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Prudent Practices for Handling Hazardous Chemicals in Laboratories

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A National Research Council (NRC) committee chaired by Herbert O. House recently issued a report with the above title (*1, 2*). The committee was formed in response to chemists' concerns about long-term toxicities of many chemicals used in research laboratories. The goal of the committee was to develop authoritative guidelines for the handling and disposal of chemicals in laboratories. It was thought that the guidelines would be useful to laboratory supervisors and would help agencies to develop appropriate policies for health hazards in laboratories as distinct from pilot plant and manufacturing operations.

Summary. A National Research Council report has recommended practices for safe handling and disposal of hazardous chemicals in laboratories. They are a practical alternative to detailed regulations on individual chemicals.

Philip Handler, president of the National Academy of Sciences, in a letter transmitting the report to Eula Bingham of the Occupational Safety and Health Administration (OSHA) and other federal officials, said of it:

> The report provides safety guidelines for handling chemicals in laboratories—particularly in research laboratories whether they be in academia, government, or industry—where numerous chemicals are stored in small quantities, many of them used only infrequently; where a given chemical is rarely handled for an extended period; and where perhaps the greatest risks arise from working with substances of less-than-well-known toxicity and from acute accidents. A balanced approach is presented to the full range of hazards associated with chemicals in a laboratory setting—risks from fire, explosion, acute toxicity, and chronic toxicity including carcinogenicity. While no set of procedures is likely to make a research laboratory entirely risk-free, the report's thesis is that, with adequate physical facilities, including properly operating ventilation; handling all new substances as though they were toxic until actual toxicological data are available; using appropriate protective clothing and gloves when necessary; and an institutional commitment to a vigorous safety program, the laboratory can be a safe workplace. Experience, especially in industry, has shown this.

This article is mostly drawn from the NRC report and states its main conclusions and recommendations.

The hazards of chemicals in laboratories are quite different from those in pilot plants or manufacturing plants. In the laboratory one generally works with milligrams or grams of material, in plants with pounds or tons. In laboratories one tends to work with a wide variety of chemicals, many new or little studied; in plants one tends to work with a relatively small number of chemicals for weeks, months, or years, and their properties are better known than those of most laboratory chemicals. Regulations that require extensive monitoring of exposure levels, medical surveillance, voluminous record-keeping, and specific work practices for individual chemicals may make good sense in a large-scale plant operation that involves the same people for years. To apply the same regulations to a laboratory that uses regulated chemicals only intermittently and on a small scale, as well as many chemicals of unknown but sometimes highly hazardous properties, will restrict research without much increase in safety. A more effective way to achieve a high level of safety in the laboratory is to develop and follow good general guidelines for handling all chemicals. Such guidelines should apply to all chemical research laboratories, for they are similar in character whether in universities, government, or industry. They should apply equally well to research laboratories in other sciences, such as biology and physics, where chemicals may be used more sparingly, but where the awareness of chemical hazards tends to be lower. They should likewise apply to analytical and teaching laboratories that use chemicals. Such are the guidelines described in the NRC report.

Laboratories contain a great variety of hazards, and indeed, much of the training of a scientist is learning how to carry out laboratory operations safely. The hazards can be grouped as physical or chemical.

Physical Hazards

The physical hazards—fire, explosion, electric shock, cuts—have been overshadowed in recent years by the toxic hazards of chemicals. However, safety can be improved with respect to these more familiar hazards, which still claim too many victims. Electrical heating has largely banished the Bunsen burner and its kin from the laboratory, thus lessening the chance of fire and explosion. However, more can be done to remove sources of fire and sparks. For example, the quantity of flammable liquids stored in the laboratory should be limited, and motors should be of the nonsparking induction type.

With regard to explosions, there is general awareness that certain classes of compounds, such as acetylides, azides, ozonides, and peroxides, are explosive.

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Yet there is insufficient awareness that ethers and alkenes can form explosive peroxides on long exposure to air.

The extensive introduction of electrical heating and instrumentation into the laboratory, while decreasing fire hazard and increasing productivity, has increased the potential for shock. Three-prong grounded equipment is much safer than the old-style two-prong type, and two-prong receptacles should be replaced. With ground-glass joints becoming common, the incidence of cuts from unskillful shoving of glass tubing into stoppers is declining. Cuts from glassware are still common, however, and many are preventable by greater care and the use of leather gloves.

Chemical Hazards

By chemical hazards we mean the toxic effects associated with chemicals. All substances, natural or synthetic, have toxic effects at some dose level by some kind of exposure. It is well known that ingesting a small amount of potassium cyanide (about 200 milligrams) can kill a human; it is less well known that 250 grams of table salt is also lethal. Because all chemicals are potentially harmful and few have been thoroughly studied toxicologically, a good strategy for controlling chemical hazards is to minimize exposure to all chemicals. In practice this means having a good, properly installed hood; checking its performance periodically; using it properly; carrying out most operations in the hood; protecting the eyes; and, since many chemicals can penetrate the skin, avoiding skin contact by good techniques and appropriate use of gloves and other protective clothing. If these simple rules are followed conscientiously, one is unlikely to get into serious trouble with laboratory chemicals.

Toxic effects are classified as acute or chronic. Acute effects are observed soon after exposure and include burns, inflammation, allergic responses, damage to the eyes, lungs, or nervous system (for example, dizziness), and, as in the above example of potassium cyanide, death. The effect and its cause are usually obvious, and so are the methods to prevent it. In the past, acute effects received more attention than chronic effects. Although the latter now have the spotlight, acute effects must not be neglected. Not only are they important in themselves, but an institution's incidence of acute effects is a good indicator of its general level of safety.

Most acute effects arise from inhalation or skin contact, so they should not be a problem if one follows the admonition to "work in a hood and keep chemicals off your hands." Ingestion of a chemical rarely occurs; it is usually the result of some poor practice, such as eating in the laboratory or not washing hands before eating.

Chronic Hazards

Chronic hazards cause effects that result from long exposure or effects that appear after a long latency period. The effects may involve cumulative damage to any of numerous organs. Some chronic effects are reversible if exposure to the chemical is stopped, but others are irreversible, especially after extensive damage has occurred.

Of the chronic effects of chemicals, cancer has received the most attention lately. Only about two dozen chemicals have been definitely established as human carcinogens. However, hundreds have been found to be carcinogenic to laboratory animals at some dose level, and many that have not been tested are probably carcinogenic to some degree. Because different species can be affected quite differently by particular chemicals, there is no direct correlation between carcinogenicity in animals and carcinogenicity in man. Nevertheless, it appears that a significant number of chemicals used in laboratories have some degree of potential for carcinogenicity in man.

The question arises whether laboratory exposure to potential human carcinogens puts chemists at greater risk of cancer than members of other professions or the general public. Several epidemiologic studies of relative mortality among chemists indicate that chemists have a higher than expected risk of death from cancer. However, a recent study comparing 3,686 male Du Pont chemists with 19,262 male Du Pont nonchemists in the same salary categories found a somewhat lower cancer mortality among the chemists (*3*). The evidence from epidemiology is thus equivocal, and the NRC report recommends further research. However, whether or not chemists are at a greater risk of cancer than others, the undeniable hazard of handling a variety of chemicals is sufficient reason for laboratories to employ good practices.

Accordingly, the NRC report recommends laboratory practices that should enable one to work safely with most substances, whatever their chemical, physical, or toxicological properties, whether known or unknown. The report summarizes these practices as "Procedure B." It also recommends a more stringent "Procedure A" for substances of known high chronic toxicity if amounts in excess of a few milligrams to a few grams are to be used. Examples are the heavy-metal compounds dimethylmercury and nickel carbonyl and the potent carcinogens benzo[*a*]pyrene and hexamethylphosphoramide. OSHA has published detailed procedures that must be followed when working with 2-naphthylamine, acrylonitrile, vinyl chloride, and 15 other chemicals that the agency has classified as carcinogens. The NRC report outlines these procedures, which are more stringent than Procedure A.

Laboratory Ventilation

The key to safe handling of chemicals in the laboratory is a good, properly installed hood, and the NRC report devotes many pages to hoods and the subject of ventilation. It recommends that in a laboratory where workers spend most of their time working with chemicals, there should be a hood for each two workers, and each worker should have at least 2.5 linear feet of working space at the hood face. Hoods are more than just devices to prevent undesirable vapors from entering the general laboratory atmosphere. When closed, they place protective barriers between workers and chemical operations. Moreover, a hood is an effective containment device for spills. A hood should not be used to store more than small amounts of chemicals and other materials, for large amounts block the flow of air and lower hood efficiency. Chemicals should be stored in ventilated cabinets instead.

Air velocity at the face of a hood should be about 60 to 100 feet per minute; surprisingly, velocities greater than this may degrade hood performance by creating turbulence within the hood that can cause vapors to spill out into the laboratory. Equipment should be placed as far back in a hood as practical. However, vapor concentration falls off so rapidly as a chemical is moved back from the face of a hood that merely taking care to carry out operations at least 10 centimeters behind the front edge of the hood is an effective aid to safety. Hoods should have a gauge so the user can tell at a glance if the hood is operating properly. Periodic inspections should be made to check on such things as the air velocity at several points along the face of the hood, whether the hood is overcrowded, and the airtightness of the ducts and exhaust system.

Hoods are just one aspect of the total

ventilation system of a building with laboratories in it. The laboratories will probably contain glove boxes, ventilated storage areas, and other air outlets. Air of proper temperature, humidity, and purity for the occupants will be coming into each laboratory, as will air for the hoods and other special facilities. Changes that affect one part of this complex system affect all. With sharply rising energy costs, there is a temptation to lower the cost of heating, cooling, and humidifying air by cutting down the airflow to laboratory buildings. Such changes should be carefully examined before being executed, as they may lower the airflow through hoods so much that the hoods no longer provide adequate protection. By imparting a false sense of security to the laboratory worker, an inadequate hood can be worse than none at all.

Protective Equipment

Specialized equipment can minimize exposure to the hazards of laboratory operations. Impact-resistant safety glasses are basic equipment and should be worn at all times, for unlikely accidents are often the most hazardous ones. Safety glasses may be supplemented by face shields or goggles for particular operations, such as pouring corrosive liquids. Because skin contact with chemicals can lead to skin irritation or sensitization or, through skin absorption, to effects on internal organs, protective gloves are often needed. There is no glove material that serves all purposes; natural rubber, butyl rubber, neoprene, and polyvinyl chloride are four of the most commonly used materials, and each has its own spectrum of chemicals for which it is an effective barrier. Aprons, lab coats, and jump suits are among the kinds of apparel that may sometimes be useful or even necessary.

Laboratories should have fire extinguishers, safety showers, and water fountains to flush chemically contaminated eyes. Respirators should be available for emergencies. These and other kinds of emergency equipment, such as first-aid materials and blankets for covering injured persons, are generally best kept in a central location. Emergency equipment must be inspected periodically.

Procurement and Storage of Chemicals

Safe handling of hazardous chemicals begins with the person who needs and orders them. Before ordering them he must be sure that they can be stored, handled, and disposed of safely.

The chemicals will generally arrive at a receiving room, from which they will be sent to storerooms. The receiving and storeroom personnel must be trained in handling containers of hazardous chemicals and dealing with chemicals in case of spills.

Too often in the design of laboratory buildings, insufficient storage space is provided. This may result in overcrowding and in storing incompatible chemicals together. The storage rooms should be cool and well ventilated. Bulk quantities of flammable liquids should be kept and dispensed in a separate room, preferably in a fire-resistant building away from the main building. Cylinders of compressed gases should also be in a separate area and should be grouped by type (for example, flammable, highly toxic, corrosive). Highly toxic substances should be segregated in a cool, dry area away from direct sunlight. Stockkeeping should be on a first-in, first-out system. Stored chemicals should be inspected at least annually, and any that have deteriorated, lost their identification, or begun to leak should be discarded.

In the laboratory, storage of large amounts of highly toxic, reactive, or flammable chemicals is to be avoided. Hazardous materials are best stored in ventilated cabinets connected to a hood. Bottled chemicals, especially liquids, should be in trays that will contain the material if bottles break. Flammable liquids should not be stored in refrigerators that are not of an approved, explosion-proof type.

Chemicals in the laboratory should be inventoried periodically, and in the interest of safety, unneeded items should go back to the storeroom or be discarded.

Disposal of Chemicals

The Resources Conservation and Recovery Act (RCRA) and local laws increasingly regulate the disposal of chemical wastes, and familiarity with these laws is the first step in developing a disposal plan.

Used or unwanted chemicals must be disposed of in ways that do not harm people and have minimal impact on the environment. Many chemical wastes can be handled satisfactorily by sewage treatment systems. Such wastes can be safely flushed down the sink to the sewer system, but the limitations of this method must be recognized. Only water-soluble substances should be disposed of in this manner. Flammable materials and strong acids and bases should be well diluted. Volatile chemicals that are highly toxic or bad-smelling should not be put down the drain, as they may emerge from an interconnected drain and affect people elsewhere in the building. Local regulations often set further limits on this method.

Other liquid wastes must be collected in labeled bottles or cans to be disposed of on the site or by a contractor. Usually the liquids should be segregated into several classes, such as hydrocarbons and water-soluble compounds. Segregation of halogenated compounds is desirable if they are used in large volume, for on incineration they yield hydrogen halides that may require scrubbing. Because the cost of acceptable waste disposal is rising dramatically, recovery of laboratory chemicals that were formerly discarded is becoming economically attractive. Examples are mercury and common solvents like toluene and acetone.

Solid wastes must be collected in a systematic way. Bottles of solid chemicals must be labeled and placed in metal drums or buckets.

Before disposal, the most hazardous substances, such as strong carcinogens, peroxides, and vesicants, should be chemically transformed to less hazardous materials when feasible. For example, dimethyl sulfate, a carcinogen in animal tests, is readily hydrolyzed by alkali to methanol and sulfate.

The final disposal of wastes is one of the most difficult problems of a research institution. Incineration is the most environmentally acceptable way to handle most organic chemicals as well as products of biological research contaminated with chemicals, such as animal carcasses, feed, and excrement. A high-temperature incinerator will convert these materials to elemental oxides that generally present little problem. Secondary equipment such as electrostatic precipitators or an afterburner may be attached, so modern incinerators are complicated, expensive devices that require trained operators and mechanics. Nevertheless, a large institution will often find it best to have its own incinerator to ensure that wastes are properly disposed of. This also avoids the need for surveillance of contract haulers and disposers and much of the extensive labeling and record-keeping required under Department of Transportation regulations and the cradle-to-grave provisions of the RCRA.

Solid chemical wastes not suitable for incineration must be buried in a landfill approved by the Environmental Protection Agency. Finding an approved landfill at a convenient distance is often difficult. Moreover, the problem is worsening because communities do not want landfills for hazardous waste disposal nearby and will fight to keep them away. On top of that, there is a shortage of reliable contractors to haul waste away and put it in landfills. As a result there is a rising interest in incinerating all hazardous wastes that are combustible and minimizing the amount of those that are not.

Safety Program

An effective laboratory safety program must have strong support from the head of the laboratory and must be based on the participation of all members of the laboratory. The goal is that all those directing or carrying out operations with chemicals be safety-minded so that possible hazards are foreseen and guarded against before experiments start. A safety coordinator who can advise on safe practices and inspect the laboratory for compliance with its rules is essential to a good safety program. However, he cannot relieve the head of the laboratory of the responsibility for the safety of that laboratory, nor the managers or professors for the safety of the operations under their jurisdiction, nor the individual employees or students for the safety of their own operations.

Many of the best safety programs are in industry. The following features are common in such programs: monthly meetings of the head of the laboratory with the laboratory managers to review safety performance and plan improvement; monthly meetings of all members of each research group to act similarly within their area; monthly inspection of each area by some of the employees working in that area; quarterly inspections of the whole laboratory by a committee of employees; a handbook of rules and practices for handling chemicals; and easy access to books and data sheets giving the chemical, physical, and physiological properties of laboratory chemicals so that they can be known before experiments are started (*4*). The importance of commitment to safety at the top of the laboratory organization can hardly be exaggerated; a laboratory's safety record is directly related to its management's commitment. For the laboratory management to be effective, of course, they must have strong support for the safety program from the administration of the organization of which the laboratory is a part.

In principle, any laboratory, whether in industry, academia, or government, can emulate the laboratories with the best safety records. Those who manage laboratories or work in them will find good guidance for safety policies and practices in the NRC report (*1*).

Conclusion

No facilities or procedures can make chemical operations totally free of hazards. However, the laboratory can be a safe place to work if there is institutional determination to have a strong safety program; active participation in it by the whole staff; good ventilation, including an ample supply of well-designed hoods; appropriate protective clothing; storage, handling, and disposal of all chemicals in ways that recognize that every chemical can be toxic under some circumstances; and acceptance of the main principles of the NRC report. The facilities and operations in a laboratory must be monitored regularly, with particular attention to the ventilation facilities. However, for most laboratory environments, the regular analysis of air for many chemicals is unnecessary and impractical.

References and Notes

1. Committee on Hazardous Substances in the Laboratory, National Research Council Assembly of Mathematical and Physical Sciences, *Prudent Practices for Handling Hazardous Chemicals in Laboratories*, xiv + 291 pp., $12 (National Academy Press, 2101 Constitution Avenue, NW, Washington, D.C., 1981).
2. The committee included Herbert O. House, Georgia Institute of Technology, chairman; Robert A. Alberty, Massachusetts Institute of Technology; Jerome A. Berson, Yale University; Robert W. Day, University of Washington; Thomas S. Ely, Eastman Kodak Co.; Ronald W. Estabrook, University of Texas Health Science Center; Anna J. Harrison, Mount Holyoke College; Donald M. Jerina, National Institute of Arthritis, Metabolism, and Digestive Diseases; Marvin Kuschner, State University of New York Health Science Center; Elizabeth C. Miller, University of Wisconsin-Madison; Robert A. Neal, Vanderbilt University; J. E. Rall, National Institute of Arthritis, Metabolism, and Digestive Diseases; George Roush, Jr., Monsanto Co.; Alfred W. Shaw, Shell Development Co.; and Howard E. Simmons, E. I. du Pont de Nemours and Co. William Spindel, National Research Council, was the study director.
3. S. Hoar, thesis, Harvard School of Public Health, Boston (1980); *J. Occup. Med.*, submitted.
4. The NRC report includes a compilation of the chemical, physical, and physiological properties of 33 common laboratory chemicals known to constitute a hazard under some conditions. This kind of data sheet, if available for about a thousand chemicals and kept up to date, would be a big aid to safety in the laboratory.