plans were tailored for various stages of response, each involving only those control forces required based on the extent of the emergency. This gives the philosophy of the Corporate staff or, as they are often referred to, "Those guys in the Ivory Tower." Each division has to take these general guidelines and develop an emergency control program that will meet the needs within the division.

In PPG's Chemical Division, a general policy and procedure guide was issued requiring that each plant develop an emergency control organization to meet the following minimum requirements:

1. The plant will have a defined program in writing and forward a copy of the original and all revisions to the appropriate profit center manager and to the division's manager of safety and loss prevention and the corporate safety section.

2. The plant program will include an outlined organization of the job functions required to cope with plant emergencies and the names of the man assigned along with their responsibilities. The plant manager should be the administrator. The minimum of the plant program includes:

   a. Correction of mechanical defects.
   b. Evacuation of plant personnel, rescue work where necessary, and notification of the public in cases of evacuation or rescue.
   c. Establishment of a communication system for emergency call-ins.
   d. Possession of respiratory, fire fighting, and personal protective equipment.
   e. Establishment of a readily distinguishable alarm emergency signal.
   f. Placement in proper locations of equipment that indicates to employees the wind direction which is necessary for evacuation and rescue work.
   g. Conducting a drill every six months to test the response to previous training. Drill reports should be forwarded to the appropriate profit center manager, the manager of safety and loss prevention, and the corporate safety section.
   h. Review of the emergency program at least every two years.

Also, cooperation with other local industries and organizations should be fostered. Lists of emergency equipment available from other plants should be obtained and, when requested, the plant should supply a list of equipment available in case an emergency arises within a neighboring plant.

What I have discussed thus far has related primarily to guidelines and philosophy concerning emergency preparedness; however, the implementation of these guidelines and philosophy by the plant is the most vital factor, since this is where the emergency will occur and they are the people who must respond. Let's define what we mean by an emergency. An emergency can be defined as a condition which cannot be handled in the normal routine manner. This may be the result of: fire, explosion, excessive accumulation of hazardous and/or toxic vapors, storm, flood, power failure, bomb threats, civil disturbances, or other causes.

An emergency may also pose a threat to the general public in the area surrounding the plant; therefore, an emergency control program should contain measures to protect the public when and where necessary.

An incident confined to a limited area which may be safely handled by the emergency squad or other plant personnel present at the time of the incident does not directly fall under the emergency control program. If escalation of an emergency is unavoidable, a responsible member of the "E" squad will usually activate the use of the larger emergency control program. Emergency control organizations must be maintained as viable effective forces capable of successfully coping with any eventuality. This involves the services of a core of individuals specifically selected for these assignments and trained in emergency control techniques, methods, equipment, and team work.

Each plant has an emergency squad that is composed of selected production personnel, maintenance employees, members of the guard force, and other management personnel. The exact number of employees on the squad will vary depending upon the size and potential hazards of the plant.

The "E" squad is the first line of defense, and if the situation cannot be handled by the "E" squad, the emergency control organization is activated. The emergency control organization is usually headed by the works manager as the general chairman or by the coordinator (assistant works manager). Reporting to him are the various functions which make up the organizations such as operations control, maintenance, rescue and fire, mutual air radio, communications, medical, and press representatives.

Each plant has the responsibility to thoroughly train its emergency squad members in emergency first aid, rescue, and fire fighting techniques. To establish some standards and give guidance to the plants, our division has developed a number of fire fighting training exercises that can be utilized to train "E" squad at the plant sites in the fire fighting techniques. These fire training exercises establish a lower level of expertise, and some plants have developed fire training grounds that give a higher level of training. Suggested fire training exercises are: pan fire, pit fire, Christmas tree, trench fire, simulated pump fire, simulated paint rack fire, and spill fire with obstacle.

This training should be extended to all front-line supervisors annually, and all employees should receive training on extinguishing a pan fire with hand fire extinguishers once every five years. New members appointed to the plant emergency squad should receive this training within one month after being appointed or as soon as practical.

At those plants with an older work force, where the employees are more prone to heart attacks, the emergency training given to the "E" squad has been pertinent in giving first aid to PPG employees as well as contractors' employees. At one of the Chemical Division plants, the "E" squad has responded to 10 such emergencies during the past year.

The training techniques, however, vary from plant to plant. Following is an outline of one plant's training program that is given to each new "E" squad

member and covers 40 hours: multimedia - first aid; cardiopulmonary resuscitation (CPR) techniques; emergency rescue; familiarization with first aid station equipment and ambulance first aid equipment; breathing apparatus training; properties and types of fires; extinguishing agents and application; protective clothing for fire fighting; familiarization with fire fighting equipment, including hoses, nozzles, portable fire extinguishers, wheel units, and fire trucks; field training in fire fighting with protective clothing; and familiarization with plant fire protection systems. This program consists of classroom sessions as well as field training. The last two days are spent in the field extinguishing Christmas tree fires, impingement fires, pan and spill fires, and others.

In addition to their initial training, emergency squad members participate in monthly drills and training sessions. This training consists of review sessions on items such as a breathing apparatus, rescue techniques and fire fighting as well as new films and slide programs. Simulated rescue drills are utilized in training "E" (emergency) squad members in rescue techniques. While the simulated drill is being conducted, the "E" squad is observed. The observations are presented during a critique after the drill.

As an additional training exercise, an overhead transparency showing a specific area of the plant is projected on the screen which indicates all the underground and aboveground fire protection systems. The "E" squad is divided into two groups, each with a leader, and each group is given a problem situation along with all the adverse conditions pertaining to it. Group members are required to come up with a solution and present it to the group. After both groups have done this, the entire "E" squad discusses both problems and the solutions given.

To provide more realism for the "E" squad in fighting large fires, in 1975 our division established a PPG Chemical Division Fire School at the Texas A&M Fire Training grounds, and we have trained about 100 people at this facility.

Our division recommends that the plant conduct at least one drill every six months, and once a year it should have a full scale emergency drill in which all employees are evacuated from the plant except those required to operate the plant. Checklists are utilized to assure that all employees are evacuated and observers are pre-selected and located in key positions around the plant in order to observe the response of the "E" squad. Problems are noted for discussion after the completion of the drill and corrective action is taken to eliminate the problem areas. These drills should on occasion involve other members of the mutual aid group when possible. The drill, depending upon the degree of emergency being simulated, can range from removing one man who has been overcome with toxic vapors from the second floor of a process rack to simulating a large release in which 40 people have been overcome with toxic vapors such as chlorine or ammonia. In a drill such as this, the problem of securing transportation immediately for 40 people, locating enough hospital space in the nearby community for treating the injured, and maintaining an accurate record of where each injured person was sent so that the family can be notified, can be quite complex and require extensive planning.

Our "E" squads have had to respond to many crises ranging from heart attacks to major fires. Each time, following the concept of using minimal force, only the personnel actually needed to cope with the emergency have become involved. The philosophy here is having a responsible individual always on hand to assess the situation and to call for support if needed.

This concept avoids the complete disruption of the operations at the plant when dealing with potential disaster. Yet it allows for the complete mobilization of all resources and the evacuation of personnel without impairing the response of the select emergency squad.

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SYSTEMS SAFETY ANALYSIS — METHODS AND IMPLEMENTATION

By HARLAN CARROLL
Systems Safety Analyst, Celanese Corp.,
Charlotte, NC

A systems safety analysis is an in depth look at a system or process or component of these with a stated objective of finding problems and potential problems, evaluating them for hazard, and recommending ways to minimize or eliminate incidents and their effects.

Why are we involved? Loss prevention—that's the name of the game for all of us, whether we're dealing with people or plant and equipment or both. Sometimes no formal or thorough review is made on the processes and equipment around which we and other employees are required to work. I don't know how you feel, but I want to be as sure as I can that I have a safe place to work. As an example, we all too often perform our own individual design reviews, everyone is doing his own thing without much regard for the other areas of responsibility. This is what happens when we have the uncoordinated reviews which are the most commonly held—if any are held at all. Each specialty looks at his area only, and little thought is given to the interrelationship of all factors.

When we get everybody together to analyze a problem and they get the whole picture, they can see that what was thought to be one problem is a whole different animal.

One way to initiate a systems safety review is for the plant safety officer to call for it. The company should have an established procedure for systems safety analyses or design review, or you may start them by establishing a standing committee charged with the systematic review of all areas of your plant. The key to getting the process design review procedures started lie in first convincing the plant and company management of the effectiveness and need for reviews, and second, getting the commitment from the busy people who will make up the review team.

When we start talking about the mechanics of design reviews, several topics come to mind depending on the experiences each of us has had. Some of these might be: hazard analysis; operability studies; risk evaluation; fault tree analysis; failure mode and effects analysis; and catastrophe analysis. These all have many strong points to recommend their use to evaluate a process for obscure dangers to personnel and equipment. However, we can do a good job of evaluating the hazards of a process or system by taking some pointers from all of these types of studies.

Some form of systems and process review has probably been used in several of your plants on many different processes, such as material handling, heat transfer systems, and chemical processes. The technique is not limited to any specific area or process. In fact, most methods of systems and hazard analysis can be traced back to the development of military and space hardware. We are not usually so well funded as the DOD or NASA and may not feel the need for the detail or sophistication of the programs they had developed, so what I want to suggest here is a combination and simplification of several methods.

In my opinion, a very effective way to evaluate a process or system is to sit down with a group of people who are familiar with it and generate an atmosphere of questioning which draws out answers from sometimes unlikely sources and in turn generates more questions.

In order to provide more consistent

results though, a somewhat structured approach is recommended. The following is one suggestion.

The first step is to establish a review team. These people should have knowledge of the process and hazards involved. They can be only plant people. They can include members of a design team. They can include corporate safety. For an objective review, use a person from another area not directly concerned with the success or failure of the project. Keep in mind also that the team should be small enough to be efficient. It must be firmly committed to the study.

The most experienced people can give a continuity of thought and direction to the team. This central group should always include a member of the safety department. The central group should not dominate the review meeting but should see that the proper questions are asked. Each team member should be on an equal basis with the other members. Let me again emphasize that the team must be firmly committed to the study!

The second step is to plan and conduct the review meetings. A process review can normally be conducted from piping and instrument diagrams and equipment layouts. This review should be in depth rather than in petty detail. If your reviews are to be of existing equipment, a schedule should be set to allow for adequate preparation and the in-depth study. When too many process reviews are scheduled on a crash basis, you will tend toward shallowness. Areas included in the review schedule besides process operations should be utilities, maintenance, shops, etc.

We need to establish guidelines for the conduct of a review in order to be most effective. The first order of business in a review meeting is to outline the operation of the system so that all team members have a good understanding of the process or system under review. As I said earlier, the study is based on a procedure which generates questions. One method assumes that a problem, in safety or operations, can only arise when there is a deviation from the operating or design intent. The technique then is to explore the system or process design and operation systematically, looking for every deviation from normal. Included in every review should be a study of: process chemistry; hazardous properties of all materials; and physical operations, including flow charts and plant layout.

The question might now arise as to who will generate all the questions necessary to find every deviation from the norm. An article by H. G. Lawley in *Hydrocarbon Processing* has laid out a method which you may find useful. In his article, he illustrates the flow of steps through which problems are readily identified and presents a list of guide words for the generation of deviations.

The study begins by applying the full checklist of guide words to a selected line or other system part where it enters a larger system. For example, a process vessel may have several lines and/or openings to which the list of guide words can be applied so each is searched thoroughly using the complete list. When all points have been examined, the vessel itself is studied. Only the guide word *other* is used for this because examination of the lines, etc., joining the vessel should have generated the same answers as would show up now.

This process is repeated on a line-by-line, vessel-by-vessel, area-by-area basis until the whole section has been studied.

Now that we have a review going, what are we going to do with it? Well, the third step in this process is to evaluate the hazards for their potential effect on the process or people involved and prioritize them on the basis of severity and probability of occurrence. At this point, a rough working knowledge of failure rates for pumps, valves, etc. is helpful. If this study brings out a severe problem, or the potential for one, a more critical analysis can be done using FTA or FMEA.

Where action is clearly necessary and the best solution is fairly obvious, agreement should be quickly reached by the team and recorded before moving on. This modification can then be immediately factored into the discussions as it relates to other deviations on the item under discussion.

Where a satisfactory solution is not immediately apparent, the point should be recorded for future action outside the review meeting. When agreement on a solution is not quickly reached, that problem should also be deferred to a meeting outside the review. Prolonged discussion of a problem is undesirable because it interrupts the chain of thought and wastes the time of team members not directly involved. Make recommendations for, but don't try to engineer, solutions.

You may not want to make a formal record of this chart, but the end result of the review will be a list of actions or questions relating to the design changes or important operating points as they appear in the "action required" column. A team member is made responsible for following up on an item to insure that action is taken or further study and resolution are achieved.

The last step in this style of process review is to prepare a report of actions and recommendations. This report should be definite and concise. It should be a listing of hazards, recommendations, assignments of responsibility for action, and target dates for completion. A follow-up meeting could also be scheduled if appropriate. Each report should be dated and addressed to a specific person—usually the plant manager or project manager—with carbons sent to other interested personnel.

Now that we have a design review report published, we can sit back and relax, right? Wrong! The whole review team effort could be negated with disastrous results by a single change made late in the construction phase without proper forethought as to its acceptability. In fact, a formal systematic pre-startup check of all new or modified units should be made to insure that all recommendations were fully implemented and that no unauthorized changes were made.

The use of the process design review team concept should not be allowed to lull you into a false sense of security. By this I mean, don't overlook other equally important and mandatory reviews covering specific areas such as layout, relief and blowdown, electrical area classification, fire protection, etc. These may or may not enter into the design review discussions. Therefore, there should be a formal mechanism which insures their happening.

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EXPLOSION VENTING FOR BUILDINGS

By W. W. RUSSELL
Principal Process Safety Specialist,
Monsanto Company, St. Louis, MO

Building explosions are a major cause of death, injury, and financial loss in the chemical industry. Buildings act as containers that trap and accumulate flammable vapors, mists, or dusts which leak from process equipment. Ignition of a relatively small leak can cause major explosion damage. For example, combustion of only five pounds of vapor of a typical hydrocarbon such as propane or benzene will release enough energy to raise the internal pressure in a 100,000 cubic foot building about 1 psig. Most chemical plant buildings will suffer severe damage, sometimes even collapse, at this amount of overpressure.

There are two basic approaches to explosion prevention/protection for buildings. The first is to install hazardous processes in open structures which are separated from other facilities. An open structure has no walls to permit leaking material to accumulate. The wind will normally provide much more dilution and dispersion ventilation than can be afforded by mechanical means. Thirty air changes per hour is a high rate of mechanical ventilation for a typical process building. For a 100,000 cubic foot structure of dimensions 20 x 40 x 125 feet, 30 air changes per hour are equivalent to about a 1 mph wind blowing in the lengthwise direction. The wind velocity perpendicular to the long axis would need only to be about 1/3 mph to ventilate the structure at the rate of 30 air changes per hour. These are rough figures which include a 30 per cent loss in air flow rate as the wind passes through the structure and around equipment, piping, and etc.

An open structure offers maximum area for safe venting when ignition does occur. Consequently, the use of open structures which are adequately separated from other facilities is the recommended approach to controlling the building explosion hazard. This approach also provides maximum basic protection against exposure to toxic materials. Enclosed structures, even with good mechanical ventilation, do not represent the best safety technology. The decision to enclose a hazardous process is based on the acceptance of explosion risk. An enclosed building can be equipped with explosion venting to minimize property loss, but vents, particularly when covered with explosion panels, do not prevent the structure from acting as a container. Containment increases the amount of flammables accumulated and jeopardizes the safety of people who are inside the structure when combustion occurs. This is the major consequence of the decision to accept a greater-than-minimum building explosion risk.

Summary of Procedure

The NFPA 68 procedure defines how to calculate the vent area required for a building to allow burning material and hot gases to escape without causing excessive pressure buildup. The equation for making the calculation is as follows:*

$$A = K L_1 L_2 / \sqrt{P} \qquad (1)$$

- A = required venting area.
- L_1 = shortest building dimension.
- L_2 = next shortest building dimension.
- P = maximum allowable overpressure.
- K = constant which adjusts units and relates to the burning characteristics of the vapor, mist, or dust in question.

*NFPA 68 *Explosion Venting*, 1974, p. 68-34ff, National Fire Protection Association, Boston, Mass.

The equation assumes open, unobstructed vents which are symmetrically distributed on the outer surfaces of the building. For actual buildings the effect of obstructions such as equipment, piping and steelwork needs to be taken into account. The effect of building shape must also be considered. The need for symmetrical placement of vents must be respected in actual practice as much as possible. However, the effect of lightweight vent panels must be suitably designed, installed, and maintained so that they relieve rapidly as the pressure begins to rise and do not significantly increase the total pressure achieved during the explosion. Guidelines to assist in applying the equation to real buildings are suggested below.

Guidelines for Vent Area Calculations

The equation is subject to the following considerations and limitations:

1. *Building Volume.* The equation can be used for buildings which are larger than 3,500 cu. ft. (100m³). For smaller buildings or for rooms, the method described in NFPA 68 for gas or dust combustion venting from vessels can be applied.*

2. *Maximum Length of the Longest Dimension, L_3.* The longest dimension of the building, L_3, does not enter into the equation. However, a maximum length of L_3, is implicit in the model on which the equation is based, and is given by

$$L_3 \leq 3\sqrt{L_1 L_2}$$

When $L_3 > 3\sqrt{L_1 L_2}$, the structure needs to be considered as two or more buildings set end to end.

3. *Maximum Allowable Overpressure, P.* The purpose of the building venting is to prevent serious structural damage and generation of lethal projectiles. The maximum allowable overpressure, P, is the static loading which the weakest member of the structure can withstand.

Care must be taken to be sure the weakest member is recognized. All members of the structure, wall, windows, floors, ceilings, and roofs need to be considered. It is important to keep in mind that floors and roofs are not often designed to take much loading from beneath.

A qualified structural designer is needed for making the evaluation. His analysis must be based on the actual design and present condition of the structure to be protected.

4. *The Constant, K.* The value of the constant depends on the type of flammable present and whether the calculation is made in English units (ft, psi or lbf/in²) or in SI units (m, kPa). For vapors such as natural gas, pentane, benzene, acetone, or vinyl acetate, and for most flammable mists and dusts the recommended value for the constant is 2.6 in English units, 6.8 in SI units.

Materials like ethylene, butadiene, and hydrogen burn faster than aliphatic or aromatic hydrocarbons. The recommended value of the constant for ethylene or butadiene is 4 in English units, 10.5 in SI units; for hydrogen, 6.4 in English units, 17 in SI units.

5. *Vent Area, A.* As mentioned earlier, the procedure is based on the assumption of open, unobstructed vents. Later in this article we will discuss vent panel design criteria which permit closed vent performance to approach that of open vents.

6. *Reinforcement of the Building.* It is not always possible to obtain enough vent area to protect the integrity of a building unless some of the weaker members of the structure be reinforced. To evaluate the amount of reinforcement required, the expected overpressure needs to be calculated, using the actual available vent area. Weak members must be reinforced to withstand this expected overpressure. The expected overpressure can be calculated from the following equation:

$$P\text{-}exp = (P)(A/A\text{-}act)^2 \qquad (2)$$

- P = maximum allowable pressure as defined in Item 3 above
- A = vent area required so that pressure does not exceed P.

A-act = vent area actually obtainable.
P-exp = expected overpressure with A-act.

The expected overpressure can also be calculated from a simple rearrangement of Equation (1).

$$P\text{-}exp = (K\, L_1 L_2 / A\text{-}act)^2 \qquad (3)$$

However, Equation (2) is frequently more convenient to use, as may be seen in the following sample calculation. Consider the following building:

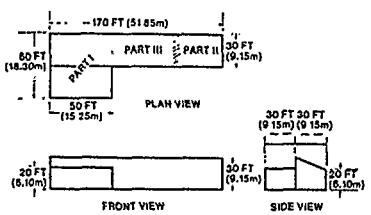

FIGURE 1 ILLUSTRATIVE BUILDING

1. *"Normalization" of Building Dimensions.* Calculate the required vent area according to Equation (1). Before the calculations can be made, the shape of the building needs to be "normalized" and the building considered as separate parts. Normalizing consists of combining several irregular portions of a building into a simple rectangular structure of equivalent surface area and volume. The building shown above can be divided into three parts and each part normalized as follows:

a. Consider the foot of the "L" as one structure, called Part I of the illustration. Normalize the height to the area of End Wall I.

Wall I area = (60 x 20) + (0.5 x 30 x 10) = 1,350 ft² (125.55 m²)
Normalized height = 1,350 ft²/60 = 22.5 ft (6.86 m)

The vent area required for Part I will be the same as for a structure with
L_1 = 22.5 ft (6.86 m)
L_2 = 50 ft (15.25 m)
L_3 = 60 ft (18.30 m)

b. The leg of the "L" is normalized on the basis of the area of End Wall II.

Wall II area = (30 x 20) + (0.5 x 30 x 10) = 750 ft² (69.75 m²)
Normalized height = 750/30 = 25 ft (7.62 m)

Therefore,
L_1 = 25 ft (7.62 m)
L_2 = 30 ft (9.15 m)

The maximum permissible length to which L_1 and L_2 can be applied is

$$L_3 = 3 \times \sqrt{L_1 L_2} = 3 \times 27.38 = 82.16 \text{ ft } (25.06 \text{ m})$$

The actual length of the leg is 170 ft minus 50 ft = 120 ft (36.60 m). Therefore the leg needs to be considered as two parts. These are designated Part II and Part III in the illustration. Part II and Part III will require the same vent area according to the calculation procedure. The boundary between Part II and Part III should be located in a way which permits symmetrical distribution of vent area over the entire building. Sometimes it is not necessary to locate the boundary to make calculations. Sometimes it is. Both cases will be illustrated.

2. *Calculations of the Vent Area for Normalized Parts I, II and III.* Let us assume for purpose of illustration that the maximum allowable overpressure for the building has been estimated by a structural engineer to be 0.5 psi (3.45 kPa), and that the flammable material in the building is a typical aliphatic or aromatic hydrocarbon for which the K value is 2.6 in English units, 6.8 in SI units. The vent area required for each part of the building can be calculated as follows:

a. For Part I

L_1 = 22.5 ft (6.86 m)
L_2 = 50 ft (15.25 m)
$A_1 = 2.6 \times 22.5 \times 50/(0.5)^{1/2}$ = 4,136.6 ft² (384.7 m)²
or
$A_1 = 6.8 \times 6.86 \times 15.25/(3.45)^{1/2}$ = 383.0 m²

(The difference in the two values of A_1 expressed in m² results from the "rounding off" bf conversion factors.)

It is recommended practice to locate vents only in outside walls and, as necessary, in roofs. Inside walls and the imaginary boundaries which are used to facilitate calculation of vent areas cannot be included as vents. Consequently, for Part I the maximum area available for locating vents is:

Wall surface = (60 x 20) + (0.5 x 30 x 10) + (50 x 20 x 2) + (50 x 10) + (30 x 20) = 4,450 ft² (413.8 m²)
Roof surface ≅ 50 x 60 = 3,000 ft² (279.0 m²)
The total maximum available surface ≅ 7,450 ft² (692.8 m²)

For Part I, the vents can be located in the walls, only if virtually all the wall surfaces are available. Every reasonable effort should be made to locate vents on the wall surfaces. In actual practice, however, wall surfaces may not be sufficient for the location of explosion vents. In some cases some of the vent area may have to be located in the roof. Special problems with roof vents are discussed in Item 8 below. If roof locations were not available, some members of the structure would have to be reinforced to prevent serious damage.

b. For Parts II and III

L_1 = 25 ft (7.62 m)
L_2 = 30 ft (9.15 m)
$A_2 = 2.6 \times 25 \times 30/(0.5)^{1/2}$ = 2,758 ft² (256.5 m²)
or
$A_2 = 6.8 \times 7.62 \times 9.15/(3.45)^{1/2}$ = 255.3 m²

The total vent area required for Part II and III combined is:

$$2A_2 = 5{,}516 \text{ ft}^2 \ (513.0 \text{ m}^2)$$

This is the vent area required to protect the leg of the "L" of our illustration.
The total wall surface available on the leg is:

750 + 120 x (30 + 20) = 6,750 ft² (627.8 m²)

The required vent area needs to be distributed as symmetrically as possible over the available surfaces, avoiding use of the roof if possible.

Since sufficient area is available for placing the vents, location of the boundary between Part II and Part III is not required in this example. See 3b, below, for an illustration of the case where location of the boundary is required.

3. *Estimate the Effect of Actual Vent Area on Expected Overpressure.* It is not always possible to get sufficient vent area to assure that the maximum allowable overpressure will not be exceeded. For example, let us assume that the leg of our "L" shaped building has certain venting restrictions; namely, that only the end and front walls are available for venting. The back wall and roof cannot be used. The available wall surface in this example is:

750 + 120 x 30 = 4,350 ft² (404.6 m²)

This is not enough vent area to keep the maximum expected overpressure below 0.5 psi (3.45kN/m²). Serious explosion damage could be expected unless the structures be strengthened. There are two ways to proceed.

a. Consider the leg as a single structure. From Equation (2) the expected overpressure with the limited vent area is:

$P\text{-}exp = (P)\,(A/A\text{-}act)^2$
$= (0.5)\,(5{,}516/4{,}350)^2$ = 0.80 psi (5.55 kPa)

The members of the structure, walls, ceilings, roof, etc., which cannot withstand this amount of expected overpressure will need to be strengthened so that they can withstand it.

b. Consider the leg as two parts (Part II and Part III). By proper location of the

imaginary boundary, Part II can be sized with sufficient vent area to keep its expected overpressure to 0.5 psi. In this case the length, L_3, of Part II needs to be enough for the required vent area of 2,758 ft² (256.2m²) to be provided.

$$750 \text{ ft}^2 + 30\ L_3 = 2{,}758 \text{ ft}^2$$
$$L_3 = (2{,}758 - 750)/30 = 67 \text{ ft } (20.44 \text{ m})$$

Since this dimension is greater than L_2 and less than No. $3\sqrt{L_1 L_2}$ it meets the criterion for length and results in acceptable proportions for Part II. With these dimensions, Part II, would not need to be reinforced. The length of Part III is consequently, 120 - 67 = 53 ft (16.20 m). This length likewise falls between L_2 and No. $3\sqrt{L_1 L_2}$ for Part III, so that the proportions of Part III are acceptable. However, the area available for venting Part III is only 30 x 53 = 1,590 ft₂ (147.9 m²) and

$$\text{P-exp} = (0.5)\ (2{,}758/1{,}590)^2 = 1.50 \text{ psi } (10.35 \text{ kPa})$$

The structural members which comprise Part III would therefore need to be strengthened to withstand this overpressure.

c. Finally, we can consider the case where a major part of the building cannot be vented except into another section of the building. Assume, for example, that Part I can only vent into Parts II and III. In this case the effective vent area for Part I is only 750 ft² (69.8m²), and the expected overpressure is:

$$\text{P-exp} = (0.5)\ (4{,}137/750)^2 = 15.2 \text{ psi } (105.0 \text{ kPa})$$

Structural failure will almost certainly occur in Part I, since reinforcement to withstand this pressure is not feasible. The case is presented to emphasize the need for symmetrical distribution of vents. It shows that if vents are not symmetrically distributed along external surfaces, significant overpressures can develop in parts of a building. Severe damage can result.

4. *Effects of Compartments.* Buildings are often compartmentalized into several rooms and levels. Usually each compartment must be treated as an independent unit for purposes of evaluating its explosion protection requirement. As stated above, venting must be to the outside, not inside to other parts of the building.

Consider, for example, a fully enclosed room with dimensions 15 x 20 x 30 ft located on the second floor of a building. The dimensions of the outside wall available for venting are 15 x 20 feet. For a typical hydrocarbon combustion the expected overpressure, by Equation (3), is calculated to be:

$$P = (2.6\ L_1 L_2/A)^2 = [2.6 \times (15 \times 20)/(15 \times 20)]^2 = 6.76 \text{ psi } (46.6 \text{ kPa})$$

The interior walls, doors, windows, duct seals, floor, ceiling, etc., must all be able to withstand this overpressure in order to prevent structural failure of the room. A thorough investigation of the room and its components is required to be sure every member is reinforced as necessary. Achieving this strength will be difficult.

5. *Vent Locations.* The function of an explosion vent is to allow the escape of hot gases and flame from a building where combustion is occurring. Explosion venting is a hazardous process. Vents must be located so that hot gases and flame can be discharged safely. Criteria for safe location of vents are summarized below:

a. Use only outside walls and, if unavoidable, roofs for the location of explosion vents. Inside walls are not suitable.

b. Locate vents so that they will discharge into remote areas which can be reliably restricted to limit exposure to people and valuable property.

c. Locate vents where they are as free as possible of obstructions which will impede gas flow. Among possible obstructions to consider are equipment, tanks, piping and ducting, container storage and nearby buildings. Building struts and columns must also be considered. Where obstructions cannot be avoided, their effect needs to be expressed as a reduction of vent area.

d. Provide guarding to prevent people from falling through the vent opening.

6. *Effect of Vent Obstructions.* The effect of a vent obstruction depends on the size and location of the obstruction in relatin to the vent. Experimental data on the effect of obstructions are lacking.

Estimating the effect is a matter of judgment. Obstructions which are close to a vent cause a blockage of gas flow at least equal to their shadows projected directly onto the plant of the vent. Obstructions which are 10 vent diameters or more downstream of a vent (i.e., outside the building) would have little effect provided that the vent can discharge freely upwards as well as horizontally. Inside a building, obstructions located more than two of their own diameters away from a vent probably do not greatly impede gas flow. In making the estimate it is recommended that the diameter of the obstruction be taken as the "hydraulic diameter" of the projection of the obstruction against the plane of the vent. The hydraulic diameter is equal to four times the cross-sectional area divided by the length of the perimeter bounding the area.

The distance between the obstruction and the vent should be measured from the widest portion of the section of the obstruction which is parallel to the vent. The vent diameter can, likewise, be taken as the hydraulic diameter.

The area inside and outside the vent opening must be kept free of drums and other temporary obstructions. The opening must not be blocked by installation of new equipment.

Guidelines for Explosion Vent Panel Design

Open vents are recommended. However, vents may be covered with lightweight panels if the decision has been made to keep a building enclosed for normal operations. The panels must be designed, installed, and maintained so that they move rapidly out of the way in the event of explosion and do not form dangerous projectiles. Guidelines design are given below. For additional discussion of closures, consult NFPA 68, Chapter 4, p. 68-42, 1974 edition.

1. *Maximum Weight of Panels.* The total weight of an explosion panel assembly needs to be kept to 1.5 lb/ft² (7.3 kg/m²) or less. The weight limit includes the hardware that will remain attached to the panel and move with it during an explosion. The purpose of the weight limitation is to keep panel inertia to a minimum so that vents will open up rapidly when needed.

2. *Materials of Construction.* Plastic paneling with a flame spread rating of 25 or less is recommended. Corrugated fiberglass reinforced polyester sheet of about 1/16-inch (1½ mm) thickness can be obtained which meets this criterion. Metal hardware will typically be steel or galvanized steel. Some special fabrication may be needed to meet performance requirements and weight limitations. Use of asbestos cement panels is not recommended in this service. Asbestos cement panels are heavy and brittle, and can form dangerous projectiles when a building explodes. Metal panels, though lightweight, are also considered more dangerous than plastic.

3. *Relieving Pressure.* The panels must be set to relieve at as low a pressure as possible consistent with wind loading requirements. In some plant locations the panels may be set to relieve at a pressure of 20 lb/ft² (about 0.96 kPa). In places with severe winds, the setting may need to be as high as 30 lb/ft² (1.44 kPa).

4. *Panel Restraint.* A restraining device is needed to keep a panel from blowing completely free of the building and thus becoming a projectile. A chain or cable can be used, attached to a non-relieving member of the building and an edge of the panel. In principle any edge can be used for attachment of the restraint, but for a specific installation there may be reasons which favor use of one edge over another for making the attachment. The edge used for making the attachment needs to be reinforced to take forces applied during venting, for example, by means of a

bar or angle iron attached at several points along the length of the panel.

5. *Panel Size.*

a. The size of a panel needs to be limited to the size of the vent opening which protects a specific compartment in a building. For example, one whole side of a building may serve as an explosion vent if the zone inside is a single large space. If the space is divided by walls and partitions, the side wall of the building will consist of at least as many vent panels as there are compartments which vent to the side wall in question. The restriction imposed by this criterion is to assure that the pressure developed by the explosion will be applied to the entire panel.

b. Each panel must be small enough to swing free of obstructions, i.e., air conditioning ducts or pipe racks, which may be located outside near a vent. Consequently, more than one panel per explosion zone may be required.

c. Panels must be sized so that they are not likely to hit people when they open.

6. *Guarding.* Guarding is needed along a paneled vent to keep people from falling if the panel be accidentally opened.

7. *Insulation.* Explosion panels in walls can be insulated if necessary, provided the total weight of the assembly, including insulation, does not exceed 1.5 lb/ft^2 (7.3 kg/m^2). A single panel with insulation attached to the inside face is recommended, rather than a double panel with insulation sandwiched between.

8. *Roof Vent Panels.* The criteria for the design of roof vent panels are basically the same as those for side wall panels. Since the panels are not likely to be safe to walk on, people must be prevented from going out on them. If access to the roof cannot be prohibited, the vent panel portion of the roof must be separated from walkways by guardrails and warning signs.

In some climates it is necessary to prevent accumulation of snow and ice so that roof vents are always in operating condition. In these climates it is recommended that roof vent panels not be insulated; the panels will normally be kept thawed by building heat. Special heating will be needed if building heat is insufficient.

9. *Vent Panel Maintenance.* Building explosion vents are items of equipment whose proper function can be assured only by good design, installation, and maintenance. The area inside and outside the vents must be kept free of container storage, new equipment installations and other temporary or permanent obstructions. Vent panel assemblies must be inspected on a regularly scheduled basis and kept in good repair. The pressure settings for relief must not be allowed to be increased above that required to hold the assemblies in place for normal pressure variations.

10. *Non-Relieving Siding and Roofing.* Portions of the siding which are not constructed as vent panels should be made of plastic siding rather than asbestos/cement. These need to be anchored s that they will stay in place at the expected overpressure.

The non-relieving portions of a roof may be made of conventional material such as poured concrete or concrete slabs. As with the siding, the non-relieving portions of the roof need to be anchored to stay in place at the expected overpressure.

English Units	x Conv. Factor	= SI Units
ft	0.305	m
ft^2	0.093	m^2
psi (lb/in^2)	6.900	kPa
psi (lb/ft^2)	0.048	kPa
lb	0.454	Kg

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FIREPROOF COATINGS — THEIR EVALUATIONS

By R. J. PETRUCCO
Mgr., Safety & Fire Protection,
Mobil Research & Development Corp., Paulsboro, NJ

Fireproof coatings are materials which will protect a substrate from the heat and damage associated with a fire. The generic term, fireproof coating, can include a spectrum of materials, but the specific subject of this presentation deals with fireproof coatings and their use in the petroleum industry.

Traditionally, two materials have been widely used in the petroleum and petrochemical industries. They are concrete and gunnite. Concrete is a mixture of sand, cement, and gravel, while gunnite is simply a mixture of sand and cement. These materials have received widespread acceptance as fireproofing because they are effective. They do an excellent job of protecting structures in the event of a fire. In spite of this, they do have several disadvantages. First, they are expensive. The cost of both the materials themselves and the labor to apply them is constantly rising. A second problem associated with the use of concrete type materials is that they often require engineering considerations. Concrete is heavy, weighing approximately 150 lbs. ft^3. Before a structure can be fireproofed using concrete, one must be sure that the structure will support the added weight. Because of these shortcomings, new fireproofing materials began to find application in the petroleum industry.

Some of these new materials were initially developed for military application. They were employed as heat resistant coatings for bombs, i.e., to keep the bomb from exploding in a fire exposure. The coating technology was also utilized in the space program. In this application, coatings were used to protect missile payloads from the extreme heat encountered when they reenter the earth's atmosphere. Because of their excellent performance and low weight, extension of this technology to protecting petroleum and petrochemical plants was only a matter of time.

The fireproof coatings used in the petroleum industry include:

1. Intumescent mastics. These materials function by expanding when heated in a flame front. The expansion serves to insulate and protect the coated substrate. In addition to expanding and insulating, some intumescent mastics also sublime. Sublimination is a transition from solid phase to vapor phase, with subsequent high energy absorption. The added parameter of sublimation serves to cool the structural member being protected.

2. Cementitious type materials. These coatings are based on, as the name indicates, cement plus other additives. Basically, cementitious materials are insulators.

3. Inorganic salts. In addition to being insulators like the cementitious type coatings, fireproof coatings based on inorganic salts release water of hydration when heated in a fire. The vaporization process, in a manner analogous to the sublimation process previously discussed, serves to cool the surface of the structural members being protected.

Before the new materials could be used by the petroleum industry, they had to be tested. As with any new products, the

people associated with the development of the coatings sought out an established test method for their evaluation. After a careful survey, they selected ASTM E-119 as a suitable evaluation tool. ASTM E-119 (Fire Tests of Buildings and Construction Materials) is a totally enclosed, low pressure gas fire developed to test the fire performance of walls, columns, floors, and other building members. This method has a prescribed temperature rise as defined in Table 1.

TABLE 1

1000°F (538°C) at 5 min.
1300°F (704°C) at 10 min.
1550°F (843°C) at 30 min.
1700°F (927°C) at 1 hr.
1850°F (1010°C) at 2 hr.
2000°F (1093°C) at 4 hr.
2300°F (1260°C) at 8 hr. or over

Because of the versatility of this test method, test conditions can be varied considerably, with fire exposures from 0.5 hours to 6.0 hours, or longer. Because E-119 is a low pressure fire with a prescribed, carefully controlled temperature rise, test repeatability is very good. This is an extremely important characteristic of any test method that will be used to compare the relative performance of different fireproofings.

There are, however, several disadvantages to ASTM E-119. As noted, ASTM E-119 utilizes the programmed temperature rise detailed in Table 1. The problem with respect to evaluation of fireproof coatings is that this slow temperature rise is not typical of the type of environment you would see in a fire situation. In addition to the slow temperature rise, E-119 also has a low flame velocity and a low convective heat component. These are also not typical or characteristic of an involved petroleum fire. In general, a refinery fire, or any hydrocarbon fire for that matter, is usually accompanied by a very high flame velocity with large convective and radiant heat components.

Realizing that E-119 was not the ideal solution to the testing problem, alternatives such as pool-type hydrocarbon fires were used. Pool-type hydrocarbon test fires are characterized by a rapid temperature rise similar to that encountered in petroleum fires. In addition, high levels of both radiant and convective heat, also similar to petroleum fires, are present. But these tests suffer from poor temperature control and limited repeatability. This is a tremendous shortcoming if an attempt is made to perform a relative evaluation of different coatings. A final problem with this type of test is the tremendous amount of air pollution that is associated with the testing program.

To overcome the problems discussed so far, the MRDC Safety Group in Paulsboro, in conjunction with associates in the MRDC Engineering Department in Princeton, set out to develop a test that would realistically simulate a fire in a petroleum environment. Test criteria include a rapid temperature rise (within one-two minutes) to 1800°F, excellent temperature control, good reproducibility under the majority of weather conditions, and finally, with the test specimen totally enveloped by the fire. To accomplish all of the objectives, a fire box was developed. Propane is used as the fuel since it permits more effective control of fire box temperature and causes considerably less air pollution. Flame temperatures reach 1800°F in about two minutes with a radiant heat flux of 2.2 cal/cm/sec. and 3.2 cal/cm/hr.). The test temperature is monitored via chromel alumel thermocouples.

A four-inch diameter by 10 feet long Schedule 40 IPS pipe is the substrate most often used in the coating evaluation. Three thermocouples are placed circumferentially at angles of 120° around the pipe at its center. Three additional thermocouples are similarly placed one foot on either side of the three centrally located thermocouples. This four-inch pipe is the preferred substrate because it allows the coatings to be subjected to thermal expansion and contraction

stresses which they could possibly be exposed to in a fire situation.

In the majority of cases, the fireproof coating is applied by the manufacturer. This route was chosen because the various coating manufacturers are adept in the proper application of their materials. When the coated test pipes are received from the manufacturer, the coating thickness is checked by measuring the circumference of the coated pipe in eight locations.

In all tests, coating failure is recorded as the time when the pipe surface reaches 1000°F. This is the temperature at which steel supports begin to lose their structural integrity. Comparing the results obtained with the fire box test that we have been describing and the ASTM E-119 tests, we found that two inches of concrete gave a protection time of three hours in the ASTM E-119 test. However, in the fire box test, that same two inches of concrete protected the substrate for only one hour. Hence, the fire box test is more severe than the E-119 test, and it also better simulates the type of fire environment coatings will be exposed to in a fire emergency.

In addition to the four-inch Schedule 40 pipe, other test substrates have included instrument cable trays and steel I-beams. Each substrate is used depending on the fireproofing requirements.

An essential performance characteristic of any fireproofing coating is its ability to withstand exposure to varying weather conditions. To evaluate the weatherability of the fireproof coatings in our test program, coated Schedule 40 pipe is exposed to the ambient conditions for a three-year weathering cycle. Weathered specimens are tested annually during the three-year period. For a coating to be acceptable, it must perform to minimum requirements for the entire cycle.

With respect to minimum protection times, it must be emphasized that there is no linear relationship between coating thickness and coating effectiveness. As an example, if a 0.25-inch-thick coating affords 30 minutes of protection, it is not necessarily true that a 0.50-inch-thick coating will afford 60 minutes of protection. For this reason, multiple specimens of varying coating thicknesses are evaluated in the initial phases of our test program. Based on these results and protection requirements, appropriate coating thicknesses are used for the weathering phase of our evaluation.

Several additional approaches to fireproofing are worth mentioning:

1. Combination Protection For Instrument Cable Trays. Insulating board is placed in the cable tray to insulate the cables from the flame front. This approach, of course, assumes that the primary impact of the fire will be from below the cable tray. Additional protection can be obtained by employing mineral insulated cable, followed by covering the entire cable tray with a fireproofing coating.

2. Blanket Type Insulation. Fire protection can also be achieved by wrapping the cable tray in blanket type insulation such as mineral wool. The thickness of the wrapping would be governed by the amount of protection required. Here, again, mineral insulated cable could be used to increase the protection.

3. Fireproofing Emergency Control Valves. Control valves present a special problem with respect to fireproofing. They must be serviced periodically and often, when servicing is accomplished, the fireproof coating is taken off and not replaced. Several manufacturers market a product that would allow wrapping the valves with an insulating material to protect them from a fire. When the valve must be serviced, the wrapping can be removed, the valve serviced, and the wrapping reinstalled to give you the protection you need. This looks like a very valid approach to protecting control valves.

With respect to new development in testing of fireproofing material, ASTM has realized the E-119 test is not completely satisfactory, so it is currently attempting to develop a test which would

realistically simulate a fire in a petroleum environment. The proposed test method will probably have both open and totally enclosed fire boxes for maximum utility. The open box would realistically simulate the environment as noted. The enclosed box would give better control of the testing parameters. In addition, combustion products in a totally enclosed box can be properly treated to make it environmentally compatible in metropolitan areas.

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EPA & OSHA CONVERGING REGULATIONS

By DAVID BURRE
Environmental Department, Borden, Inc.
Columbus, OH

In talking about OSHA and EPA it is difficult to find many bright spots. You will be happy to know, however, that there are at least 11 federal laws to protect us from ourselves and environmental harm.

The first to come to mind, and most recent new piece of legislation, is the Toxic Substance Control Act (TOSCA), which for the first time gives EPA authority to regulate production of every chemical produced or used in the United States. EPA is no longer just concerned about waste discharges and pollution control, but it is a full-fledged regulatory agency, just like all the other alphabet agencies which control the commerce of this country.

However, I won't talk about TOSCA because I am not actively involved with it. Actually, I know very little about it. Since TOSCA involves production activities, its requirements are more effectively implemented by our production people and compliance is the responsibility of the corporate technical director and the quality assurance laboratory.

The environmental department of corporate engineering of Borden, Inc. is concerned with regulatory compliance and technical consulting in a broad brush, general way. An industrial hygiene group at the corporate level also functions in a similar manner. The responsibility, decisions, and results for safety, health, and environmental programs lie with our divisional, profit center, and plant management. In fact, our successful safety and OSHA programs are conducted entirely by managers at the divisional level.

Our approach to OSHA and EPA in Borden has been along the classic lines of worker environment and ambient surroundings. A rather clear line of responsibility exists at the external building surface in the case of air, at the sewer or drain grate in the case of water, at the point of egress for solid wastes, and at the property line for noise. I say responsibility is clearly defined, but our interests certainly overlap. OSHA regulations go to the landfill and cover pollution control equipment, just as EPA regulations are influenced by waste collection systems in the work place, the use and conservation of production materials, and operating procedures.

We are fortunate within Borden to have the people and communication between them to make this division of responsibility work with what I feel, as a relative newcomer to the organization, rather successful results.

I mention this mainly to put my remarks in perspective and tell you what I do know about. That is the pollution control laws and their relationship to OSHA. Particularly, I'd like to talk about the Federal Water Pollution Control Act Amendments of 1972 and the Clean Air Act of 1970 and, to a lesser extent, the Safe Drinking Water Act and the Resources Recovery and Conservation Act of 1976.

In case you've been counting, I've mentioned six federal laws involving EPA and OSHA. The other five laws are the Marine Protection Act, Consumer Product Safety Act, Transportation Safety Act of 1974, Federal Insecticide, Fungicide, and Rodenticide Act, and Food and Drug Act. I hope at this point you are convinced of Big Brother's concern for your well being, because it is all downhill from here. That is, downhill as

far as those of us charged with interpreting and complying with the EPA and OSHA bureaucracies are concerned.

I say this because what were once clearly defined pollution control programs aimed at obvious and gross problems have now become crusades in search of the problems. In fact, EPA's predecessors were the FWPCA and NAPCA.

Water quality and ambient air quality standards were set along classic sanitary engineering and chemical lines. Effluent limitations and performance standards were then established to meet these accepted (although not unanimously) parameters. The result was equivalent secondary treatment, NPDES permits, process weight tables, and solvent substitution. Things did get a little esoteric with eutrophication, nutrient removal, and SO^2 scrubbers. But even these were responsive to problems and valid concerns.

All the while, public health, fish happiness, and visibility were primary objectives of the environmental control efforts. Toxic materials were considered as well, as evidenced by the early standards and wastewater treatment for cyanide and heavy metals.

Now it's environmental protection programs and, as one seminar called it, the approaching toxics era. Why? What's changed? It's still public health and aesthetics. But it is also enhancement and zero risk. The environmental program is finally catching up with industrial hygiene. The EPA and OSHA programs are rapidly converging with their emphasis on human health and toxicology. Secretary of Labor Ray Marshall confirmed this for OSHA in recent remarks and, under the pressure of environmentalist-induced court decisions, EPA is also committed to toxics control.

Because EPA must consider long-term exposure in the ambient environment and protect the frail and infirm, their regulations will be even more stringent than those being established by hygienists for the work place. Congress has mandated not only this zero risk approach to toxic and hazardous materials, but EPA is allowed to set the required standards without regard to economic justification and technical feasibility.

No longer do the regulations limit only BOD, pH, suspended particulates, and reactive solvents. Regulations now cover specific contaminates, products containing them, and design of the equipment producing them. Asbestos, beryllium, mercury, and vinyl chloride are already regulated under Section 112 of the Clean Air Act. EPA is considering 129 specific priority water pollutants. Benzene has just been named a hazardous air pollutant for which emission performance standards will be set.

I would hate to think what would happen if EPA established regulations for all of the 400-odd gases and vapors for which maximum tolerable limits have been set by OSHA. I can envision that in the not-too-distant future OSHA and EPA may be evaluating everything from copy machine radiation to pickles. Yes, pickles!

There is a West Texas story that may illustrate what I've been saying. From a slightly irreverent perspective, let us consider the future environmental, health, and safety factors effecting the building of a new Borden pickle plant.

Look ahead with me, if you will, to the ominous year of 1984. Borden market researchers have determined that conditions are ripe to expand the Aunt Jane's pickle line to a new market in the southwestern U.S. The expansion will involve a new "grass roots" plant near Cucumberville, Texas, a rural community of about 15,000 in the Rio Grande River Valley.

Preliminary project briefings are set up by foods division management in Columbus to insure an orderly approach to all issues which may become relevant in project execution. It soon becomes clear that market condition economics, stable raw material supply, labor pool, and all the other elements that used to influence

investment decisions are no longer primary controls. The question of whether or not we build a pickle plant will be answered by the environmental and health effects assessment and, ostensibily, by the public hearing where the assessment will be weighed by the citizenry and their elected officials.

Borden's environmental department, therefore, is assigned the lead role in developing the data and expert opinions that will form the foundation for the assessment. Concurrently, plant engineering must begin in order to develop flowsheets and material balances to the point of establishing effluent and emission parameters to factor into the assessment. Issues to be addressed in the assessment go far beyond these, however, so consultants are engaged in fields of expertise ranging from micro and macro biology to sociology, so that effects of plant construction and operation on everything from animal specie habitat and migration to projected resettlement patterns of plant workers can be defined. Large scale animal studies of cucumbers, salt solutions, and acetic acid are begun so that worker exposure to these raw materials can be proven safe. Secondary effects of fuel acquisition for our utilities, the community expansion, and product and raw material shipping must also be thoroughly documented and their effects on resource locations assessed as well.

The consultants have the added task of preparing, submitting, and subsequently defending their technical input—in some 25 permit applications. Federal, state, regional, and local government regulations overlap to cover various aspects of such items as process wastewater quaternary treatment plan approvals and discharge permits, emission control system approvals, equipment and processing safety certification, water supply well certificates, spill prevention plans, emission episode plans, domestic sewage permits, dredge and fill approvals, discharge structure permits, building permits, and many, many more.

Borden management finds it must fund the engineering and environmental assessment phases to approximately 15 per cent of the full project cost—before there is any assurance the plant can, in fact, be built. Marketing and economic types are, understandably, getting jittery. The project they supported when the signs were bright is now six months along and only five permit applications have been submitted and the "assessment" has reached 250 pages (Volume I) and is yet considered ony 30 per cent complete. Calm reasurrances by environmental dept., the Cucumberville Chamber of Commerce, and the county agriculture agent keep the ulcers under control and the work plods deliberately ahead. Bright "spots" in the effort appear—a nearby daily newspaper heralds the prospect of a pickle plant in an editorial as "positive progress"—the county hydrologist approves water well plans, provided the company provides a reservoir suitable for Cucumberville's domestic needs (agreed). In between—the depths of despair—Cucumberville is only 50 miles from a state game preserve—Class I area, says EPA, no emissions of fuel oil, sulfur, or particulates allowed—find natural gas for boilers (finally found at $3.25 per 1000 cu. ft.—delivered). Similarly, OSHA has learned from our animal tests that pesticide residues on raw cucumbers cause benign tumors in 0.1 per cent of rats fed at 50 grams per gram of body weight. "Cancer suspect agent," they say—requires signs, closed system washing, and gloves on all workers. Local union people, going a few steps further, ask for (and get) furnished uniforms cleaned daily and a pay premium for handling freshly-washed cucumbers.

At the one-year mark, things look good indeed—most of the little problems are ironed out—we've agreed to arrange breeding and stocking the county open areas randomly with the 246 jack rabbits and 32 king snakes our operation is calculated to displace. We'll have three 20-car security-patrolled parking lots on the northern, eastern, and western city limits of Cucumberville and will van-pool

the people to the plant. And the option on the southern site was, inevitably, renegotiated to a 250 per cent increased price—since the site decision was dictated by the planning commission in public session.

Nevertheless, it was a bumper year for the cucumber crop, and salt and vinegar prices even went down a little, too. Project return on investment has dropped just a few (maybe five) per cent say the economics boys—and the paycheck period has slipped only a year and a half or so. Things are rocking along! In just three months, after the seventh set of questions from the various agencies are replied to—we're gonna have the hearing!

The final days of sparring are hectic ones, indeed. Our lawyers are pushing for documents, guarantees, provisional permit approvals, locating consultants whose work has long since been completed, and the books—the ever-loving five-volume (1500 page) set—complete with aerial photographs, pictures of terrestrial models and structural models made of papier mache and balsa wood—and lots of acetate overlays. Every detail of the process, including all safety items, is clearly portrayed. Even scaled worker "dolls" are ingeniously installed in the models in their actual workplaces, so that all OSHA-related protective techniques can be observed. What a show we are going to put on for that Cucumberville regional planning commission! The books, with each volume personally embossed, are sent out to the commissioners two weeks in advance—and a preliminary vote count indicates we have five of nine votes in our pocket. The four opponents include a hunting club president who wanted deer instead of jack rabbits and king snakes; the high school principal, who doesn't want his seniors to be enticed to drop out and work in a pickle plant; a beautician who can't stand the smell of pickles and is certain it will pervade the community, regardless; and a relatively obscure associate librarian, who has said nothing in previous meetings or in public. We think maybe he's the swing vote for the two-thirds majority needed for approval.

Finally comes the big night. The town hall is packed—maybe 200-300 people have come for the biggest thing in town since Muhammed Ali's plane landed to refuel there in 1974. We are "on" first, and our lawyer is splendid—dapper and resplendent in a real "down-home" leisure suit. He smooth-tongues his way through 14 well-prepared witnesses—pausing only to punctuate each community-supportive reply with a "could you elaborate on that a bit, Mr. X." The commissioners and their counsel appear overwhelmed by the logic and persuasiveness of it all—blinking their eyes in wonderment that a humble, little pickle plant could mean so much to their community's well-being.

It was all so positive—even OSHA, USEPA, Texas Air and Water Board regional reps, and the county board of health people added remarks, which if not totally reinforcing, were certainly not contradictory.

It was almost time to vote, and we scanned the faces of the commissioners looking for tell-tale signs which would declare that we'd cinched our two-thirds. Suddenly, the associate librarian seemed to come to life—his eyes flickered and his tongue and teeth became visible as he uttered a request for recognition. He rose slowly and shuffled a single shred of paper in his hands as he fumbled uncertainly with the new microphone provided for the occasion. The audience hushed, the commissioners sat in rapt attention as he spoke with a clear, bold, voice:

"I've been doing a little research at the library at odd hours and I've concluded that: Pickles are associated with all the major diseases of the body. Eating them breeds wars and communism. They can be related to most airline tragedies. Auto accidents are caused by pickles. There exists a positive relationship between crime waves and consumption of this fruit. For example, nearly all sick people have eaten pickles—the effects are obviously cumulative; 99.9 per cent of all

people who die from cancer have eaten pickles; 100 per cent of all soldiers have eaten pickles; 96.8 per cent of all communist sympathizers have eaten pickles; 99.7 per cent of the people involved in air and auto accidents ate pickles within 14 days preceding the accident; and 93.1 per cent of juvenile delinquents come from homes where pickles are served frequently.

"Evidence points to the long-term effects of pickle eating: of the people born in 1839 who later dined on pickles, there has been a 100 per cent mortality; all pickle eaters born between 1889 and 1899 have wrinkled skin, have lost most of their teth, have brittle bones and failing eyesight—if the ills of eating pickles have not already caused their death; even more convincing is the report of a noted team of medical specialists—rats force-fed with 20 pounds of pickles per day for 30 days developed bulging abdomens. Their appetites for wholesome food were destroyed.

"In spite of all the evidence, pickle growers and packers continue to spread their evil. More than 120,000 acres of fertile U.S. soil are devoted to growing pickles. Our per capita consumption is nearly four pounds.

"Eat orchid petal soup. Practically no one has as many problems from eating orchid petal soup as they do with eating pickles."

You can guess the rest—it was 1984 and "zero risk" was the law of the land. Somehow, someway we'd never conceived the idea that pickles were anything but nourishing and healthful. We lost and lost big! All the pickle plants in the nation were shut down pending collaborative studies anticipated to take five years. After that, no one started up, even though they were cleared—the real culprit turned out to be mustard. By 1990 pickles were no longer found in the USA except for an occasional curio shop or food museum, and by 2000 the word was dropped from the dictionary—just like, for example, aldrin, dieldrin, polychlorinated biphenol, kepone, and nitrosamines, which had been purged from the condensed chemical dictionary in 1990.

So much for this euphoria. I might add parenthetically that since Bailey conceived of this little scenario Aunt Jane has been sold by Borden. I can only wonder if this had anything to do with that decision. We are still in the vinyl chloride business, so maybe not. In fact, almost every incident in this story has actually happened at one time or another. That is indeed a sad commentary on the future and fortunes of industry.

The message is clear. Just as the slide rule has given way to the pocket calculator, so is pollution control engineering giving way to health effects sciences. The industrial hygiene controls are being brought out from the confines of the work place and applied to the ambient spaces of the community—with appropriate tightening for accumulative effects and the susceptible. What is good enough for the shop can't be at all that bad at home, even if there is no exposure.

Since this has been such a completely objective presentation so far, I won't begin to editorialize now on the merits of this approach. This is the direction that I see the environmental enhancement program heading. The OSHA and FPA programs are converging here in the toxics era. We environmental engineers will be seeing a lot more of you people in safety and health. It will be us environmental types coming to you to learn.

78 1947

EXPECTATIONS OF THE OCCUPATIONAL PHYSICIAN

By ROBERT H. JONES, M.D.

Rehabilitation Consultant to Medical Department and Medical Consultant to the Human Factors Section, Eastman Kodak Co., Rochester, NY

With the passage of time, the physician is asked to be more accountable to his patient, his peers, and to society. This accompanies an expectation that he cure more ills. In the industrial setting, these requests have a certain character which also define how the occupational physician compares with his non-industrial counterpart.

In an industrial setting, it is important to develop a set of expectations for oneself and one's peers in occupational medicine and management. Certain expertise as well as certain expectations are essential to solve, effectively and efficiently, some of the problems relating to safety, health, and illness at the worksite.

This presentation of my views is divided into two parts: (1) what is expected of an occupational physician; and (2) what he should expect in return.

In the main, I hope the physician to be a diagnostician. Not in the classical sense, where the major concern is an individual with a specific complaint. Rather, the special contribution should be to focus on groups of people who are exposed to specific conditions at the worksite which may constitute hazards to health. One request would be to produce analyses of risk, in terms of frequency and severity. These should focus, in turn, on several specific entities, such as industrial accidents and illness of the stress-strain, wear-and-tear variety, both physical and emotional.

In order to assess risk for these conditions, the occupational physician should either possess certain skills and fund of knowledge or have consultants available for use in problem solving. These include epidemiology, statistics, work physiology, biomechanics, the psychology of stress, and functional evaluation of disability.

Implicit in these expectations is one that the occupational physician focus on function and that which interferes with it. Also, I hope he would relinquish the classical response that physical activity is a certain threat to the status quo and replace it with an attempt to establish the frequency and the severity of risk associated with given levels of work activity.

Given such insights and capabilities, one can then tackle certain problems more meaningfully. Let us assume a hypothetical situation and assess the risk of unwanted events. By unwanted events, we are talking about unsafe conditions and the extent to which a task may be unsafe for a few, many, or all individuals. Consider a group of men involved in manual materials handling. What is the risk of low back disorders? The approach of Lowrance, depicted in his book *Of Acceptable Risk,* would be as follows: define the conditions of exposure; identify adverse effects; relate exposure with effect; and then to estimate overall risk.

In our hypothetical case, the conditions of exposure are: 551 men lifting units of greater than ten pounds three times per shift daily. Consider that the medical records of these 551 men demonstrate the principal adverse effects to be low back pain, degenerative disc disease, musculo-skeletal injuries, and contact injuries.

There are several ways of portraying the relationship between exposure and effects. Chaffin has studied one set of variables, from which one of the easier estimates of exposure is shown.

TABLE 1

Exposure vs. Effects

Weight Lifted, Lbs.	*Incidence Of Back Injuries**	*Severity, Days Lost & Restricted**
<50	35	9
50-80	106	609
>80	69	2,554

*per 10^4 man hours

Note that as the weight of items lifted increases, so does the frequency and severity of disability. Exposure is demonstrated in two ways: according to load and duration of work.

Since this is not a treatise on the detailed analysis of such a relationship, let me state merely that analysis of weight lifted may be neither the best nor the most sensitive indicator of the relationship.

In attempting to estimate overall risk, several determinations can be made. The relative risk of back versus other injuries might turn out as is shown in Table 2 for these hypothetical lifting jobs. While the risk of other injuries is much greater, back injuries seem to be more severe and disabling if viewed on the basis of lost time.

TABLE 2

Risk of Back vs. Other Injuries in Lifting Jobs

Condition	*Frequency*	*Severity*
Back: other injuries	1:9	4:1 lost time
Back injuries, per cent of total	10	33

Given these differences, one should still ask if low back disease is associated only with manual materials handling. The risk of having such a disease, irrespective of job, is: for non-lifting jobs—35 per cent; for lifting jobs—47 per cent. These prevalence figures are from the work by Rowe.

Let us view the problem, nonetheless, in terms of interference with work. A study might show a ratio of lifting to non-lifting jobs of 118:1. Low back disease in our hypothetical study interferes significantly in lifting jobs, in terms of lost time, at a rate of 118:1 when compared with non-lifting jobs.

From a different vantage point, low back disease might be found to have low risk of necessitating a job change for non-lifting jobs, i.e., 1:200. For lifting tasks, the example shows a seven-fold increased risk, i.e., 1:30.

If these figures represented reality, one would immediately sense that disease defined by x-ray and physical findings differs from that defined by function: namely, what a person does. In fact, the example clearly demonstrates the need to think of disability and disease as being composed of three parts: host, agent, and environment. More about this view later.

In such a fashion, after much hard labor, my ideal occupational physician could clearly and precisely assess risk of unsafe conditions. It would be a technical effort. His unique contribution would end at this point. Given these facts, the effort would now shift to consideration of the acceptability of such risks; a social decision to be weighed by many interested parties. Not that the physician should be barred from such effort; rather, he has no unique knowledge or skills when it comes to deciding what is an acceptable risk.

Having gone this far, let us then examine briefly some other expectations of the occupational physician in relation to the manual materials handling analysis already cited. In the technical or scientific vein, he should have a working familiarity with some of the biomechanics and exercise physiology of the lifting work envelope in both space and time. Figure 1 illustrates the spatial aspects of the work envelope—the extent of horizontal and vertical reach while lifting—and some estimates of force on the lumbosacral disc while lifting a 25-pound object through various parts of the work envelope.

Figure 2 shows the percentage of maximum strength available for lifting in various positions. If maximum strength were 100 pounds, and a person were to lift a 25 pound package from the floor 30" in front of his ankles, the forces on the disc would be high and the available strength

inadequate for the task without a maximal ballistic effort.

Force on L-S Disk (lb.)

	12"	24"	36"
60"	275	375	475
40"	275	400	525
20"	400	500	600
0"			

FIG. 1

Available Lifting Strength (Per cent of max.)

	12"	24"	36"
60"	60	50	10
40"	75	50	15
20"	100	50	15
0"	100	60	20

FIG. 2

In terms of energy requirements, a 25-pound lift every six seconds from waist to shoulder height would cost three Kcal/min.; from floor to waist height, 5 Kcal; and from floor to shoulder height, 6.5 Kcal.

The duration of sustained effort within this work envelope determines what per cent of a person's aerobic capacity is available for the task at hand. An exercise stress test may show the floor-to-waist-high lifter to have a capacity of 10Kcal/min. The requirements for this lift are 5 Kcal/min.; however, if the lifter works for two hours without a break, demand equals or exceeds capacity.

Thus, in pursuit of unsafe aspects in lifting, one can quickly see that a detailed analysis of the dynamics may be needed before the specifics of the hazards to health are identified. Equally, such analysis may be needed before one can determine precisely what changes should be made to decrease risk.

Let us now turn briefly to another cluster of illnesses and conditions important to the occupational physician: those which may be related to, affected by, or contributed to by job stress. The conditions may include coronary heart disease, hypertension, peptic ulcers, symptoms of mental disorders, and high blood cholesterol and glucose levels; work related accidents; decreased productivity and high absenteeism. The time is at hand for enlisting the physician's aid to help assess risk for these problems and the nature of the relationship—if any—between them and job stress.

Here, the type of work pursued by Alan McLean and Robert Nideffer may be helpful when planning the strategy of analysis. McLean emphasizes terms used earlier: host, agent, and environment. The host is analyzed in terms of his vulnerability to particular stressors (agents), and the setting or context either enhances or neutralizes the power of the stressors. If these three factors are not preceived by the person as being important, there is no overlap and thus, no problem; if two factors do overlap, there still may be no problem. However, if all three are important, an unwanted stress reaction may emerge.

Nideffer's approach focuses on the degree of match between the individual's coping style and the demands of the job. He describes people as having styles with two variables. The first relates to whether the person is focused primarily on events external or internal to self. The second relates to the breadth of this focus, whether narrow or broad. A person of the broad-external type, is well suited to complex, rapidly changing situations in the world around: the salesman with three phones ringing. The exact opposite may be the isolated quality-control expert working in the dark. If the narrowly focused, internally-oriented person is placed in the salesman's situation, one would expect obvious stress reactions. The same for any other mismatch.

Consider also possible low productivity or poor quality control work because of poor matches.

As if all this were not too much to expect, one more capability is needed: the ability to clearly distinguish between the structure and nomenclature of disease on the one hand and the functional impact of disease on the other. For example, the x-ray picture of 60 per cent occlusion of one artery in the heart and the associated diagnosis of coronary heart disease tells me nothing about the ability to function on a job, nothing about risk. However, a dynamic functional description of the job demands and the exercise capabilities of the worker tell me a great deal about risk.

I can hear the requests that these expectations be lowered, that they are excessive and unattainable. I can also hear requests for other additional skills and expertise. To answer this: our medical department has these and other skills available either internally or by consultation with other groups within the company or the community. They do not all reside within one person; they are available to all. The trick is to have such skills thoroughly utilized.

Let us now have the occupational physician present his own expectations of the company for which he works. These are based largly upon the definition of disease as being the product of host, agent, and environment. First, despite all the above knowledge and skills, it must be recognized that, by himself, the physician may not be able to change the outcome by more than 10 per cent in terms of industrial health and illness. This is so for many reasons; One is that at least one-third of the patient's environment is determined by the dynamics of the worksite. If the physician cannot alter the worksite, he may have no therapeutic power to alter the outcome.

In addition, the patient's genes, social setting, and coping style all have great power over the outcome; in combination with the environment, they may well account for 90 per cent of it.

If this be true, the patient and supervisor must join the health team to work jointly to affect the outcome. This is no easy task. The patient is already busy working; the supervisor is also heavily laden with demands; both feel the health team is the principal change agent; and the physician may well labor under the feeling that they are correct—it is up to him. That, after all has been his training.

The ideal occupational physician, of course, recognizes the fallacy of such beliefs; if the desired outcome includes a change in the patient's behavior and function, then the patient must be active in pursuit of such a goal. Similarly, if the environment affects health, then clearly those with some control over it must actively work to change it.

The dynamics of these many problems and solutions emphasizes two points: interrelation and interdependence of effort to reduce unsafe conditions. Therefore, the basic expectation should be recognition and action in that manner.

78 1948

THE IMPORTANCE OF CONTROLLING INHALATION EXPOSURES IN THE WORKPLACE

By F. OWEN KUBIAS,
Manager, Loss Prevention,
SCM/Glidden Coatings & Resins, Cleveland, OH

The chemical industry has long recognized its basic responsibility to control employee exposures to chemicals. Recent increased emphasis on health exposures makes it important that we better understand the exposure problem and how to control it.

There are three principal modes of exposure to poisonous chemicals: ingestion, absorption, and inhalation. Of the three, the inhalation exposure is of the greatest concern in industry. Our lung tissue is the most efficient medium that the body possesses for absorbing material. The lungs' basic function is that of the transferring gas/vapors to the liquid blood stream. This occurs in the deep reaches of our lungs through the transfer surfaces called alveoli. It is estimated that 600-700 square feet of transfer surface is in our lungs.

A single breath will draw one-half to one liter of air. Breathing rates vary from about five liters at rest to 25-30 at the average work rate and can range up to 130 liters per minute for extremely strenuous activity. At an average breathing rate of 20 breaths per minute we will take in something like 2½ million breaths each year or, on a weight basis, about 7,000 pounds of air. We consume more air in a year's time than we do food or drink.

Our system does have natural defense mechanisms, such as the hair in our nose to knock out large dust particles or to trap them, and a mucous escalator to move small particles out of the lung where the cough and sneeze reflexes can clean the particles from our respiratory system.

Small dust particles (less than three microns in size) and gases or vapors are most critical because they can be drawn into the alveoli portions of our lungs where the transfer to the blood stream takes place.

Dust and vapor contaminants can be classified by their biological action. Dust contaminants can range from the relatively inert materials which simply result in irritation and discomfort, such as graphite and starch, to the seemingly inert materials which do produce changes in the lung systems, such as asbestos and silica. Also included in dust contaminants are materials that become systemic poisons when transferred to the body fluids; chemical irritants that affect the nose, throat, and bronchial system; allergy producing dusts; and metal fumes that cause metal fume fever.

In a similar classification, the gases and vapors can range from simple asphyxiants such as nitrogen, hydrogen, or helium to chemical asphyxiants such as carbon monoxide and hydrogen cyanide. Also, gases or vapor may cause systemic poisoning when transferred to the body fluids, be corrosive irritants to the respiratory system, or produce anesthetic effects.

In all, cases we are talking about have extremely small quantities of these materials in the air—parts per million of vapors and gases and milligrams per cubic meter of dusts and other particles. We are talking about test tube quantities or less when suspended in a room of a 1,000 cubic feet.

Where substitution or containment cannot be had, the most effective control

of these potential exposures is through local exhaust ventilation. While local exhaust ventilation must be designed by industrial hygiene engineers and ventilation engineers, there are some basic concepts that operations people must recognize and apply to effectively use the exhaust ventilation they are given.

Exhaust ventilation is working on the suction side of a fan. Thus, the ability to move air at any velocity for great distances is substantially reduced as compared to the discharge or positive pressure side of a fan. As a result, it is very important that local exhaust pickup is placed as close as possible to the source of contamination. This is important not only from a contaminant control standpoint but from an energy conservation standpoint also.

When positioning workers at a ventilated workplace, it is important that their work positions do not block the ventilation system and void its control. Similarly, it is important that the path of control does not draw the contaminant to the breathing zone of the worker.

With local exhaust ventilation we are doing just that, exhausting air, and we cannot do it if we starve the work area. We must provide heated makeup air to the work area commensurate with the quantities being exhausted for control of contaminants. It is important in the control of contaminants that this makeup air does not creat turbulence or drafts at the pickup points so as to disturb the pickup stream.

Another important point on makeup air is care in placing the intake of the makeup air so that the air being introduced is not contaminated from outside sources. Similarly, the makeup air source must be placed so that it will not draw back into the work area the exhausted contaminant from the local exhaust system.

As much as possible, the operation that releases contaminants should be enclosed. This not only gives better control of the contaminant and prevents cross drafts, but also reduces the air rate needed for control. Wherever possible, the shape and the location of the exhaust pickup should be such that the initial velocity of the contaminant will throw it into the hood opening.

In addition to providing proper control of contaminant release, it is important that our workers receive adequate training and education concerning the materials they are handling. They must know what materials are potentially hazardous, how they may act on the body and, most important, how to properly protect themselves. This must include an understanding of the exhaust controls and containment system instituted to protect the individual, how to tell when the controls are not functioning properly, as well as proper use of protective equipment that is required. Good housekeeping of the work area is important, and good personal hygiene should be stressed.

78 1949

Fertilizer Sessions

FERTILIZER & CHEMICAL FIRE AND EMERGENCY PLANNING FOR FIRE DEPARTMENTS

By M. L. GREINER
Director of Training & Safety,
J. R. Simplot Co., Pocatello, ID

The fertilizer industry has a responsibility to assist the fire service in developing the necessary expertise and confidence to cope with emergencies of fires involving chemical fertilizers and related products.

There is such a variety of chemicals and chemical mixes manufactured and shipped throughout the country that one can easily understand the tremendous educational and training problems facing fire departments today.

I wrote the following prayer to help emphasize the chemical challenge facing the modern-day fire chief:

The Fire Chief's Prayer

Lord, help me to understand the character and personality of each fire I must fight; help me to apply myself to this learning task; make me knowledgeable and wise that I may win without threatening the safety or health of any of those entrusted to me.

When fire breaks out in a chemical manufacturing plant, storage facility, or transport vehicle, the fire department responds with a degree of uncertainty. This is no less so when the fire involves agricultural chemicals and fertilizers.

Firemen have been known to completely back off from a burning warehouse and allow a million dollar fire loss simply because the fire reached a few bags of ammonium nitrate fertilizer, when actually, they could have continued to fight the fire without fear of any consequences from this fertilizer product.

When there is an emergency involving anhydrous ammonia, there is often uncertainty as to what to do. A ruptured transfer hose, an overturned nurse tank, a highway collision, or an overfilled storage tank could be the cause of a sudden release of ammonia vapors.

The fireman should become familiar with the fertilizer plants and warehouses in this community. These should be inspected prior to any problem or emergency. He should understand fertilizer plant construction, the identification of chemicals in storage, and the characteristics of these chemicals.

What Will Burn in Fertilizer Plants?

What will burn and what are the hazards? This is what the fire fighter is asking as he looks at the thousands of fertilizer distribution plants across the country.

Well, first the buildings themselves will burn. Most of them are constructed of wood.

A typical fertilizer distribution plant will consist of liquid storage, dry bulk storage, bag storage, chemical warehouse, and office area. Some plants are the flat type divided into storage bins with front openings and bulk heads. These buildings are usually constructed of wood, although cement block or metal is sometimes used. Some plants are designed for vertical storage. The bins are deep—20 to 30 feet in height, and are loaded from the top. They may be constructed of wood or concrete.

A new type of plant found in the western states is the circular cement plant. In the center of the structure is an open circular area from which access can be made by front-end loader into each of the pie-shaped bins. These buildings are virtually fireproof.

Then there is the equipment used in these plants; front-end loaders, forklifts and trucks. Also, there are combustible fuels and other fire hazards typically found in plant maintenance shops.

In a fertilizer distribution plant there are often pesticides. These are in granular and liquid form. Many pesticides are quite flammable as well as toxic. The firefighter should learn to identify and use the labels. They are instructional guides for him.

Sulfur is often found in these plants, since it is used as a nutrient for certain crops. It is easily ignitible and its dust is explosive. It is also hazardous in contact with oxidizing materials.

Then there are various types of fertilizer solutions, nitrogen, and polyphosphate solutions stored in vertical and horizontal non-pressurized tanks.

Most liquid fertilizers do not present a fire or explosion hazard. In fact, some of the more common solutions such as 10-34-0 (ortho phosphate) make very good fire extinguishing agents, especially when diluted with two parts water for each part of liquid fertilizer. Liquid fertilizers are mildly corrosive to the skin and eyes.

Also stored at these plants is fertilizer in dry form such as ammonium phosphates, ammonium sulfates, urea, potash, ammonium nitrate, etc.

The dry fertilizers will not burn. Ammonium sulfate, ammonium phosphate, and potash, for example, will serve more as a fire inhibitor. The United States Bureau of Mines has done considerable testing to determine the explosibility of various dusts. Fertilizer dusts present no explosion hazard, including pure ammonium nitrate fertilizer dust (Bureau of Mines Report, No. 7208, December, 1968).

Anhydrous ammonia fertilizer is the most concentrated source of nitrogen available to the fertilizer industry. It is a non-flammable compressed gas commonly stored in pressurized containers at the same plant that LPG (liquified petroleum gas) is sometimes stored, since many fertilizer dealers are often suppliers of farm fuels, especially LPG.

It is important that the fire fighter recognize the characteristics of each of these compressed gases and the major differences between them.

Ammonia is classified as a non-flammable gas for shipping purposes; however, it will burn in extremely high concentrations and with a high ignition source.

Reference Source for Fire Fighters

I recommend NFPA's "Fire Protection Guide on Hazardous Materials" as a reference source for firemen. In it there is data on approximately 388 chemicals; data which includes fire, explosion, and toxicity hazards. It also contains valuable information on hazardous chemical reactions.

The NFPA (National Fire Protection Association) makes use of the Hazard Identification System, a signal system to tell the fireman at a glance the degree of health, flammability, and reactivity hazard of materials. The system also permits identification of reactivity with water, radioactivity, and fire control problems.

An excellent identification system is now being provided for firefighters through the mandatory Hazardous Materials Regulations on placarding which are effective January 1, 1978 (see 49 CFR part 172).

Vehicles or tanks transporting hazardous materials are required to display a diamond shaped placard measuring 10-3/4 inches on each side including an outer 1/2-inch white border. Each placard is colored and identified according to the hazard being transported.

For example, a flammable cargo must be identified by a red diamond placard

with the word "flammable" across it diagonally and with a flame symbol above it. These are to be displayed on all four sides of the vehicle, tank, or container carrying the hazardous material.

"Poison," "oxidizer," "flammable gas," "non-flammable gas," and "dangerous" are examples of placards the fireman will now find in use in highway, rail, and water shipments.

An example of application of the placarding requirement in the fertilizer industry is when anhydrous ammonia is transported from a storage site to the grower in nurse tanks mounted on trailers. These tanks must display a green diamond shaped placard on each side and end. The words "non-flammable gas" are on the placard. The tank must also have the words "anhydrous ammonia" on each side in letters at least two inches high. (Tank cars of ammonia require letters four inches in height.)

What About Ammonium Nitrate Fertilizers?

This fertilizer is misunderstood and feared by fire fighters. Yet millions of tons of it are being stored and handled yearly throughout North America with absolute safety and confidence by the millions of growers and dealers who value it as an excellent nitrogen source for spring and winter crops, vegetables, fruits, and grains.

Ammonium nitrate fertilizer should not be confused with the ammonium nitrate mixes used for blasting or explosives. These products are highly sensitive to explosion or detonation. Ammonium nitrate fertilizer is not, and can be stored and handled safely.

What does it take to make ammonium nitrate fertilizer explode?

Explosions involving pure fertilizer grade AN either in storage or in transit are unheard of. Explosion can only occur if the ammonium nitrate is contaminated by a carbonaceous material and then subjected to a condition of confinement or extreme shock and high temperature.

Heat, pressure, and contamination combined to produce the violent explosion at Texas City on April 16, 1947. In this situation we had closely packed bags of wax-coated ammonium nitrate—2200 tons of it, plus 1500 tons of fuel oil. The hatches were closed, thereby providing a high degree of confinement. Steam hoses were brought into play by fire fighters, adding to the heat. These factors, plus the fuel oil in storage, all combined to produce the violent explosion.

The ammonium nitrate fertilizer produced today is no longer wax-coated and is an entirely different product than that which was involved at Texas City.

The Roseburg, Oregon, explosion on August 7, 1959 was caused by reason of the fact that the Washington State shippers of this truck-load of material had pre-mixed industrial grade AN with finely ground walnut hulls and some diesel oil. This had changed the entire chemical nature of the material so that it was being transported interstate as a blasting agent. On the same truck and in close proximity were 2-1/2 tons of dynamite. The truck was illegally parked near a wooden warehouse building while the driver walked two blocks to a restaurant for dinner. During his absence the warehouse caught fire and the fire spread to the truck. The inevitable explosion of dynamite also triggered the "nitro-carbo-nitrate" portion of the cargo and a portion of the city was devastated.

At Independence, Kansas, October 19, 1949, a wooden warehouse containing 1400 tons of wax-coated prills of fertilizer-grade AN was completely destroyed by fire and no explosion occurred. The fire started in an alfalfa warehouse 40 feet away, but the fire fighters, in spite of their hose streams, could not prevent the fire from igniting the chemical warehouse by radiated heat. The lack of a contributory fuel in sufficient supply to energize vigorous combustion and the lack of adequate pressure build-up no doubt helped to avert a violent chemical reaction in this situation. It is agreed by many experts in the field that high pressure build-up in warehouses, trucks, or freight

cars is unlikely.

In some instances firemen have been known to back off from a fire involving ammonium nitrate fertilizer out of fear of an explosion, allowing a large fire loss to occur. In 1960, a $250,000 loss was suffered in an unsprinklered fertilizer warehouse of about 12,000 square feet. It was reported that it was allowed to burn to the ground by the plant and municipal fire fighters who withdrew when they learned that the fire had reached 20 bags of AN. They feared that an explosion was imminent.

On March 11, 1970, near Pickens, Mississippi, a truck loaded with 20 tons of fertilizer grade AN in bags caught fire when the right rear tire on the outside back wheel of the trailer went flat. After nine hours and forty-five minutes of burning, the burning nitrate had progressed only about three feet over the half-way mark of the trailer's length. The fire progressed about the same speed as a cigar burns, and went out whenever the wood or paper ran out. The fire eventually went out when a wrecker turned the trailer over and the material was dumped into the roadbed.

A simple demonstration to give fire fighters some confidence when approaching pure fertilizer grade ammonium nitrate in an unconfined fire situation is to ignite a pile of wood and, after it is burning good, throw on a couple of sacks of ammonium nitrate fertilizer. The results are very ordinary. The fertilizer will slowly melt and decompose, but will only continue to do so only as long as the wood continues to burn.

Ammonium nitrate fertilizer melts at approximately 330° F. From 350° to 390° the breakdown is more rapid, and nitrous oxide (N_2—laughing gas) is produced (whitish fumes). Near 575° brownish fumes indicate the formation of higher toxic oxides of nitrogen and the possibility of violent chemical reaction. The danger here is a runaway thermal reaction. As the temperature rises, the rate of decomposition increases, and, if there is a high degree of confinement, a dangerous pressure build-up will occur. The decomposition of AN into nitrous oxide and water is a "heat-producing" decomposition.

In contrast, the simultaneous vaporization and dissociation of ammonium nitrate into gaseous ammonia and nitric acid is a "heat-absorbing" process. This vaporization and dissociation begins to take place at about 175-200° F and tends to offset the heat-producing reaction—so long as water, ammonia, nitric acid, and nitrous oxide can escape freely or, in other words, so long as the pressure above the decomposing ammonium nitrate is not too high.

Accidental (or intentional) confinement of the burning material may contribute to a pressure build-up which will in turn offset the balancing endothermic or heat-absorption process, thereby causing a self-accelerating runaway exothermic decomposition which may accelerate to a point of explosion or detonation. Wax-coated prills or AN that is contaminated with carbonaceous material requires a much lower pressure build-up to upset the heat absorbing reaction. This helps explain the violent reaction at Texas City. For pure AN, 1176 psi is required to cause runaway reaction.

With good ventilation and proper storage procedures, hazards of possible pressure build-up are negative. Remember, pressure stops the heat absorbing reaction. The *Federal Register* in 1910.109 describes the mandatory storage requirements for ammonium nitrate in quantities of 1000 lbs. or more. Regarding ventilation, it is required that storage buildings or warehouses shall have adequate ventilation in case of fire. The height of bagged storage is limited to 20 feet. The height of combustible bulk storage structures is limited to 40 feet.

Federal requirements also prohibit the storage of contaminants in the same building as ammonium nitrate unless separated from this material by fire walls of not less than one-hour fire resistance rating or a space of at least 30 feet. Contaminating material is listed as

organic chemicals, acids, or other corrosive materials, materials that may require blasting during processing or handling, compressed flammable gases, flammable and combustible materials or other contaminating substances including but not limited to animal fats, baled cotton, baled rags, baled scrap paper, bleaching powder, burlap or cotton bags, caustic soda, coal, coke, charcoal, camphor, excelsior, fibers of any kind, fish oils, etc. Sulphur and finely divided metals also come under the above restrictions. Explosives or blasting agents are also prohibited.

Bagged storage is not to be within 30 inches of the storage building walls and partitions. The height and width of piles shall not exceed 20 feet and the length no more than 50 feet, unless the building is of non-combustible construction or is protected by automatic sprinklers the length of the piles, in which case the length shall not be limited. In no case shall the ammonium nitrate be stacked closer than 36 inches below the roof or supporting and spreader beams overhead. Aisles shall be provided to separate piles by a clear space of not less than three feet in width. At least one service aisle in the storage area shall be not less than four feet in width.

With bulk AN, bins shall be clean and free of materials; walls and floors must be protected against impregnation by AN; the partitions are to be of tight and solid construction; bins or piles are to be clearly identified by signs reading "Ammonium Nitrate" with letters at least two inches high; and in no case is ammonium nitrate to be piled higher at any point than 36 inches below the roof or supporting and spreader beams. In areas where lightning storms are prevalent, lightning protection shall be provided.

Federal regulations require that not more than 2500 tons of bagged ammonium nitrate shall be stored in a building or structure not equipped with an automatic sprinkler system. Suitable fire control devices such as small hose or portable extinguishers shall be provided throughout the warehouse and in the loading and unloading areas. The availability of water supplies and fire hydrants is also vitally important.

Vapors from burning ammonium nitrate fertilizer are extremely toxic. It is therefore essential that (1) the fire fighters wear suitable self-contained breathing apparatus and approach the fire from upwind; (2) residents downwind from the fire are evacuated; (3) spectators are restrained well away from the fire; and (4) the employees are removed from the fire area.

The building must be immediately ventilated as much as possible to permit the dissipation of the gases of decomposition and prevent high temperature and pressure build-up. Straight streams must be applied as quickly as possible to cool the burning material. Fire fighters should remain behind protective barriers to protect them from steam eruptions. It may happen that during the application of water, formation of steam in pockets in the piles of nitrate may cause eruptions with force comparable to minor explosions. The quicker the temperature is lowered, the less likelihood there will be of steam eruptions and the generation of oxides of nitrogen. The use of straight stream fire nozzles is more effective in reducing the temperature of the hot nitrate than spray or fog.

Note: The fertilizer grade ammonium nitrate, uncontaminated by fuel oils, acids, dynamite, or other storage taboos is *not* going to explode during the fire fighting operation.

After the fire, the loose and contaminated unsalvageable ammonium nitrate fertilizer should be buried or dumped in water—where permissible. Any residue that cannot be removed by sweeping should be washed away with hoses. Flushing and scrubbing of all areas should be very thorough to insure the dissolving of all residue—particularly wooden floors. Wet empty bags should be removed, permitted to dry out, and then burned out of doors.

It is also advisable that metals in contact with the residues of ammonium nitrate be thoroughly cleaned with water to prevent corrosion.

Some facts about fertilizer grade ammonium nitrate are:

1. There is no evidence that a spontaneous combustion of ammonium nitrate can occur.
2. There is no record of explosions of unconfined ammonium nitrate fertilizer due to heat or fire alone.
3. There is no record of commercial or farm storage fire explosions. Neither is there basis for the various theories that ammonium nitrate fertilizer is "sensitized" either by compression in a pile or by passage through a crystal transition.

Anhydrous Ammonia Emergencies

For ammonia emergencies the fire fighter should familiarize himself with ammonia and the various ways it is shipped, stored, and transported throughout the United States and Canada.

Anhydrous ammonia is the most concentrated source of synthetic nitrogen available to the fertilizer industry. It may be in either gaseous or liquid form. Gaseous ammonia liquefies under pressure at ambient temperature. Advantage of this characteristic is taken by industry, and for convenience the commodity is usually shipped, stored, and transferred under pressure as a liquid. When refrigerated to or below its normal boiling point (-28° F) it may be stored as a liquid at atmospheric pressure.

Because LPG is also a compressed gas stored, transported, and handled as liquid in a closed system, and because it is also a refrigerant with boiling temperature well below 0° F, it is often confused with ammonia.

Firefighters should be reminded of some of the basic differences between these two chemicals. LPG is heavier than air; ammonia is lighter than air.

LPG is flammable; ammonia is not considered flammable as a liquid, however concentrated vapors can ignite. LPG is insoluble in water; ammonia is highly soluble in water. LPG is compatible with brass; ammonia is not compatible with brass, copper, silver, zinc, or other alloys. LPG's greatest hazard is explosion; ammonia presents primarily a contact hazard because it is a strong alkali and also because of its water-absorbing nature.

A simple demonstration I often use to illustrate ammonia's water-absorbing quality is to inject a small amount of water into an ordinary metal gallon can filled with ammonia vapors. As the ammonia vapors are absorbed by the drops of water a vacuum is formed and the can crumples under the imbalance of pressure. This illustrates to the fire fighters the value of water when dealing with ammonia emergencies.

For LPG emergencies water fog or spray is important, but for a different reason than for ammonia. LPG is explosive. Its vapors are insoluble in water. The value of water fog is to direct the explosive vapors away from ignition sources.

Also, because LPG liquid is extremely cold (-44° F), fire fighters must keep hose lines out of the liquid to keep them from freezing.

Ammonia is cold, too (-28° F), freezing upon contact as well as burning with its caustic qualities.

From a safety standpoint the odor of ammonia is one of its greatest assets. It is detectable in concentrations as low as 50 parts per million. Due to its extremely strong odor, no one can willingly remain in concentrations that are harmful.

Ammonia is delivered from manufacturing plants to distribution points by pipeline, rail, barge, and tank truck. Here it is stored in large pressurized storage tanks of up to 30,000 gallon capacity. It is then transported to the grower in nurse tanks.

An emergency involving ammonia might occur while it is being transferred or transported. When responding to an ammonia emergency, firemen should wear protective equipment and clothing. Goggles to protect the eyes; respiratory

protection for the lungs; full body protection to guard against the freezing, caustic, and water absorption hazards of ammonia. An important point to remember, too, for ammonia emergencies is to attach fognozzles to the hose lines.

Firemen should study ammonia facilities in their area in advance of any emergency. They should become familiar with plant layout, piping, and shut-off valves. Firemen should be acquainted with the Department of Transport placarding requirements for ammonia nurse tanks as well as tank design.

For most ammonia emergencies the procedure is basically the same: hook up large diameter hose lines with fognozzles attached; wear protective rubber or nylon clothing; wear rubber boots and gloves; wear face, head, and respiratory protection; and approach leak from up-wind behind water fog to effect rescue work or emergency shut-off or whatever is required to correct the situation.

Sometimes a leaking rail car of ammonia might have to be pulled out into the country where its pressure can be safely vented off or the contents transferred to other tanks to reduce the internal pressure and stop the leak.

Water is the best emergency first aid treatment for ammonia burns. Get water onto exposed areas immediately. If burns are extensive and a water tank is available the victim should get into the water. The burned areas should be flushed or irrigated for at least 15 minutes. Do not apply salves, ointments, or oils for at least 24 hours.

Contaminated clothing should be removed as soon as practical. Because of the freezing action of anhydrous ammonia, clothing may be frozen to the skin, in which case thaw with water first.

Keep the victim warm, get him to a physician. If breathing has stopped, begin artificial respiration immediately and administer oxygen.

I cannot overemphasize the need for eye protection. Ammonia can cause severe eye damage. And if there is accidental exposure, the eyes must be irrigated with water immediately to minimize the injury.

Firemen must prepare well for emergencies involving chemicals. Ammonium nitrate and anhydrous ammonia are deserving of special attention.

Fires involving pesticides

In responding to fertilizer plants, fire fighters are likely to encounter pesticides—agricultural chemicals used to control insects, weeds, and plant diseases.

Pesticide storage areas contain many types of granular and liquid chemicals, many of them highly toxic and flammable. These hazardous chemicals may be stored in retail fertilizer outlets, commercial warehouses, freight terminals, county weed control centers, canal companies, and aerial and ground pesticide applicator facilities.

A fire may involve a truck transporting these chemicals. Firemen should refer to the DOT placarding for quick identification of the hazardous qualities of a vehicle's cargo. These placards also parallel in design the internationally recognized labels on each pesticide container.

When responding to a pesticide fire the firemen should immediately notify doctors and hospitals in the area of the situation and advise them to be ready to treat for pesticide poisoning. Firemen should also have immediately available the area's poison control center phone number.

Protective equipment must be worn to prevent hazardous chemicals from entering the body. There are three ways in which firemen can be poisoned: dermal—through the skin; inhalation—through the lungs; and ingestion—through the stomach and intestines.

A few drops of some of these chemicals on or in the body can kill. For example, three drops of TEPP on the skin can kill; 18 drops of phosdrin on the skin can kill; and 64 drops of parathion on the skin can kill. This is why the fire fighter must have adequate protection.

Hands must be protected by waterproof gloves which must be impervious to the toxic solvents. Cotton and wool material absorbs the poison and must not be used. These poisons can enter the body through the feet, too. Leather-soled shoes, for example, will absorb the poison and allow poisoning to occur. Waterproof footwear must be worn.

Some agricultural chemicals can be harmful to the eyes, therefore suitable protection should be worn. Respiratory protection must also be provided to fire fighters because of the extreme toxicity of the fumes and smoke from a pesticide fire.

Some solvents found in these pesticides are petroleum distillates and as such feed the fire. Explosion hazards will be faced by the fire fighter. The number one rule when approaching a fire is to stay upwind.

In the fire fighting strategy, size up the situation before attack. Look for information from placards, employees, and reference files from previous inspections of the premises.

If the storage area under fire is upwind from a townsite or any residences consider evacuation procedures.

Watch for exploding drums due to the flammable and volatile liquids which might be involved. Also, beware of drums which become ruptured and begin leaking. Pesticides will contaminate the run off water. Look out for hazardous chemicals on the ground. Don't walk through them or drag hose lines through them.

Falling drums and cans of pesticides can also be a hazard. They are usually stacked on pallets and so could fall very easily.

Use a fine spray or fog instead of straight stream pattern with the fire nozzles. This is especially important where bagged chemicals are involved. This will reduce bag rupture and contamination hazard. Also, some of the fine powders could be explosive. The fog can also be used to cool drums of liquid pesticides to prevent rupture.

Dike run off water around site if possible. Prevent contamination by sewage systems, ditches, canals, streams, ponds, and lakes. Keep bystanders away from the area.

Fire fighters should not smoke or eat at the fire site, to avoid the danger of inhaling or ingesting the poison.

For treatment of poisoning in any toxic exposure: terminate the exposure; maintain respiration; and, administer the correct antidotes.

Carbamates include a wide spectrum of insecticides effectively used against pests of fruits, nuts, vegetables, forage crops, cotton, etc. Organic phosphates are derivatives of phosphoric acid. They are both cholinesterase inhibitors.

The organic phosphate insecticides act as more or less irreversible inhibitors of the vital enzyme cholinesterase, found in nerve tissue. When this enzyme is tied up by the pesticide, much of the nervous system can no longer function properly. These are some of the effects: headache, giddiness, blurred vision, coughing, tightness of chest, salivation, twitching, dilated pupils, nervousness, nausea, cramps, diarrhea, and sweating.

Xylene, a petroleum solvent used in insecticides, is also highly toxic and causes burning of the skin and eyes, headaches, blurred vision, nausea, lack of body coordination, and eventually a coma. Xylene is also very flammable.

The symptoms of chlorinated hydrocarbon poisoning is as follows: partial paralysis of the tongue, lips, and face; apprehension; disturbed equilibrium; dizziness; confusion; tremor; headache; fatigue, weakness, and convulsions; and paralysis of the hands in the case of extreme poisoning. The recommended treatment in the case of chlorinated hydrocarbon poisoning is phenobarbital. Some common chlorinated hydrocarbons are BHC, chlordane, and toxaphene.

Some common organophosphates found in fertilizer plants and chemical warehouses are: Co-Ral, Demelon, Diazinon, Guthion, Malathion, Methyl

Parathion, Ethyle Parathion, Phorate, Phosdrin, TEPP, Thimet, Di-Syston, Systox and Dyfonate.

After a fire involving pesticides, decontamination procedures must be followed. This includes a personal shower with lots of soap and warm water. Fire fighting equipment should also be decontaminated. For small items a mixture of chlorox (one quart), detergent (1 cup), and one gallon of water. For large areas such as walls and floors a water spray consisting of 50 pounds of lime to 100 gallons of water may be used. All clothing must also be laundered.

After exposure to pesticides, each fire fighter should have his blood tested to determine cholinesterase levels. These tests should also be given to firemen before they are exposed to poisonous chemicals so that base levels can be determined.

Summary

I hope through this brief review of fertilizer and chemical fires and emergencies the fire service will gain a better understanding of the problems involved and how to approach them. There is no shortcut to preparedness. The fire fighter must study, inspect, and plan in relation to the fertilizers and chemicals stored, transported, and used in his community.

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Research & Development Sessions

SOLAR ENERGY RESEARCH AT SANDIA LABORATORIES WITH UNIQUE HEALTH AND SAFETY PARAMETERS

By LAWRENCE L. YOUNG
Safety Consultant, Sandia Laboratories,
Albuquerque, NM

This nation, as well as the rest of the world, has become increasingly concerned over the rapid depletion of conventional fossil energy sources. Our national energy independence has been given a high priority, which has stimulated the research in, and development of, alternate energy sources. Sandia Laboratories, a prime contractor to the United States Department of Energy, has be come a leader in the development and evaluation of specific solar energy systems in an attempt to economically harness this extensive source of electrical and thermal power.

Since there are a variety of solar components and subsystems which offer potential, Sandia Laboratories has established several different solar facilities. These experimental projects will serve as unique prototypes and national engineering evaluation centers. Evaluation of various systems will provide the empirical data necessary to determine the areas of greatest potential for commercial applications.

In this presentation, I will attempt to present a general overview of the major solar energy projects which are currently being performed by Sandia Laboratories. The main emphasis will be on the unique hazards associated with reflecting concentrated solar energy to a receiver. I will not attempt to discuss the hazards associated with the normal industrial setting such as construction, high pressure systems, or other common industrial hazards.

In addition to direct solar energy, Sandie Laboratories is also interested in harnessing solar-derived power from the wind. The prime objective is to demonstrate the feasible advantages of a vertical-axis wind turbine power system in a power grid application. Two intermediate goals of such a system are: (1) an initial design test device which will allow early total system investigations, and (2) a scale-up to a design comparable to the ERDA funded 100 kW_e NASA design horizontal-axis system, which will allow comparative judgments to be made. The final goal will be the design and installation of a megawatt range system.

The initial design and test device has already been constructed. The 17-meter Darrieus vertical-axis wind turbine is undergoing initial testing in a two-blade configuration. The initial results have agreed with predicted structural and performance estimates.

Sandia's solar total energy test facility is composed of two separate functions: the solar total energy system test facility and the collector module test facility.[1]

The solar total energy system test facility will use primary heat to generate 32 kW electrical power and up to 750,000 Btu's per hour of thermal energy for heating and air conditioning. The system will basically consist of solar collector fields, fluid transfer systems, high and low temperature heat storage tanks, heat exchangers, organic Rankine cycle turbine/generator, cooling tower, temperature and flow sensors, com-

puterized controls and acquisition equipment, and support equipment which includes a complete weather station.

The collector field, at the moment, is made up of four different collector types. Each type provides approximately 24 per cent of the solar power. Each collector field can function independently or in conjunction with the other three fields.

The parabolic trough field, designed by Sandia, consists of four 60-foot-long parabolic troughs in two rows on an east-west axis. The collectors are front surface reflectors made of aluminized Teflon laminated to Mylar and bonded to aluminum sheets, then attached to the plywood trough. The stationary receiver tubes are coated with highly absorptive black chrome, sealed in evacuated black tubing and extended the full length of each set of troughs. A minicomputer accomplishes the sun tracking and control of the collector field. The tracking is performed by comparing the collector elevation angle with a sun position program for that specific day of year and sends the correction signals to the single axis drive motors.

The parabolic dish is a three-collector array designed by Raytheon, Inc. The collector is a segmented dish composed of silvered glass mirror surfaces. The 22-foot collector concentrates the solar radiation on a receiver mounted at the focal point. The non-absorbing surfaces of the receiver are heavily insulated to prevent heat loss, and the receiver cavity is plated with black chrome on its absorptive surface. The tracking of the parabolic dish, as with the parabolic trough, is controlled by a computer except that the dish has two-axis tracking.

The fixed mirror solar collector by General Atomic Company consists of precision cast concrete troughs with longitudinal silvered glass facets. The two collector rows, each 200 feet long and seven feet wide, are oriented on an east-west axis. Each row of collectors has a movable receiver assembly which tracks the sun's reflected and focused image. Changes in the sun's position are detected by special sun sensors which send a signal to activate the receiver tracking motor.

The SLATS, or solar linear array thermal system, consists of two rows of reflectors, each 140 feet long and 10 feet wide. This system was designed by Sheldahl Company and is oriented on an east-west axis. The mirrored SLATS track the sun and concentrate the solar radiation onto a fixed receiver assembly. A sun sensor is also used in this system.

There are two high temperature storage systems which maintain the temperature of the heat transfer fluid. The first storage system is a stratified single tank insulated by an evacuated jacket filled with multifoil insulation, 24 inches of bulk insulation at the top and bottom, and rockwool bolts for the outer insulation of the tank. Capacity of the first storage system is 1300 gallons. The second system consists of three 3000-gallon tanks with bulk insulation.

The fluid transfer system interconnects all the subsystems of the facility. The heat transfer fluid, Therminol-66 (T-66), circulates through the solar collector receivers where it is heated to 400°-600° F. The heated T-66 is then pumped through insulated pipelines to the high-temperature storage tanks (to be used later) or directly to a toluene heat exchanger where it becomes the energy source for boiling and superheating the toluene. The toluene is the turbine/generator working fluid. After heating the toluene, the T-6 returns to the high-temperature storage tanks for recirculation through the collector fields.

The toluene heat exchanger is the interface between the heat transfer fluid (T-66) and the turbine working fluid (toluene). Heat exchange is accomplished in four phases: one preheating, two boilings, and one superheating. The toluene is heated to 588° F and 275 psi and enters the turbine as superheated high-pressure gas. The superheated toluene expands through an axial-flow rotor to power the turbine/generator, which delivers a rated electrical output of 32 kW. When the toluene is exhausted from the turbine/generator, it is cooled as it passes through a regenerator and a water-cooled condenser. The cooled toluene is pumped back to the heat exchanger for reheating.

The single-stage turbine/generator is driven at speeds up to 25,000 rpm by toluene gas. Reduction gears drive the generator at 1800 rpm to produce up to 32 kW of electrical energy. The turbine condenser coolant, water, is stored in a low-temperature storage tank and becomes the energy source for the heating and air conditioning components of the system.

The solar collector module test facility test bed contains the fluid test loops and instrumentation for testing individual concentrating collector modules. Either water or T-66 (heated to 630° F and 2700 psi) can be used in the three test loops. The loops have pumping and cooling capacities which are adequate for collectors of about 500ft^2 maximum size.

The control and equipment center contains the control and data acquisition equipment and is located in the same building as the toluene heat exchanger and the turbine/generator. The two low temperature storage tanks, each with a 5000-gallon capacity, store the heated condenser cooling water until needed for operation of heating or cooling components.

The induction-spray evaporative cooling tower dissipates excess heat from the turbine and absorption air conditioner and serves as part of the test load for systems under evaluation. The cooling tower can cool 350 gpm of water.

The goals of the Solar Total Energy Test Facility are:

1. Practical testing and evaluation of solar energy components and subsystems.
2. Development of an analytical and technological data base for further solar energy advances.
3. Evaluation of system interactions.
4. Identification of potential areas for research and development emphasis.
5. Simulation of operation modes for candidate solar total energy large-scale experiments.
6. Confirmation of analytical predictions of system performance.
7. Operational test bed for personnel training.

Sandia Laboratories, along with ERDA and the State of New Mexico, has utilized one of the test collector designs to produce a solar-powered irrigation system.[2] The system will pump enough water to irrigate 100 acres of mixed crops, as well as a greenhouse and fish farm, as part of an alternate season operation.

The system consists of a solar collector field utilizing parabolic troughs, an energy storage tank, a solar engine, irrigation pump, controls, and a water-storage pond. This equipment is located on less than four acres of land.

The solar engine, again the organic Rankine cycle/turbine, delivers 25 shaft horsepower to the irrigation pump. The pump will deliver 880 gpm from a well 75 feet deep during the 100-day irrigation season. The plastic-lined pond will store up to 4.5 acre-feet of water for demand as needed.

The sun-tracking parabolic troughs heat the heat-transfer fluid to 420° F. When the system is not operating the irrigation pump, it can generate 10 million Btu/day of heat or 200 kW/day electrical power.

This solar irrigation experiment has been engineered and developed using available technology. The accumulation of data is an important parameter of this project. Several temperature sensors and flow indicators have been incorporated into the system, and a small weather station monitors all environmental conditions. A multi-channel data recording unit will record data from the temperature sensors, flow indicators, and the weather station. The data will be used to analyze system performance. A 20-year lifetime is the design goal for the system.

Preheated heat transfer fluid is pumped into the collector field and is heated in the parabolic trough receivers to 420° F. There is 6720 ft^2 of reflective

surface in the collector field. A control valve which is thermally controlled directs the hot fluid either to a thermal storage tank or to the boiler/heat exchanger. In the heat exchanger, Freon R113, is heated to a gaseous state until it reaches a temperature of 325° F and a pressure of 220 psi. The heated high pressure Freon gas drives the turbine which operates the irrigation pump. The Freon is then exhausted from the turbine and circulated through a regenerator heat exchanger, a condenser heat exchanger, back through the cooling side of the regenerator heat exchanger, and returned to the boiler/heat exchanger as a liquid.

The heat transfer fluid flows from the boiler/heat exchanger either back to the thermal storage tank or to a mixing tank. The mixing tank limits the temperature at which the fluid enters the solar collector receivers and helps control the temperature leaving the collector.

Water is taken from the storage pond for irrigation by a conventional pumping system. This conventional pump operates on demand to allow different types of irrigation equipment to be tested. System operation is designed to be automatic with a manual backup control system for emergencies. The collectors will be rotated to an upside down position when the system is not operating.

Photovoltaics,[4] the direct conversion of solar energy to electricity, is one of the newest technologies for trapping the sun's power and offers a promising method for major electrical power generation. Modern photovoltaic/systems have provided on-board power for many satellites.

Sandia Laboratories has a leading role in the National Program of Systems Definitions Project. The long-term goals of the project are to identify promising applications for photovoltaic power generation systems as well as the establishment of optimum performance levels within practical economic limits.

The immediate objectives of Sandia's Photovoltaic System are to:

1. Make conceptual design studies to identify photovoltaic systems which are worthy of further research and development effort.

2. Analyze systems and make related studies to gather information on performance, economics, legal factors, and environmental effects of large-scale power systems.

3. Establish design requirements and performance goals to guide development efforts toward low-cost systems and the use of new materials.

4. Provide system definition support to actual application and demonstration projects.

5. Define performance requirements for power generation systems and identify technical problem areas which require additional research to make systems perform to standards.

6. Initiate hardware experiments to establish the validity of analytical models, and confirm predicted performance.

Sandia scientists are also experimenting with high intensity solar cell development called the "photovoltaic/thermal system," which operates at high illumination and temperature levels. This results in increased output efficiency. Cells under investigation include those made from silicon, gallium/arsenide, gallium/aluminum/resenide, and other compound semi-conductor materials.

Specific development of the high intensity silicon solar cells has led to the design and construction of an advanced photovoltaic/thermal array enhanced with optical concentrators with the intent to trade expensive solar cell area for cheaper concentrator area.

The array generates one kilowatt electrical and five kilowatts thermal power. A silicon solar cell five centimeters in diameter is the basis of the array. Each of the 135 cells in the array generates 7.4 watts of power in full sunlight. The array has a two-axis tracking system controlled by sun sensors.

A Fresnel lens system serves as the optical concentrator for the array. The lenses, which look like transparent, square phonograph records, are mounted in a framework at a fixed distance above the solar cells. They intensify the solar radiation on the cell surface 50 times, which in turn increases electrical output of each cell by a comparable amount.

Excess heat, which deteriorates the solar cells, is removed by mounting the cells on collector tubing through which water is circulated. This prolongs cell life while providing hot water which can be used for space heating, air conditioning, and domestic or process hot water supplies. Fourteen per cent of the available sunlight falling on the photovoltaic/thermal array is directly converted to electricity and an additional 50 per cent collected as heat, for a total radiation use of 64 per cent.

A cost comparison indicates a non-concentrating, one-kilowatt array of solar cells costs about $15,000 against an estimated cost of $3,500 for the photovoltaic array enhanced with Fresnel lens concentrators. Analysts believe even more substantial cost reductions are possible. Current goals are to produce a system costing only $2,000 per kilowatt capacity by 1978, and to further reduce the system cost to $500 per kilowatt by the mid-1980s. These costs would make photovoltaic systems competitive with conventional power generating methods.

Sandia Laboratories also boasts the largest solar thermal test facility (STTF) in the world. The STTF is the major test facility for the National Solar Central Receiver Program.[3]

The major goals of the STTF are to provide experimental data for the design, construction, and operation of unique component systems for proposed solar thermal electrical plants. The STTF project has a five megawatt maximum thermal capacity and will emphasize scaled-down solar receivers and heliostats typical of those proposed for use in operational power plants.

While similar to the projected commercial solar thermal power plants, the STTF has a broad test capability. The design and instrumentation will provide a facility to test a variety of solar receivers (which have many similarities to conventional boilers) and heliostat fields as well as materials evaluation, other energy conversion techniques, and unique chemical and metallurgical processes.

Solar energy is collected and concentrated by sun-tracking heliostats. Each heliostat array consists of 25 four-foot by four-foot glass mirrors (facets) which are focused and aligned to produce a single concentrated beam of solar radiation at any desired test location on the central tower.

The individual heliostats are also aligned with each other so that multiple heliostats produce a single three-dimensional spot at the focus and alignment point. The north sector heliostat field will contain over 200 heliostat arrays which will direct up to five megawatts of thermal solar energy on the tower receiver or other experiments. The site computer maintains positive beam control during heliostat operations.

Other prototype heliostat systems will also be evaluated at the STTF; all heliostat systems track the sun by using sun sensors and/or minicomputers for beam control.

The central tower rises 200 feet and contains three other test bays at 120, 140, and 160-foot levels in addition to the receiver location on the north face of the tower. The tower is served by a 100-ton capacity elevator and will also contain test instrumentation, heat rejection equipment, and a laser scanning device which is used to focus the heliostats.

The thermal solar receiver may weigh up to 100 tons and extend up to 80 feet above the top of the tower. Each receiver will be different, with unique features which require specific testing. Water, steam, or air circulated through the receiver under test is heated to temperatures up to 1000° F with resulting pressures up to 1400 psi. In an operational solar power plant the high-temperature, high-pressure fluid would be used to drive a conventional tur-

bine/generator to produce electricity. A high-temperature storage incorporated into the system could be used to assure uninterrupted power into the evening hours.

The STTF is expected to be completed by December 1977 at an estimated cost of $21 million.

Perhaps the most unique hazard associated with many solar collection systems is the reflection and reradiation of concentrated solar energy into the surrounding area. In most instances, this is a spectral reflection which occupies a distinct volume of space. The most sensitive parameter to this hazard is the retina of the eye. If the exposure of an unprotected eye is at a safe level, then all other parameters (skin, hair, physical structures, etc.) are at a safe exposure level.

When I first came to Sandia, I was asked to evaluate this eye-hazard problem as well as the associated hazards of high density spectral solar reflections. The primary areas of concern are:

1. Eye-hazard criteria: geometry and distances of hazards; optics; separated images; threshold values/retinal burns, corneal and/or iris lesions, pigment bleaching, photochemical bleaching, and photophobia.

2. On-site personnel exposure parameters: operators—eye hazards, skin hazards, facility hazards, administrative controls; visitors—personnel protective equipment, administrative controls and exclusion zones.

3. Off-site personnel exposure parameters which affect hazards: beam geometry—convergence and divergence; optics and intensity levels; probability factors for organic damage, physical damage to non-biological parameters, flashblindness to airplane pilots, passengers, and motorists in the immediate vicinity or airspace.

The first area attacked, of course, was the eye-hazard criteria. Once this is established the solutions to the other areas will fall in place. The major portion of the remainder of this essay will therefore be concerned with chorioretinal burn criteria.

As alluded to earlier, the retina is the most sensitive tissue of the mammalian body to solar radiation wavelengths of 400-1400 nm.[6] This spectral band encompasses the major portion of reflected solar radiation. If all the safety standards are defined in terms of retinal thresholds for unprotected eyes, then all other biological effects on the other tissues of the eye and skin will have been compensated for.

Let us briefly examine the gross anatomy and physiology of the eye as well as its associated optical parameters. As the light comes from a source, such as the sun or an image of the sun reflected from a specular surface, it hits and transverses the ocular media. As the light goes through the ocular media, it is attenuated due to absorption, reflection, and scattering.[7] At the same time the light is focused into a smaller area. Therefore, the power density on the retina may be different from what it is at the cornea.

The first anatomical structure the light hits is the cornea, which is not transparent to far UV but is transparent to light of longer wavelengths into the infrared. The cornea also acts to help refract the light. The next structure is the aqueous humor, which is transparent to light in the UV, visible, and near-infrared spectrum.

The lens is the next structure which must be traversed. The lens is responsible for the gross focusing ability of the eye. The lens is transparent to wavelengths from 400 nm to 1400 nm.

The largest component of the eye is he vitreous humor, which is a gel-like material behind the lens. The vitreous humor is transparent to most of the light from 33 nm to 1300 nm.[8] After passing through the ocular media the light finally reaches the retina. Approximately 74-77 per cent of the light which is incident on the cornea, with an adequate angle to pass through the pupillary opening, actually reaches the retina.[8] The retina is virtually transparent to light. An estimated ten per cent or less of the light incident on the retina is absorbed by the visual pigments and neural structures of the retina. The rest of the light is absorbed by the pigmented layer which separates the retina from the choriod.[7]

When light enters the retina, it must pass through two layers of neural cells before it strikes the photoreceptor cells. These photoreceptor cells, which are known as the rods and cones, contain the visual pigments and transduce photo stimuli into electrical impulses. These impulses travel to the brain by the optic nerve tract. Directly below the rods and cones lies the pigmented epithelium of the retina. The retinal pigmented epithelium prevents backscatter of the photons by absorbing them.

The retina and its associated pigmented epithelium contain no blood supply and therefore has a decreased ability to dissipate heat. The blood supply and the resulting heat-dissipating mechanism is contained in the choriod, which lies immediately under the retinal pigmented epithelium. Most of the light energy which reaches the retina is absorbed by the pigmented epithelium and converted to heat. Due to the poor heat removal mechamism of the retina, the retinal image size on the retina is the most important parameter in initiating thermal damage (chorioretinal burn) for exposures of short duration.

The optical properties of the eye play an important role in determining chorioretinal injury parameters. Factors such as retinal image size, pupil size, spectral absorption and scattering by the ocular media, irradiancy of the source, and reflectivity of the reflective surface must all be considered. Perhaps the best way to approach the subject is to discuss the relationship between external focusing systems, such as reflective solar energy concentrations systems, and the optical focusing system of the eye, thus relating the skin or corneal radiation intensities with the retinal irridaition.

Most of us are familiar with focusing phenomena. The closer an external target is to the reflective surface in front of the focal point (or the further away beyond the focal point) the larger the image is on the target. But this is not true on the retina of the eye. The retinal image size is largest at the focal point and becomes smaller as you increase the distance from the focal point. When the eye is at the focal point, the complete reflective surface is filled with the sun's image. As the eye moves away from the focal point, the beam size becomes larger and the pupillary opening can only see part of this beam at any one time. Therefore, the apparent image size of the sun on the reflective surface, as perceived by the eye, becomes smaller.

By the law of conservation of brightness, no optical system can increase the brightness of a light source. Because of this conservation of brightness, the retinal irradiance cannot be brighter than that resulting from direct viewing of the source (in this case, the reflected image of the sun as opposed to direct viewing of the sun).

In viewing a non-focusing external system on-axis, as one moves away from the source the intensity of radiation at the cornea decreases as the square of the distance. During the same period, the intensity of energy on the retina remains constant (ignoring scattering and attenuation due to relatively short distances) and the retinal image size becomes smaller.[9]

We can extrapolate from this and state that in an on-axis focusing system, as the eye moves closer to the focal point, the corneal irradiance increases, the retina image size increases, and the retinal irradiance remains constant. As the eye moves away from the focal point, the corneal irradiance and retinal image size become smaller and the retinal irradiance still remains constant. Therefore, ignoring atmospheric attenuation, the retinal image size and the intensity of energy on the cornea may change, but the intensity on the retina per unit area remains the same.

This change in retinal image size and

corneal irradiance is known to be true.[10] The theory that the on-axis retinal intensity per unit area remains constant is commonly accepted but has not yet been proved. Personnel of Sandia Laboratories are currently working on experimentation to determine whether retinal irradiance per unit area is indeed a constant. So far, indications are confirming this commonly held belief. Ignoring atmospheric attenuation is a valid procedure, considering the short distances we are concerned with.

If we know the damage threshold to the retina and all the variable parameters associated with the same, we can arrive at safe exposure levels that can be tolerated by humans. Let us now look at these variable parameters.

The pupil, which is the limiting aperture of the eye, determines the total amount of radiant energy entering the eye. The energy entering through the pupil, and therefore reaching the retina, is proportional to the area of pupillary opening. For the normal outdoor daylight-adapted eye, the normal pupil diameter will be 2-3 mm. Momentary viewing of the sun causes the pupil to constrict to approximately 1.6 mm.[11]

The angle subtended by the source also plays a role. A light source of a given luminance will cause a different pupillary diameter dependent upon viewing distance (i.e., image area on the retina) and upon the luminance of the surroun ling field.[11]

The angle subtended by single extended source defines the retinal image size. The retinal image size (d_r) can be calculated if one knows the effective focal length of the relaxed eye (f, ~1.713 cm), the viewing distance (r, in cm) and the dimension of the light source (D_L)

$$\left(D_L = \frac{4\ (\text{Perimeter}).}{\text{Area}}\right)$$

$$d_r = \frac{D_L f}{r} \qquad (1)$$

This formula does not hold for very large angles (error at 60°).

The radiance of the solar reflecting source (L, in W/cm^2 · sr) can be calculated if the solar insolation (q), the reflectivity of the solar reflector (η), and the half divergence angle (β, 4.66 x 10^{-3}rad) is known.

$$L = \frac{q\eta}{\pi\beta^2} \qquad (2)$$

This value is important in computing the theoretical retinal irradiance, E_r. The theoretical retinal irradiance is a function of the pupillary diameter (d_p), the radiance of the source (L), the transmissivity of the ocular media (τ, ~0.74), the percentage of solar insolation between 400 and 1400 nm (v, ~0.88), and the ocular focal length (f).[10]

$$E_r = (\pi \cdot d_p^2 \cdot L \cdot \tau \cdot v)/4f^2 = 0.27 d_p^2 \cdot L \cdot \tau \cdot v \qquad (3)$$

For most computations this equation can be used for a single source image. Once the equipment has been built, one could measure the corneal irradiance and compute the retinal exposure for that particular solar insolation. This can be done by the following equation:[10]

$$E_r = \frac{\tau \cdot E_c \cdot v \left[\left(\pi d_p^2\right)/4\right]}{A_r} \qquad (4)$$

where

τ = ocular transmissivity (~0.74)
E_c = corneal irradiance
v = % of radiation between 400 & 1400 nm (~0.88)
d_p = pupillary diameter
A_r = retinal image area

Once the retinal irradiance and the retinal image size is known, a maximum permissible exposure (MPE) can be determined. Retinal hazard thresholds are strongly dependent on image size for momentary viewing (i.e., exposures ranging from 0.15 second blink response reflex to several seconds). Sliney and Freasier [10] have developed criteria which varies with image size based on rabbit retinal burn thresholds,[12,13,14] based on data obtained by a steady heat transfer solution equation of the retina and choriod. A safety factor of 2.5 was

applied to achieve suggested MPE levels. The actual safety factor in these criteria is greater than 2.5, since it has been shown that rabbits are more sensitive to chorioretinal burns than primates,[15] and the typical retinal exposure times required for maximum temperature rise are greater than the duration of the blink reflex response (90 per cent temperature rise in the first 300 msec).[16] More recent published threshold data suggest an inherent safety factor in these criteria which varies between ~5 and ~20, depending on exposure time and image size.

A generalized rule of thumb for safe retinal irradiance which is slightly more conservative than the MPEs shown can be extrapolated from Sliney and Freasier.

$$E_r = \frac{0.002}{d_r} \qquad (d_r \leqslant 2 \times 10^{-3}\text{m}) \qquad (5)$$

$$E_r = 1\text{W/cm}^2 \qquad (d_r \geqslant 2 \times 10^{-3}\text{m}) \qquad (6)$$

where

E_{rs} = safe retinal irradiance in W/cm^2 assuming circular image and 0.15 second exposure
d_r = retinal image diameter in meters.

Safe retinal irradiance for a 158μ circular retinal image diameter (the same image that would be 12.66 W/cm^2 for momentary viewing. This safe E_r is about 150 per cent of what would actually occur. Again, under most circumstances, there is a five to 20 safety factor in this criteria.[10]

One must remember that the hazard criteria does not represent a distinct line between safe and hazardous exposures. Each situation must be interpreted based upon practical knowledge of exposure conditions and the latest empirical data.

Until more empirical studies are performed which show these criteria to be too conservative, it would probably be advisable, and a reasonable practice, to follow these accepted guidelines.

For example, let us examine an occurrence that happened in Livermore, California, where a workman was exposed to a non-focusing heliostat beam. He was working on a roof of a building approximately 700 feet from the heliostat when he glanced into the beam. The exposure duration was estimated to be 0.15 second (blink response time). Although he experienced flashblindness and was taken to medical, he suffered no long-term impairment or discomfort.

The estimated circular diameter of the image on the non-focusing heliostat is 2.14 meters. The heliostat has a total reflectivity of 0.73, therefore,

$$d_r = \frac{(2.14\text{m})\ (1.713\text{cm})}{2.13 \times 10^4\text{cm}} = 1.72 \times 10^{-4}\text{m}$$

If the solar insolation was 1.0 W/cm^2, then the radiance of the source was

$$L = \frac{(1.0\text{w/cm}^2)\ (0.73)}{\pi(4.66 \times 10^{-3}\text{rad})^2} = 10.7 \times 10^3\text{w/cm}^2 \cdot \text{sr}$$

From this information the theoretical retinal irradiance can be calculated:

$$E_r = (0.27)\ (0.2)^2\ (10.7 \times 10^3)\ (0.74)\ (0.88) = 75.3\text{w/cm}^2$$

The computed safe retinal irradiance is:

$$E_{rs} = \frac{0.002}{3.92 \times 10^{-4}} = 5.1\text{w/cm}^2$$

As can be seen, the actual exposure was approximately a factor of 10 more than the computed safe exposure level. We can extrapolate, therefore, based on our limited human data, that the theoretical criteria incorporates an adequate safety margin.

When dealing with many kinds of solar reflectors there will be a finite possibility of multiple coincident beams. When the eye is exposed to this situation, the flux density is additive at the cornea as a function of the number of coincident beams. Due to optical properties of the eye, the flux density on the retina is not increased. The total amount of energy that enters the eye and the total area of the retina that is exposed is increased, but the power density of solar radiation on the retina does not change since the images do not overlap.

If the eye is in coincident beams from

case histories

widely separated sources, each retinal image will be separated and thermally independent of each other. There is some critical distance (which may also be a function of the specific power density of the images) between retinal images at which the separated incident energies can be dissipated by normal physiological mechanisms without having synergistic effects on each other. Equal to, or greater than, this critical distance, the images are thermally independent. Less than this critical distance there is some mathematical relationship between the thermal properties of the images. The mathematical relationship of the flux density is never additive because the images will never overlap.

In evaluating eye hazards from multiple solar reflecting sources, the following research needs to be performed:

1. Determination of critical image separation distances on the retina as a function of image flux density for thermal and photochemical interaction between images.

2. Determination of the mathematical relationships in the thermal and photochemical properties of retinal images separated by distances less than the critical distance as a function of flux density.

3. Determination of chorioretinal burn threshold values for primates and maximum permissible exposure levels for multisource solar spectrum radiation with: (a) separated images greater than or equal to the critical distance separation (thresholds and MPEs should probably be the same as for single source radiation); (b) separated images less than the critical distance separation.

Although as yet we do not have the needed information to quantitatively assess the eye hazard from multiple sources, an accepted procedure for eye hazard analysis is to assume the worst-case condition. This scenario would group all the images immediately adjacent to each other in order to make a single large image of an area that is the sum of all image areas. This is a very conservative assumption but will provide a means to assess the worst condition that may need to be controlled.

From this assessment, decisions can be made using practical knowledge of the hazard, of the equipment, and of its intended use. T.D. Brumleve has used a similar approach to examine the eye hazard from heliostats at the 5-mw_t solar thermal test facility and to suggest beam control criteria.[17]

Another area in which applied research is needed, is in the area of airplane pilot flash-blindness from multisource solar spectrum radiation reflected from long focal length reflectors, to determine the amount of retinal intensities a pilot can tolerate without posing a hazard to his flying ability. This criteria could also be used to evaluate hazards to motorists driving in the area of the solar reflector.

The hazard of erythema (sunburn) depends upon the flux density and the duration of exposure. Multiple sun corneal (skin) intensities would become sufficiently uncomfortable that evasive action would be quickly taken.[6] Fairly high flux levels could be tolerated for short reaction times (20 suns for 10 seconds). The burn hazard from inadvertently touching the solar energy receiver or a hot fluid loop is greater than a brief exposure to the reflected beam, except of course, exposure within very close distances to the focal point.

To evaluate fire hazards from reflected solar flux, experiments by Sandia Laboratories[19,20,21] and others[22] suggest that easily combustible cellulosic materials such as dry brush and wood may be ignited by flux levels as low as 20 suns. Again, as evidenced in reference 21, the hazard is time dependent. The higher the incident flux, the shorter time needed to cause ignition, but there does seem to be a level at which a fairly long exposure time is needed to initiate ignition.

As one can readily determine, we are a long way from being able to supply exact quantitative analysis to all the unique safety and health hazards associated with solar energy collector and receiver systems. But we are making progress quickly. Research in this area, especially the eye hazard, is continuing and more extensive work is planned.

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POTENTIAL HAZARDS OF RECOMBINANT DNA RESEARCH

By SOL MILLER, Ph.D.
Supvr., Industrial Hygiene, Corporate Biohazards Control,
Abbott Labs, North Chicago, IL

Science fiction writers anticipated travel in space by a number of years before space travel became a reality. Likewise, genetic engineering has been fictionalized by science writers for some number of years and we now find that at least the beginning of our ability to manipulate genes is also a reality. Genetic materials—chromosomes and their basic units called genes—are composed of deoxyribonucleic acid, otherwise known as DNA. All living things, with the exception of certain viruses, use DNA both to store their hereditary information and direct all of their normal life processes. It is DNA, for example, that makes a horse a horse instead of a man, an insect, or a tree. Slight chemical variations in DNA also differentiate individuals within a given species.

The science of genetics has made a very great contribution to strain improvement of organisms. Few plants or animals used in agriculture resemble those found in the wild. These have been taken and subjected to a rapid process of mutation, crossing, and artificial selection to produce varieties very different from anything that has gone before and from anything that would occur in nature. Selection has often been for a single character such as yield of grain, resistance to disease, production of wool, butter fat, or breast muscle. This has at times produced a kind of "monster" that can survive only when cultured under highly artificial conditions. For example, the breasts of some commercial varieties of turkeys are so large that the birds cannot mate—they have to be artificially inseminated.

The same principles apply to industrial micro-organisms. Micro-organisms used in fermentors for making antibiotics, amino acids, or enzymes cannot be wild strains; genotypes able to produce comparatively huge yields of a single product are needed just as in many branches of agriculture. Hardly anyone would challenge the need to change the genotype of micro-organisms to improve this yield. Disagreements or misunderstandings arise only over the choice of the most appropriate route to the desired goals. Breeding a microbe to maximize the yield of a single metabolite, such as an antibiotic when it is the end product of a long, regulated path-way of biosynthetic steps, needs a surprisingly large number of genetic changes. Recombination is the bringing together of pre-existing genetic information into new combinations. For example, parts of two existing genotypes or part of one and the whole of another combined to give a new genotype. It would be possible, theoretically, to derive by mutation a strain of micro-organism that synthesizes insulin; however, the problem is well nigh impossible. The probability of all of the mutations occurring simultaneously is essentially zero, and fails for lack of a selection method to recognize intermediate steps in the succession. Thus; people are trying to find the solution to the problem by recombination, bringing together pre-existing genes of mammals and bacteria.

In 1973, new opportunities in genetic research had become apparent. Enzymes had been discovered that permitted splitting and recombining DNA at highly specific sites. Four years ago, the members of the 1973 Gordon Conference on Nucleic Acids were the first to draw public attention to the possible hazards of recombinant DNA research. In April

1974 a special committee of the National Academy of Sciences met and passed a resolution that all researchers honor a temporary ban on certain types of recombinant DNA experiments deemed potentially the most dangerous: those involving animal tumor viruses and those increasing drug resistance or toxicity in bacteria. In February 1975, 134 scientists, including many leading molecular biologists, plus a handful of lawyers and 18 interested reporters, assembled at the picturesque Asilomar retreat among the pines and redwoods of California's Monterey Peninsula. This led to a decision to continue their ban on worrysome experiments. The group also decided to request the National Institute of Health (NIH) to establish levels of safety that should be required for different experiments. They also decided that precautions to keep research organisms from escaping from laboratories had to include biological containment. This required the creation of mutated strains of *E. coli* so disabled that they could live nowhere but in a test tube. If they did escape their special media and enter the atmosphere, or the human gut, they would die almost instantly.

In July 1975 the NIH group did publish guidelines for recombinant DNA research in the *Federal Register*. In their present form, the guidelines provide a framework for continuance of recombinant DNA research under regulatory surveillance. Certain types of experiments are not to be initiated, such as recombinant DNA's with highly infectious organisms in Classes III, IV, or V of the classification of etiologic agents on the basis of hazard published by the Center for Disease Control, Atlanta, Georgia; deliberate formation of recombinant DNA's containing genes for potent toxins of bacteria, insects, or snakes; deliberate creation of DNA's with plant pathogens; transfer of drug resistance trait to micro-organisms that are not known to acquire it naturally. In addition, large scale experiments (for example, more than 10 liters of cultures) with recombinant DNA's known to make harmful products are not to be carried out.

The guidelines further specify physical and biological containment procedures. Four levels of physical containment are specified known as P-1, P-2, P-3, and P-4. P-1, which is the minimal containment, requires strict adherence to standard microbiological practices in a laboratory commonly used for micro-organisms of minimal biohazard under ordinary conditions of handling. P-2 level (low) in addition to the P-1 procedures, requires: (1) limited access to the laboratory during experiments, (2) precautions against the release of aerosols (for example, centrifugation should be carried out in air-tight cups or rotors, sonofication blending should be similarly contained or carried out appropriately in enclosed biological safety cabinets); (3) mouth pipetting is prohibited—mechanical pipetting devices are required; (4) all potentially hazardous material must be inactivated before it is disposed of.

P-3 (moderate), in addition to P-2 procedures, this level requires: (1) the laboratory be separated from areas open to the general public; (2) access to the laboratory is controlled; (3) biological safety cabinets are available within the controlled laboratory area; (4) directional air-flow is provided within the controlled laboratory area—the ventilation system is balanced to provide an inflow of air from the access corridor into the laboratory; (5) exhaust air is prevented from re-entry into the building unless it has been appropriately treated. Operations which release aerosol should be contained in biological safety cabinets.

In addition to all the requirements for P-3, P-4 (high) experiments shall be confined to work areas in a facility of the type designed to contain micro-organisms that are extremely hazardous to man or may cause serious epidemic disease. The facility is either a separate building or a controlled area within a building which is completely isolated from all other areas

of the building. Class III biological safety cabinets are used for all work in the area. A P-4 facility has engineering features which are designed to prevent escape of micro-organisms to the environment.

The guidelines further outline the levels of biological containment. About 90 per cent of all recombinant DNA work involves the use of a common organism, *E. coli,* which is a normal inhabitant of human and animal bowel but has been enfeebled by maintenance on laboratory media for about 50 years. This organism is known as K-12 strain of *E. coli* and has the lowest level of biological containment, known as EK-1. A modified *E. coli* K-12 known as X-1776 has been genetically altered so that, on the average, only one bacterium in 100 million would be expected to survive in the environment outside of the laboratory. This is biological containment level EK-2.

EK-3 is an EK-2 system in which the K-12 strain of *E. coli* has a proven safety factor of no survival by test feeding of the bacteria to animals including primates and humans.

Despite the appearance of the NIH guidelines, the debate over recombinant DNA research was not layed to rest. Instead, the debate has increased in intensity and in the range of public involvement. The recombinant DNA research has become a political issue. This is due to a large extent to the widely publicized objections of a handful of scientists who demand much more severe restrictions on research in this field and to various activist groups such as the Peoples Business Commission and Citizens for a Better Environment.

Let us look at some of the possible good and bad of recombinant DNA research. The research may provide major new social benefits, such as isolating the gene for insulin production and then mass producing insulin in *E. coli* bacteria; more effective and cheaper pharmaceutical products; creation of nitrogen-fixing bacteria for more abundant food crops; better understanding of the cause of cancer; creation of organisms that increase the efficiency of waste disposal; and even new approaches to the energy problem. If nothing else, the research will dramatically push ahead the general knowledge of genetics and better understanding of how cells develop specific functions. The worst case scenarios which can be conceived would be worldwide epidemics caused by newly created pathogens, the triggering of catastrophic ecological imbalances, new tools for militarists and terrorists, and the power to dominate and control the human spirit.

The scientists who originally called to the public attention the possible hazards were for the most part molecular biologists who failed to recognize how much of the problem of estimating those hazards lay outside of their field. In fact, the ability of an organism to give rise to an epidemic, and the mechanism of its spread, are problems in epidemiology. To be sure, in order to establish the pathogenicity of any novel recombinance with precision, direct tests would be necessary. The problem is also one of evolutionary biology, since it involves the survival and spread of novel organisms in nature. Epidemiology may be seen as an applied branch of evolution, concerned with the genetic and ecological factors that influence the spread of agents of disease. But evolutionary considerations were also neglected in early considerations. This is hardly surprising, since biologists interested in physiological mechanisms and those interested in evolutionary origins have long lived in two rather separate cultures.

It is obviously easy to draw up a limited hypothetical scenario and it is easy to magnify the problem by demanding assurance of absolute freedom from risk. But to be realistic one must perceive the probabilities for an "Andromeda Strain" scenario. Three probabilities must be examined: (1) that a particular kind of DNA will produce a dangerous organism; (2) that it will infect the laboratory worker; and (3) that it will spread outside the laboratory. Experiments with highly infectious organisms are specifically prohibited by the guidelines. The recombinants using human DNA or even DNA from other mammals which may carry tumor virus genes are restricted to P-3 containment facilities. The likelihood of spreading tumor viruses has been enormously exaggerated. A mammalian cell contains a million gene equivalents of DNA of which only a few would be inserted in any bacterial recombinant. Thus, even if the genes for a tumor virus were present in the donor cells, the probability of picking them up is very low. Moreover, the frequency of tumor viruses being present in human cells is probably rare.

Whether mammalian DNA inserted into bacteria in the laboratory is a radical procedure creating an entirely novel class of organisms is purely an assumption. Bacteria can recombine with free DNA not only in the test tube but also in the animal body, particularly in the gut. Bacteria must be continually exposed to fragments of host DNA, released by the death of adjacent host cells. Since the mechanism of bacterial uptake of DNA would not exclude mammalian DNA, we must assume that this DNA does occasionally enter bacteria.

Free DNA survives only briefly in the gut and even under the favorable conditions present, the uptake is probably very inefficient. However, the human excretes around 10^{22} bacteria per day. Thus, even if the incorporation of DNA should be as small as 10^{10}, probably below normal experimental detection, it is almost certain that such recombinants have been formed in nature continually over millions of years and are being formed today. Recognizing that a harmful recombinant has a low probability, let us consider the probability that such an organism, if formed, might cause illness in a laboratory worker. *E. coli* and the closely related pathogens of typhoid and dysentery are ordinarily spread by swallowing large quantities in contaminated food or water. The most virulent of these enteric pathogens are handled in thousands of diagnostic laboratories throughout the world and are relatively safe to handle with just simple precautions.

Strain K-12 of *E. coli* used in all the current work with recombinant DNA was originally isolated from a patient, but during the years, one rare mutation after another has been selected by the artificial media on which it has been grown until the present organism is so radically altered, that if it were to be isolated today, it might not even be classified as *E. coli.* In recent tests with a large dose in man, much larger than could be expected from a laboratory accident, cells of this strain cease to appear in the stools after a few days. Thus, *E. coli* K-12 outside the laboratory is like a hot-house plant thrown out to compete with weeds.

A very large further safety factor is added by the biological containment requiring the use of host cells called EK-2. These have been drastically impaired in their ability to multiply and even to survive except under very special conditions provided only in the laboratory. In addition to its special nutritional requirements, this strain of organism is extremely sensitive to ultra-violet light. Any exposure to sunlight would kill it. In other words, the EK-2 strain has been genetically coded for self-destruction. It is also easily destroyed by common household detergents. Furthermore, it will not survive in human serum and it is ultra-sensitive to lysis by bile salts. In the gut, an EK-2 strain not only fails to multiply, but fewer than one in a hundred million cells survive after 24 hours. Certainly, it would take a most unusual laboratory accident that would cause the ingestion of a hundred million cells. It is estimated that a hundred million people would each have to take up a hundred million bacteria containing a dangerous recombinant DNA in order for the escape of that material to become probable. Certainly the risk of laboratory infection by *E. coli* recombinants is much smaller than the risk encountered with known pathogens in medical laboratories.

Another point I would like to make is that recombinants in *E. coli* are not half *E. coli* and half some other genetic material. The recombinants made possible by the new technique are genetically 99.9 per cent *E. coli* with about 0.1 per cent foreign DNA added. Thus the chances of radically expanding the virulence of *E. coli* is highly improbable.

Illness in a laboratory worker caused by a recombinant organism would require compounding of three probabilities, all of which are low: (1) that a dangerous gene will inadvertently be incorporated in the EK-2 cells; (2) that a large number of cells will be taken up; and (3) that these cells will cause harm despite their short survival. Thus the danger appears to be vanishingly small compared with a very real danger faced continually by microbiologists working with a known virulent infectious organism well adapted to survive and produce disease.

The NIH guidelines for recombinant DNA research apply only to individuals or institutions who receive funds from NIH. However, those commercial and industrial corporations who either have or plan to have recombinant DNA research performed in their organization have agreed to abide by the NIH guidelines. Nevertheless, the unfavorable press, the eagerness of some to draw attention to the "epochal" nature of their work, the constant search by the powerful mass media for the spectacular, and the necessity to acquire a cause by whichever individual organization for whatever their political or other purpose, results in demonstrations against continuation of recombinant DNA research.

Society has every right to be impartially informed of both the benefits and the real danger of any human activity. The public is entitled to "freedom from fear," regardless of whether the fear is caused by potentially dangerous experiments or due to authoritative or unfounded statements of alarming nature. Perhaps the single point that has been most misunderstood in the controversy about recombinant DNA research is that the discussion of risk relates entirely to hypothetical and speculative possibility. Unfortunately, most of the speculation has been interpreted as fact. No dangerous organisms are known to have accidentally arisen out of decades of mutagenic treatment of *E. coli* and other organisms. Likewise, no harmful organisms have been produced during five years of recombinant DNA research, even though the present safety precautions which should lower the potential danger by a factor of hundreds of millions were not yet in effect.

It seems to me that what is being asked is that there be not only no evidence of hazard but that there be positive evidence that there is no hazard. In developing guidelines for recombinant DNA research, an attempt has been made to take precautionary steps to protect ourselves from hazards that are not known to exist, and this unprecedented act of caution is so novel that it has been widely misinterpreted as implying the imminence or at least the likelihood of danger.

Unfortunately, the public has been led to believe that the biohazards described in various scenarios are likely or probable outcomes of recombinant DNA research. The story goes that if the scientists themselves are concerned enough to raise the issue, then the problem is probably much worse than anyone will admit. Thus, what we really need is proper publicity, and scientists need public credibility.

The only threat I see is the possible break in technique by individual workers which, of course, can be prevented by orientation, by training, and by reorientation—with vigilance internally, externally, and eternally.

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IDENTIFICATION AND ANALYSIS OF BIOHAZARDS IN RESEARCH OPERATIONS

By DAVID L. WEST
Environmental Health Eng., Office of Biohazard Safety,
National Cancer Institute, National Institutes of Health,
Bethesda, MD

The identification and analysis of biohazards in biological research operations are essential to the process of assessing the risk of laboratory research. For the purpose of this discussion, a biohazard is defined as a microbiological agent or biological material presenting a real or potential hazard to the well-being of man, animals, or plants, either directly or indirectly. Biohazards include infectious pathogens, biological toxins and allergens, and potentially oncogenic agents. The definition may be broadened to include conditions or circumstances involving biohazardous materials.

The research operations do not constitute all of the determinants used in assessing laboratory hazards. Other determinants include the research specimen or microbiological agent, the laboratory personnel, and the control practices and containment systems utilized. These determinants are interrelated and will be discussed here briefly, but the emphasis of this presentation will focus on the characteristics of operations that affect hazard potential for man. It must be remembered that there are other, nonbiological, aspects of hazarad assessment that apply to the laboratory setting. Although not within the scope of this presentation, these other hazards must be considered in the total analysis. They include the potentials for fire, accident and traumatic injury, chemical and radiological hazards, etc.

The nonbiological aspects have always been important, but they now have increased dimensions. Greater amounts of radioactive isotopes are used as assay markers. Larger amounts of solvents are used in biochemistry laboratories to extract biochemical components of cells and organisms. Known and suspect chemical carcinogens are used in attempts to develop *in vivo* and *in vitro* mutagenesis and carcinogenesis screening tests for chemical products. Chemicals and viruses are used, more recently, as co-insults in studying the etiology of cancer. Obviously, these nonbiological hazards complicate the overall assessment of biohazards.

Specimen or Microbiological Agent. There are several characteristics of the research specimen or microbiological agent being studied that affect its hazard potential. The first factor to consider is the host range of the infectious agent being studied (or of the agents that may accompany or contaminate a specimen being studied). Is it known that the agent infects man? In the absence of hard data, is there a hypothetical or speculative basis for believing the agent may infect man?

Other host/agent factors of primary importance are the size of an infectious dose and the route(s) or portal(s) of entry into the host. There are tremendous variations among species of organisms in the minimum size of the dose (i.e., numbers of organisms) required to infect man. Some species may infect and produce disease with a dose as low as ten organisms (e.g., the rickettsial agent of Q fever, *Coxiella burnetii*). Other species will require a dose of several million organisms (e.g., the typhoid *Salmonella typhi*). Most bacteria must be inhaled or ingested in doses over 1000 organisms to cause illness, but many types of viruses using the same portals of entry can cause disease with only very small doses.

An organism typically has a natural

route by which it infects its host. Some pathogens cause infection after they are inhaled (e.g., influenza), others after they are ingested (e.g., cholera), and still others after they enter through the skin (e.g., bubonic plague). Some organisms can cause infection through multiple routes (e.g., anthrax). As a general rule, infectin by intradermal inoculation requires a smaller dose than by ingestion. For example, the intradermal infectious dose for tularemia may be on the order of 10 or 100 organisms; the ingested infectious dose may be on the order of millions of organisms.

Having identified the host range, the virulence must be considered. This concerns the ease with which the agent infects the host, the pathogenicity of the agent, and the severity of the disease produced.

In some cases, the history of the agent or specimen may be important in assessing overall hazard potential. Viral and bacterial virulence are under polygenic control. The virulence of viruses can be attenuated or enhanced by mutations and genetic recombinations. Variations in bacterial virulence may result from mutations or from changes in the organism's environment. The history of a specimen or of a culture is also important in assessing the likelihood that the specimen or culture may be contaminated with extraneous organisms that themselves pose hazards.

The stability of an organism in the ambient environment influences its hazard potential. Some organisms are persistent and can remain viable and infective in the environment for extended periods of time. This tends to increase the hazard potential. Other organisms, however, can survive only for very short periods outside their hosts or culture media. Changes in environmental factors (e.g., temperature and relative humidity) can have significant effects on their viability. Still other organisms may remain viable in exposed environments, but their infectivity may be altered.

Another important consideration in assessing the hazard posed by an organism is whether there exist prophylactic measures to prevent disease in exposed persons or effective therapy to cure diseased persons.

Laboratory Personnel. Medical and nonmedical factors of personnel influence the overall hazard potential in a research laboratory. There are a multitude of medical factors that affect the relative susceptibility of a person to infection and disease by a human pathogen. These include, for example, genetic background of the individual, his medical history, hypersensitivities he may have or develop, temporary or permanent immunosuppression due to medical conditions or therapeutic treatments, physiological stress factors, etc. The medical liabilities of an individual that may lead to increased risk can be evaluated and minimized by a program of medical surveillance and counseling, restrictive employment practices, and the use of available prophylactics.

Nonmedical factors also contribute to the personnel component of hazard potential. These factors do not relate to the susceptibility of infection, but relate to personnel adherence to prescribed safety practices and to accident rates. Paramount is the level of personnel training in safe laboratory practices and individual awareness of safe and unsafe conditions. Closely related is the individual's attitude toward safety. Attitudes are molded by safety training and education, the individual's respect for the hazard potential present, and the prevailing atmosphere which, more often than not, is established by the principal investigator and senior staff. Personal characteristics and behavioral factors are also important.[1]

An individual's laboratory function or job responsibility bears heavily on the relative risk to which he is exposed. The majority of reported laboratory-acquired infections have occurred among those persons who frequently handled pure cultures.[2,3] These included the professional and technical research workers. There were fewer infections among janitors, glassware washers, animal caretakers, and other support personnel who did not directly handle cultures.

Control Practices and Containment Systems. The types of facility systems provided to contain research materials and the control practices implemented for their handling are important determinants of hazard potential. Physical containment and control practices reduce hazard potential. Credible exceptions may be encountered when such measures greatly exceed what is prudent. Then the measures may actually promote accidents due to unwarrantable cumbersomeness of equipment and manipulation and unfavorable personnel attitudes (e.g., annoyance, frustration, contempt, and lack of respect for potential hazards). Optimal selection of containment systems and control practices, then, closely matches the level of containment and control with the assessed degree of hazard.

Glove box enclosures, ventilated safety cabinets, ventilated hoods, and local exhaust systems are primary barriers used to confine and remove contamination that is released during manipulations of research materials. The primary barrier provides protection to the individual manipulating the hazardous material, as well as to his co-workers in the laboratory, to personnel in other areas of the building, and to the environment. The glove box enclosure (specifically, the "gastight" Class III safety cabinet) provides "absolute" containment and isolation of the research materials. This device provides protection from both vapor and aerosol exposure and from splatter and contact contamination. Other devices, such as the laminar flow biological safety cabinet (Class II), the conventional open-face negative pressure safety cabinet (Class I), or the fume hood, provide partial containment of aerosols or vapors. Since with these cabinets the operator's hands and arms are in the work environment, no protection is given by the cabinet against contact contamination. Descriptions, applications, and limitations of safety cabinets are enumerated in a publication of the National Cancer Institute[4,5,6] and qualitative evaluations of their containment performance are being made.

Architectural and engineering features of the laboratory can form a secondary barrier to protect personnel in other areas of the building and the environment from exposure to research materials released due to absence or failure of primary barriers or due to laboratory accidents occurring outside the primary barrier. The secondary barrier is not intended to reduce the risk of exposure for personnel inside the laboratory.

Control practices are probably as influential in determining hazard potential as the presence or absence of primary and secondary barriers. The procedures for decontaminating equipment and wastes before servicing, recycling, or disposing directly affect the extent to which others are exposed to the research materials. The use of appropriate safety equipment (e.g., sealable safety vessels for blenders, sealable centrifuge tubes, mechanical pipetting aids, etc.) can complement the protection afforded by the barrier systems; misuse or nonuse of such equipment can completely negate the protection of the barrier system. Likewise, personnel and operational practices can either complement or negate other safety provisions.

Research Operations. The technical work that is performed in pursuit of the research objectives interrelates with the aforementioned factors in the overall analysis of biohazards in the research laboratory. Characteristics of the actual operations will now be discussed in detail. *In vitro* research operations will be emphasized.

In vivo. Personnel engaged in work with research animals are subjected to numerous hazards. Animals and ectoparasites are frequent sources of laboratory-acquired infections;[7] it has been estimated that research animals may be involved in 30 to 40 per cent of all such cases.[8] There are three categories of

hazards confronting persons working with research animals.[9] The first category is physical injuries, such as animal bites, scratches, and kicks. These hazards are often compounded by the cuts, abrasions, burns, etc., which are common when people work on wet, slippery floors and handle heavy equipment, cages, and supplies. The second category of hazard is the infectious diseases that may be transmitted from the animals to man. The transmission of disease is often, but not always, associated with bites and scratches or some other personal injury (e.g., a cut). The third category of hazard is the allergic response of some personnel to animal antigens.

Biohazards in *in vivo* research is a topic warranting a full discussion extending beyond the scope of this presentation. Therefore, I will limit my remarks to a few questions, the answers to which should provide the essential information for initial assessment of hazards. These questions center around the organism or agent being studied and the specie of the animal host.

What pathogens, not specifically involved in the research, might be present (either latent or frankly expressed) in the animal? Lymphocytic choriomeningitis and encephalomyocarditis in mice and rats, and tuberculosis, hepatitis, Marburg viral disease, Lassa viral disease, *Herpes simiae* (B virus), measles, salmonellosis, and shigellosis in nonhuman primates are well known examples. (General references 10-14 should be consulted for extensive lists.) For each specie and for the respective agent considered, what is the hazard potential from exposure to animal exhalations, saliva, nasal secretions, coat shedding, urine, and feces? If there are hazards, are effective containment techniques implemented? Are the diseases of the host vector-born? Here the hazards to personnel and to the environment may be greatly minimized by selection and implementation of appropriate vector control practices.

Another aspect of hazard assessment deals with the accident potential in handling and maintaining the animals. The size and temperament of the animal greatly influence this potential. Closely related are the cage design, the feeding and cage cleaning procedures, and the ease in which the cage and the procedures can be contained. The experimental and observational manipulations and their frequency must also be considered.

In vitro. Cultures of organisms grown in the laboratory can be separated into two main categories. The first category is cultures grown on inanimate nutrient media (e.g., bacteria and fungi). The second category is cell cultures in which are grown obligate intracellular parasites (i.e., organisms that can replicate only when inside living host cells; these include viruses and rickettsiae). The two categories of cultures are distinct, yet both are susceptible to contamination which can be potentially hazardous.

Bacterial cultures may not always be "pure cultures" of a single species, but may be mixed cultures of two or more species. Due to different growth rates—rates that are dependent on the species, on the nutrients in the media, and culture conditions—one bacterial specie may be dominant and the other(s) may be totally inapparent under the culturing conditions. The inapparent or dormant contaminants may be become actively growing under a change in nutrients in the media, a change in the culturing conditions, or upon introduction into a susceptible host. While only bona fide "pure cultures" maintained on certified contaminant-free media pose no unsuspected hazards, bacterial cultures are not commonly contaminated with dormant pathogens. The possibility exists but the probability is slight.

Cell cultures also can be contaminated with inapparent or latent agents. Unsuspected and undetected viral genomes can reside latent within cells, and can persist through successive generations of the cell population. Mature infectious virions can be induced from cells harboring the latent viral genomes by various environmental stress factors (e.g., treatment with chemicals or hormones, co-cultivation with other cell lines, etc.) Cell cultures harboring latent viral genomes have been shown to be causes of some fatal laboratory-acquired infections.[15,16,17]

Thus, clinical tissue specimens (of animals and humans) and laboratory cultures can be contaminated with extraneous organisms that can pose hazards. These hazards can be evaluated by ascertaining the history of the specimen or culture.

Laboratory Operations. The laboratory operations can be analyzed by assessing the likelihood that personnel in the laboratory will be exposed to an infectious dose of an organism. Among the primary considerations is the quantity of the research material being handled. There are two aspects of the quantity that have a direct bearing on the potential for exposing personnel to an infectious dose: (1) concentration of the organism in the culture and (2) the volume of the culture. The product of concentration times volume gives the number of organisms present. This value, combined with information on the size of the infectious dose, leads to an estimation of how many doses are being handled. The hazards will be relatively low if only a few doses (e.g., 10 or 100) are being handled. Here it would be unlikely that a person would be exposed to an infectious dose if a small portion were released into the work environment. On the other hand, the hazard would be higher if many doses (10^{10} to 10^{12}) are being handled. The release of even a small amount of material may result in exposure of personnel to an infectious dose.

Upon closer inspection, it becomes clear that the working concentration will often have greater influence on the number of doses handled than the volume. Concentrations in research materials may range from 10^2 to 10^{12} organisms per milliliter (10 orders of magnitude), whereas volumes handled may range from a few milliliters to a few liters (3 orders of magnitude). However, volume can have a secondary influence on exposure potential. The size of the vessel can influence accident potential. Small flasks of tissue culture fluid are easier to manipulate than large, heavy carboys.

Another important factor of the exposure potentials of operations is the physical state of the *in vitro* cultures. Cultures in semi-solid media have the least potential for accidental release. Organisms overlaid with, or embedded in, agar are not easily disseminated unless the culture vessel is broken. Organisms growing on the exposed surface of an agar plate can be disseminated, but not as easily as organisms grown in a liquid media. The handling of liquids is frequently accompanied by the generation of aerosols. Bacteria grown in broth cultures and viruses harvested in cell culture fluids are easily dispersed through aerosols when these liquids are manipulated. The light, dry powders of lyophilized agents are perhaps the most difficult to control. These powders are aerosolized very easily.

In the analysis of hazards, one ultimately must review the actual procedures. In the vast realm of biomedical research, the types of procedures are innumerable. Furthermore, the procedures are destined to change with every advance in the state of the art. Rather than cataloging these procedures, I suggest reviewing each procedure by asking three general questions. First, what scientific disciplines are involved? Second, is the procedure repititious or nonrepetitious? Third, what is the potential for self-inoculation or contamination of the environment?

In today's laboratories, it is quite common to encounter research teams composed of several scientific disciplines. Virologists, biochemists, molecular biologists, and immunologists may all work on a research project. The scientific discipline will often, but not always, suggest whether or not intact organisms are being used. Cell biologists and

virologists frequently handle intact cells or virus. Immunologists sometimes handle intact agents (or cells), but other times will work with nonviable components of the agent (or cell). Biochemists and molecular biologists frequently do not handle intact agents (or cells). Their work usually involves disrupting intact agents (or cells) and working with the biochemicals found within them. Therefore, an initial step is to determine whether the research materials handled within a laboratory are intact or are biochemical components. In this regard, it must be remembered that some viral nucleic acids are infectious and that some nonviable biochemicals can still constitute a biohazard (e.g., proteins that can be allergenic).

The issue of scientific disciplines also has a subtle aspect that relates to the personnel factors mentioned earlier. Bacteriologists and virologists usually have classical microbiology training. These persons are likely to design experiments and conduct laboratory activities in manners that reflect understanding and appreciation for the potential of organisms to become dispersed and to infect nearby cultures or susceptible hosts (namely, laboratory workers). Contrarily, immunologists, biochemists, and molecular biologists usually do not have the same training in classical microbiology. During their training and throughout much of their careers, they use nonpathogenic organisms. The designs of their experiments and the conduct of their activities often will not reflect understanding or appreciation for contamination and biohazard potential. When persons of these disciplines handle intact pathogenic or potentially harmful organisms, a special measure of review is warranted. This generalization regarding scientific disciplines, like all other generalizations, has its pitfalls and it should be used with a generous amount of caution.

The repetitiousness of a procedure can influence hazard potential in several ways. If a procedure is repetitious, and particularly if it is a procedure commonly employed in many laboratories, it may have been reviewed for its hazard potential. Safety techniques may have been devised and adopted. People will usually adopt safety techniques for tasks they frequently do, but may not bother with safety for infrequent tasks. Closely related to this matter is the provision of physical containment. Repetitious procedures can be anticipated and appropriate physical containment can be devised and provided. If infrequent tasks can be confined within standard containment systems, then no problems arise. However, if the infrequent task does not lend itself to standard containment, then problems will arise. Infrequent tasks often are not anticipated sufficiently in advance to permit fabrication of custom containment systems. Even if there is sufficient time, the custom system may be ruled out for economic reasons.

Laboratory technicians can develop dexterity and competence in performing repetitious tasks. Experience and confidence reduce accident potential. Contrarily, infrequent tasks may be approached with doubt and awkwardness, which can contribute to a higher accident potential. These generalizations must be tempered with the knowledge that competence in performing repetitious or infrequent tasks depends greatly on the individual technician and the intellectual challenge of the task. Some technicians are quite comfortable with repetitious work; others are comfortable with the challenge of infrequent tasks.

Procedures involving hazardous materials must be reviewed for their potential for inoculation of the worker or contamination of the intramural environment. In a study of 3921 laboratory-associated infections, Pike reports that only 703 infections (18 per cent) resulted from recognized accidents.[7] However, data from this report show that in 827 infections (21 per cent) it was only known that the victim worked with the agent and in 767 infections (20 per cent) the cause was unknown or not indicated. These

latter two categories represent 41 per cent of all cases.

Of the 703 recognized accidents, contact with infectious material resulting from spills, sprays, etc., was the identified cause for 188 (27 per cent) of these infections. This exposure comprises inhalation of respirable aerosol particles, as well as contact contamination from splatter droplets and settling aerosol particles. This contact contamination can subsequently be transferred to the skin and absorbed through cuts or abrasions or can be transferred to the mouth. Stern, et al., in describing aerosol production associated with clinical laboratory procedures, suggests that the surface contamination resulting from aerosol splatter and settling particles can be a more important source of laboratory contamination than the aerosol *per se*.[18] In addition to the 188 aerosol-related infections listed, aerosols were the identified source of 522 other infections. This means that 710 (18 per cent) of all the reported infections resulted from aerosols. It is generally assumed that the vast number of unexplained infections (e.g., the 41 per cent in Pike's study) can be largely attributed to undetected accidents which resulted in aerosols.

According to Pike's data, the second-ranked source of laboratory infections is accidents involving needles and syringes. The third-ranked source is injury with broken glass or other sharp objects. The fourth-ranked source is aspiration through pipettes. Accepted safety precautions have ben prescribed for all these types of accidents. Open cultures should be handled within primary barrier systems so that the aerosols generated during most manipulations will be controlled and removed. Needles and syringes should be used only when there are no alternatives for accomplishing the tasks at hand. Sharp objects should be handled with care and disposed of properly. Mouth pipetting should be discontinued, particularly in light of all the mechanical pipetting aids available to the laboratory worker. When these safety precautions are adapted to the specific procedures at hand, hazards will be lessened. If these precautions are not adopted, the hazard potential, quite obviously, remains.

Summary

I have attempted to convey the idea that the analysis of biohazards in research operations is not an exact science. True, there are data (however meager) which provide insight on the occurrence of laboratory-acquired infections and their probable sources. Aerosols undoubtedly are a major source of these infections. Indeed, considerable research has been done to estimate aerosol source-strengths of common laboratory procedures and to evaluate containment capabilities of primary barrier systems. Other frequent sources of infection have been identified, and accepted safety procedures have been prescribed. But the analysis is largely subjective, and the analyst must judge the relative contributions made by each of the major determinants—the microbiological agent, the laboratory personnel, the control procedures and containment systems, and the research operations.

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R & D ACCIDENT CASE HISTORIES

By L. E. OLDENDORF
Safety and Fire Protection Engineer,
U.S. Energy Research & Development Administration,
Argonne, IL

The Research & Development (R & D) Section has reported on over 370 accidents which have occurred in research activities since Maury Golden, former editor, introduced the Accident Information feature in its January 1970 *Safety Newsletter.* Most of these accident reports were submitted by R & D Section members. The slogan under the heading of this feature, "Those who cannot remember the past are condemned to repeat it," was typical of Maury's concern to share safety lessons with others.

My objective here is to review the R & D accident experience since 1970, to summarize several of the more significant accidents, and to discuss trends and the most prevalent causes of research accidents; but before I get into these areas, I would like to share one of the more humorous accident cases reported in the first Accident Information feature. It was titled "Keystone Cops Revisited."

A wrist-action shaker was left running over a weekend to agitate a one-liter flask containing a polymer in acetone. Some time during the weekend, the shaker "walked" and broke the flask, dumping the contents on the floor. The shaker stopped and overheated the motor.

When the chemist arrived on Monday, he started cleaning the polymer off the floor by using a rag soaked in acetone. However, he neglected to disconnect the shaker. While he was washing up the spill, the motor started spontaneously, sparked, and ignited the acetone. The hair on his arms and legs was singed. At this point, he decided to disconnect the unit by grasping the cord to pull it out of the outlet. When he did this, he received an electric shock from exposed wires near the molded plug. Fortunately, he was not well grounded and the shock was minor. It could easily have been fatal.

Steps to prevent recurrences included: (1) anchor all shaking devices; (2) replace all electrical cords which have cracked or checked insulation; (3) electrically disconnect any device before working on it. In this case, turning the switch off before starting the cleanup would have been the smart thing to do.

This incident appeared humorous at first, but as I compared it with other incidents, there was an obvious difference behind the scene. Other incidents had only one or two deficiencies; this one had many. In addition to the three deficiencies noted above, five other deficiencies existed: (1) training was inadequate; (2) there were no restrictions on conducting experiments alone or unattended; (3) no procedures existed for experiments or for cleaning spills; (4) acetone was indiscriminately used as a cleaning agent without regard to ventilation and ignition sources; (5) inadequate safety inspections were made of the area.

The chemist in this incident learned his lesson the hard way, but those who hired and supervised him apparently failed to recognize that they contributed to the incident by their lack of interest in providing necessary safety training and procedures. In fact, the accident report missed five deficiencies in its findings.

It was interesting to note that the first accident cases reported in the *Newsletter* included two explosions, two fires, and two chemical burns. This was somewhat of a prediction of the types of accidents that were to occur frequently in the following seven years; e.g., 22 per cent have been explosions, 10 per cent have been fires, 22 per cent resulted in chemical or thermal burns, and seven per cent resulted in eye injuries. Chemicals were

involved in over 50 per cent of the accidents, with chemical reactions being the major cause of explosions, fires, and toxic gas releases. Again, I would like to emphasize that training and procedures were inadequate in almost all of the accidents reported.

There are three basic safety requirements that should be included in every training program covering chemicals: (1) don't mix chemicals unless you know what will result; (2) utilize proper ventilation, shielding, and personal protective equipment if the possibility of a reaction exists, or use a safe chemical substitute; (3) dispose of excess, outdated, or contaminated chemicals before they become a problem. If these three requirements were followed, I estimate that over 50 per cent of the accidents reported would not have occurred or would have only resulted in minor property damage.

One of the most fatal and unusual accidents reported took the lives of seven persons as a result of poisoning by nitrous fumes. The intensely hot weather in a printing shop caused a bottle of nitric acid to explode, and the acid coming into contact with paper gave off heavy fumes. Firemen, who were called in quickly controlled the trouble and returned to their station. Several hours later they began to feel the effects of the nitrous fumes. The first fireman died early the next morning, followed by the shop foreman, and five other firemen. This incident demonstrates the need for self-contained breathing apparatus in emergencies and for properly storing chemicals.

A more common accident case history involved an ethyl ether explosion.

"An experiment in which ethyl ether had been used as an extraction agent over an extended period of time was concluded. The ether remaining in a desiccator reinforced with adhesive tape was being evaporated over a water bath in a closed hood. An explosion having sufficient force to shatter the desiccator occurred. The bottom, a circular piece approximately six inches in diameter, was propelled downward into the water bath as a fragmented pile of glass. A piece from the upper edge of the desiccator struck the hood closure, breaking the desiccator through the middle. The remainder of the desiccator was held together by strips of adhesive tape.

"Ether is widely used in the laboratory. It has a low boiling point and is an excellent solvent. However, another property of ether that is not as well known is that when ether is exposed to air and heat, unstable peroxides are formed. The reaction time is slow and unpredictable. The peroxide is not as volatile as the ether and tends to build up in the liquid ether. Eventually, it becomes visible as a solid or a liquid. If the ether is evaporated to dryness, the peroxide can explode spontaneously, and if heated, it will decompose with explosive violence.

"Anhydrous ether is more prone to the peroxide formation, and the addition of one per cent water retards but does not prevent its formation. The addition of such oxidation inhibitors as diphenylamine, hydroquinone, bright copper, or bright iron wire is advisable. Peroxide-free ether should be used for extraction work. The presence of peroxides can be determined by several simple tests.

"Ether should not be stored in glass bottles, but rather kept unopened in the original metal container, away from heat and sunlight, until ready for use. It is hazardous to handle or to attempt to open cans or bottles of ether of unknown vintage.

"Isopropyl ether, dioxane, and tetrahydrofuran also oxidize to form unstable peroxides."

A data sheet (No. 655) "Recognition and Handling of Peroxidizable Compounds" prepared by the R & D Section provides an excellent reference for recognition and safe handling of peroxides.

Another type of explosion was reported in the November 1975 *Newsletter* which illustrates the importance of a hazard evaluation when dealing with even small quantities of flammable liquids in a confined area.

"Four individuals received facial and arm burns in a flash fire which occurred when the split cover was opened on a 300-gallon conical-bottomed sluice tank. All four men received face burns and singed hair, but no eye damage resulted, undoubtedly because they were wearing the required safety glasses. Only one day of lost time resulted.

"The sluice tank is used as a receiver for spent catalyst and had previously been cleaned and left empty. Another filtration was started. The procedure called for venting from the top of the filter through a valve and clear tubing, the end of which entered the top cover of the sluice tank. Using this procedure, some flammable liquid would be vented into the sluice tank.

"During the operation, a wisp of smoke was noticed coming from under the sluice tank cover. The two operators stopped the operation and requested help. When the smoking had stopped, the cover was lifted to see what was wrong and at that time the flash fire occurred.

"The empty tank apparently had some residual Palladium catalyst that dried and ignited the vapor-air mixture in the tank. The vapor-air mixture was the result of the venting of approximately 100cc of flammable liquid into the empty sluice tank, and the resulting air-vapor mixture probably was above the upper explosive limit. When the cover was opened, additional air entered the tank, bringing the mixture into the explosive range. For the solvent involved, the range is approximately two per cent to five per cent.

"Preventive Measures.

"1. Always keep a catalyst wet or under an inert atmosphere. In this case, the sluice tank will be kept full of water.

"2. Eliminate vapor-air mixtures. The piping and procedure for venting the filter has been changed. The operator now has an approximate 1 in. x 4 in. sight glass to check on his liquid level, with any accidental excess collected in an inerted tank which is back flushed through the filter into the now filled sluice tank when the filtration is complete. As a reminder, here is an often unappreciated fact on the general handling of even small quantities of flammable liquids: A gallon of gasoline, or any other non-water-soluble solvent with a flashpoint below the temperature of the effluent, can fill a mile of eight-inch pipe with an explosive mixture.

"3. As an additional personnel precaution, the wearing of face shields is required at all times in the handling of catalysts or systems containing catalyst."

As reported in this accident, the air-vapor mixture was probably above the upper explosive limit, but the addition of fresh air brought the mixture down into the upper explosive range. The more frequent explosion involves a spill of flammable liquid or leak of flammable gas in a laboratory with the air-vapor mixture reaching the lower explosive range. Therefore, adequate ventilation must be designed into a laboratory to prevent flammable-air mixtures reaching their lower explosive limit and ignition sources must be eliminated. Standard fume hoods and exhaust systems may be designed to vent flammable gases and vapors as well as to protect personnel from the health hazard of their experiments. Since most serious explosions occur outside the fume hood, the use of nonbreakable or standard safety containers sized in accordance with OSHA and NFPA standards is the first step in minimizing an accidental release of vapor in the daily handling of flammable liquids. Only approved piping or tubing should be used for connecting equipment and experiments to gas supply systems and cylinders. To illustrate the explosion hazard of one gallon of a Class 1A flammable liquid spilled on a laboratory floor, consider acetone which has an explosive range of 2.6-12.8 per cent by volume. A stoichiometric mixture containing 97.4 per cent of air and 2.6 per cent acetone, or 37 volumes (97.4/2.6) of air to one

volume of vapor, produced from one gallon of acetone can be calculated from the specific gravity of the liquid and the vapor density, e.g., 111 x .792 = 44 cu. ft. The product of 44 cu. ft. of vapor and 37 parts of air gives 1,628 cu. ft., which is the minimum volume of the confined area at which the lower explosive limit would be reached, approximately a 10 ft. by 16 ft. room. The explosion pressure may be anywhere from one-half to 3 psi, depending on conditions and venting features. This pressure range is sufficient to cause window and even wall and roof failure in masonry buildings. If there is a possibility of an explosion in a laboratory, its design should include appropriate venting for the risk, e.g., one square foot of explosion vent area for each 60 to 80 cubic feet of space.

Once the evaluation has identified a potential danger that can't be tolerated, a decision should be made to find a satisfactory substitute for the material(s) which reduces the hazard, e.g., higher flashpoint solvent, or to isolate the material(s) from the rest of the facility by use of an approved storage vault, storage container, or a separate building.

There are still too many incidents involving researchers failing to read labels or failing to label hazardous materials; e.g., here are two incidents reported in the April 1971 *Newsletter:*

1. "A research center employee sustained first-degree burns on parts of his face, neck, chest, and arms when he was splashed by a mixture of concentrated sulfuric acid and ammonium hydroxide. His safety glasses prevented injury to his eyes; quick washing minimized the severity of the burns.

The worker had set out to fill a reagent bottle with concentrated sulfuric acid from a larger supply bottle. He picked up a reagent bottle which was located on the shelf where the sulfuric acid bottle was usually kept. Actually, he picked up a properly-labelled concentrated ammonium hydroxide bottle. When he added the sulfuric acid, a violent reaction occurred and liquid erupted from the bottle.

"Cause: Failure to read the label on the bottle.

"Preventive Measures: Always read the label on a chemical container; never guess at its identity by its location."

2. "A chemist used some solvent from a can marked hexane to rinse a syringe that had contained a dilute aluminum alkyl solution. A rapid reaction occurred and the syringe plunger was propelled to the top of the hood. Fortunately, the chemist held the syringe away from his body and he was not hurt. It was determined that the solvent can labelled hexane had erroneously been filled with methanol."

There are many accident cases that are similar to one another, which indicates (1) a failure of communication between the readers of the accident information and those condemned to repeat the accidents; or (2) a failure to establish procedures for hazard evaluations and operations with adequate safety training.

Most accident reports result in minimal findings and corrective action. This may be an indicator that accidents are not treated seriously by management. I believe that detailed accident investigations and reports are necessary to get management interested in supporting accident prevention programs. It may require more than the usual effort at first, but once the facts are presented in a technical manner, the communication will be reviewed, discussed, and necessary action will be supported by management. Once we have implemented corrective measures supported by management, our accident prevention programs should reduce the number of repeated accidents in research.

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March 21, 2001

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