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Prudent Practices for Disposal of Chemicals from Laboratories

Robert M. Joyce

A report issued by a National Research Council (NRC) committee (*1*, *2*) provides comprehensive and practical guidelines for laboratories on the handling and disposing of waste.

Summary. A recent report of the National Research Council contains guidelines and recommendations for handling and disposing of unneeded chemicals from laboratories. Suggestions are also made for simplifying various procedures imposed by the regulatory agencies with authority over the disposal of laboratory chemicals.

Chemical waste and unneeded chemicals are unavoidable products of most kinds of laboratory work, including research, product development, teaching, analysis and testing, and quality control. Moreover, in multidisciplinary institutions, such materials are generated not only in chemistry laboratories but in others such as biology, geology, electrical engineering, art, physics, and health service laboratories as well. The NRC report defines a laboratory as,

> a building or area of a building used by scientists or engineers, or by students or technicians under their supervision, for the following purposes: investigation of physical, chemical, or biological properties of substances; development of new or improved chemical processes, products, or applications; analysis, testing, or quality control; or instruction and practice in a natural science or in engineering. These operations are characterized by the use of a relatively large and variable number of chemicals on a scale in which the containers used for reactions, transfers, and other handling of chemicals are normally small enough to be easily and safely manipulated by one person (*1*, pp. 1–2).

The unneeded chemical material generated in laboratory operations must be disposed of in ways that are safe, environmentally acceptable, and that conform to federal, state, and local regulations. These regulations are designed primarily to control disposal of wastes from industrial operations but also cover chemicals from laboratories, which according to Environmental Protection Agency (EPA) estimates, account for less than 1 percent of the total hazardous waste generated in the United States.

Because very few laboratories have facilities for disposal of unneeded chemicals at their sites, the waste must be transported to a disposal site in conformance with numerous regulations of the EPA, the Department of Transportation (DOT), and the states. The unneeded chemical material from a laboratory operation differs from that of a typical industrial operation in (i) being of much smaller quantity, (ii) having much greater chemical diversity, and (iii) changing in chemical character from day to day. It often includes significant numbers of chemicals of unknown toxicity or in quantities too small for practical characterization, and such materials must be classified, transported, and disposed of as hazardous waste. The voluminous record keeping required by regulations for this multitude of small samples not only poses a substantial problem for many laboratories but is also of questionable practical value. This problem is exacerbated by differences and overlap among various federal, state, and local regulations.

The NRC report urges EPA, DOT, and state and local governments to establish "a mutually consistent, interlocking regulatory approach" (*1*, p. 10). Seven categories of laboratory materials, reflecting chemical characteristics, are proposed: reactive, toxic, ignitable, corrosive (acid), corrosive (base), oxidizers, and miscellaneous laboratory samples. "Miscellaneous laboratory chemicals" would apply to materials that are routinely generated in laboratories—and rarely elsewhere—and the transportation and disposal of which are not addressed in current regulations. The class would be limited to small individual samples of such materials as residues from small-scale tests, minor by-products from reactions, residues from analytical procedures, used filter paper, and partially used small containers of reagents.

Record keeping could be simplified if containers of chemically compatible materials overpacked in a steel drum with inert filler (a lab pack) were allowed to be classified generically rather than listing each sample in a pack.

Although shippers can apply to DOT for an exemption to transport such containers and the containers need only have generic description of the contents (*3*), this exemption does not eliminate the EPA record-keeping requirements for individual samples. Transportation of laboratory waste must still meet requirements of both EPA and DOT, which are not the same in all respects. Furthermore, many states have regulations on transportation of hazardous waste that may overlap and differ from those of EPA and DOT. The need for more consistent and simpler regulatory requirements is clear.

The productivity and efficiency of laboratory operations could be increased by overt regulatory encouragement of laboratory procedures for reducing or destroying the hazard characteristic of haz-

The author, formerly a research director at E. I. Du Pont de Nemours & Company, Wilmington, Delaware, assisted in the preparation of the National Research Council report on which this article is based. His address is Rural Delivery 5, Box 86, Hockessin, Delaware 19707.

ardous chemicals. The development and use of small-scale equipment for incinerating limited quantities of laboratory chemicals should be fostered by regulatory incentives.

Waste Management Program

Laboratory management is responsible for formulating safe and environmentally acceptable programs to dispose of laboratory chemicals, not only because of the legal obligations imposed by regulations but also because of a moral obligation to society. Once a waste management program is developed, "It is essential that laboratory management at all levels, or faculty in an academic institution, be openly and actively committed to support of sound waste management policies and practices" (*1*, p. 7).

A viable program requires a formal waste management organization with responsibilities clearly assigned and a staff commensurate with the size and complexity of the laboratory operation. The staff must be familiar with all federal, state, and local regulations that affect waste handling and disposal. Because laboratory personnel must implement or operate under the procedures developed for handling waste material, it is recommended that they participate in developing them. All procedures and the allocation of responsibilities between laboratory workers and waste management staff should be clearly spelled out in a written manual, supplemented by training and periodic refresher sessions. Waste management procedures should be reviewed regularly, preferably annually, and modified as necessary to conform to changes in regulations and in laboratory operations.

Reduction in Volume of Hazardous Waste

Good laboratory waste management begins with preventive measures—that is, identification of steps that can be taken to reduce the volume of chemicals that enter the waste disposal process and to prevent unusual, difficult disposal problems. This can mean financial savings.

The planning of every experiment should include consideration of the waste disposal problems. The volume of hazardous waste produced in an experiment can be reduced by using recoverable solvents or the least hazardous solvents feasible, ordering chemicals only in quantities needed, and in some cases planning for laboratory destruction of chemicals that are used in or produced by the experiment.

Modern small-scale laboratory equipment, together with sensitive analytical techniques, makes it possible to run many experiments, both batch and flow, on a very small scale, thereby reducing the volume of chemical waste and energy usage. Nonstandard preparative procedures can be piloted on a microscale to optimize reaction conditions and product yields, thereby reducing the quantity of by-products.

The problems created by accumulations of reagents that deteriorate to hazardous products over time can be controlled by having laboratory personnel label such sensitive reagents with the date a container was opened and then monitoring laboratories periodically to locate and destroy reagents that have been stored for a prescribed period. This is particularly important for such common chemicals as organic ethers and unsaturated compounds that form peroxides on exposure to air. Some of these compounds can eventually deposit solid peroxides that are treacherously explosive. The NRC report provides lists of classes of peroxide-forming chemicals, ranked in approximate order of hazard from peroxide formation, and recommended retention times.

Disposal problems are also posed by reagents that have missing or illegible labels. Unlabeled, orphan reaction mixtures left behind by a departed worker can be particularly troublesome because of the need to ascertain the chemical nature of the mixture to guide its proper disposal. Periodic, preventive monitoring and a personnel check-out procedure could help prevent the problem from occurring.

Waste volume can be reduced by recovery of some chemicals for reuse. Recovery of mercury and precious metals can be done in the laboratory, or the materials can be returned to a supplier for credit. Recovery of some solvents, chlorinated hydrocarbons, for example, may also prove to be economical when recovery costs are balanced against those of disposal and purchase of new material. Laboratories may choose to do their own solvent recovery or to make arrangements with a commercial firm that will accept laboratory solvents.

Unneeded reagents in unopened original containers can be exchanged with or sold to other laboratories; regional chemical exchanges already exist in some areas. Some laboratories have set up internal exchanges that catalog and store reagents, including partially used ones and chemicals that have been synthesized and characterized in the laboratory. Such chemicals can often be put to use in other parts of the laboratory, eliminating them from the waste disposal stream and saving the cost of purchasing new material.

The costs of disposing of hazardous chemicals are based on weight and volume, and these can often be minimized by laboratory treatment. Aqueous solutions that contain heavy metal ions can be boiled down or evaporated to give low-volume sludges or solid residues for disposal; another method involves absorption of the ions onto an ion-exchange resin. Many inorganic cations can be precipitated from solutions as hydroxides, sulfides, or sulfates. Such toxic anions as fluoride and sulfide can be precipitated by appropriate cations to give inert solids. This procedure can use one waste material to precipitate another. The report contains tables of recommended precipitants for many cations and anions as well as *p*H ranges for precipitating hydroxides and sulfides, some of which can redissolve in certain *p*H ranges.

The indiscriminate dumping of chemicals down the laboratory drain, once common practice, is no longer acceptable. Nevertheless, modest quantities of certain water-soluble chemicals can be flushed down the laboratory drain with excess water. The report presents guidelines on classes of chemicals that are suitable for drain disposal; however, it should be borne in mind that local regulations control what can be put into the sanitary sewer system, and each laboratory must set up its internal practices accordingly.

It is standard practice for chemists to treat reaction mixtures to destroy substances, such as water- or oxygen-sensitive compounds, that would interfere with subsequent isolation of the desired reaction product. This practice can be extended to reduce or destroy the hazard characteristic of many classes of chemicals, both organic and inorganic, in the laboratory, obviating the need for disposing of them as hazardous waste. The longest chapter in the report is devoted to laboratory practices, many with specific examples, for reducing or eliminating the hazard characteristic of common classes of organic, inorganic, and organo-inorganic chemicals. Also included are simple laboratory tests that can be applied to unidentified chemicals to provide information for safe disposal.

Although the use of laboratory procedures to reduce the volume of hazardous waste is not likely to be an economical practice for many laboratories, some may find it useful, particularly for highly reactive chemicals that cannot be put into landfills. In addition, teaching laboratories should consider incorporating such practices into laboratory experiments to make students conscious of the need to minimize the generation of hazardous waste and provide experience in ways to do so.

The procedures described come from widely scattered literature, and many were not designed specifically for destruction of the chemicals. It is suggested that such procedures could form the basis of a publication similar in character to *Organic Syntheses*. Procedures for destroying specific chemicals could be optimized in one laboratory, checked independently in another for safety and efficacy, and published periodically.

Arranging for Disposal of Hazardous Waste

A chemical becomes a waste under the EPA regulations once a decision is made to discard it, and not to recover, recycle, or reuse it. The chemical is a hazardous waste, and subject to EPA regulations, if it appears on any of several lists in the regulations. It is also a hazardous waste if it meets regulatory characteristics for flammability, corrosivity, or reactivity, or if it contains any of eight inorganic ions or six polychlorinated insecticides that can be leached out of it by a specified test. Testing for these characteristics can be done in the laboratory; however, testing is not required, and the laboratory can simply opt to declare the chemical a hazardous waste on the basis of its identity or knowledge of its origin. For purposes of disposal, chemicals must be segregated according to these classifications. As mentioned earlier, wastes that are to be transported for disposal must also be classified according to DOT regulations, which are more detailed than those of EPA. Laboratories often use or produce chemicals that do not meet any of the EPA criteria for a hazardous waste and whose toxicity is not known or cannot be inferred from their chemical structures. Such chemicals should be classified as toxic for both transportation and disposal, even though they are not explicitly covered by EPA regulations.

Laboratories that elect to pack their wastes and make arrangements for their transportation and disposal should have staff that are thoroughly familiar with the EPA and DOT regulations from the most recent issue of the *Code of Federal Regulations* (*4*). Although the regulations most pertinent to laboratories are summarized in the NRC report, the report is intended only as a guide to these regulations. Individual state regulations, which may be more restrictive than federal regulations, are not discussed.

The alternative course is for the laboratory to hire a commercial firm to pack wastes and arrange for transportation and disposal. Laboratory personnel must still be sufficiently familiar with pertinent regulations to supervise the contractor. The EPA regulations specify that the generator of hazardous waste is ultimately responsible for its proper transportation and disposal and, therefore, for any improper actions of a contractor it may employ.

Disposal of Hazardous Waste

Few laboratories have a hazardous waste incinerator, and most commercial incinerators do not accept laboratory waste because of its uneconomically low volume and chemical diversity. Incineration is also substantially more costly than landfill burial, and most laboratory hazardous waste is put into a landfill that has a permit from the EPA or the state to accept hazardous waste. Current regulations allow disposal in landfills of lab packs that contain flammable, corrosive, and toxic chemicals in separate packs that do not contain mutually reactive chemicals. Materials that can undergo violent chemical change, inherently or on exposure to water or oxygen, are prohibited from landfill disposal. Flammable chemicals can be put into landfills only in lab packs. Legislative moves to bar all flammable materials from landfills, regardless of quantity, have been discussed; it is not clear what laboratories would do with small quantities of unneeded, unrecoverable, flammable chemicals in the event of such a restriction. Although many laboratories are located at long distances from hazardous waste landfills and must bear high transportation costs for disposal of their wastes, they currently have no practical alternative. The long-term availability of landfills for disposal of laboratory chemicals is uncertain. Hazardous waste landfills are not numerous, and the many regulatory constraints on design and construction, as well as resistance from the local community, make it difficult to establish new ones.

The current EPA regulations have provision for exempting modest quantities of wastes from regulation: the Small Quantity Generator Exemption. This exemption, which is not recognized in the regulations of some states, applies to hazardous waste generated or stored by a waste generator in quantities of less than 1000 kilograms per month (or 1 kilogram per month for wastes that are classified as acutely hazardous). These exempt wastes are permitted, under federal regulations, to be disposed of in municipal sanitary landfills. However, disposal of chemicals that pose a significant hazard because of flammability, corrosivity, reactivity, or toxicity, regardless of quantity, in a sanitary landfill is neither safe nor environmentally prudent. Such landfills usually provide no control over access by people, nor over the ultimate fate of materials in the landfill. Prudent waste management calls for disposal of such chemicals in a hazardous waste landfill.

It is probable that the limit for the small quantity generator exemption will be reduced substantially, if not eliminated, before long, and laboratories that now use this exemption would be well advised to consider other options. It would be helpful if a change in this exemption were accompanied by regulatory relief for laboratories from the voluminous record keeping currently required for multitudes of small chemical samples. Laboratories generate a much wider variety of chemicals than do small industrial firms, but disposal of these chemicals is guided by professionals who understand the nature and hazards of chemicals.

From an environmental point of view, destruction of hazardous chemicals is preferable to burial. However, current regulatory requirements for obtaining a permit to test or operate incinerators for hazardous waste in any quantity pose a severe economic barrier to the development and use of small-scale incineration equipment. Regulatory encouragement of incineration of modest quantities of the diverse chemicals from laboratories would provide a useful alternative to landfill burial. For example, the regulatory requirement for expensive trial burns for each incinerator might be replaced by a procedure for granting an incinerator permit based on results of testing a prototype of a standard design or on showing that the incinerator meets well-defined design and operating criteria.

Other methods for destroying hazardous chemicals are being explored, such as decomposition of organic materials in a molten salt bath or in supercritical water. Whether these methods can and will be adapted for laboratory use remains to be seen.

Conclusion

An array of unneeded chemicals, relatively small in quantity but chemically diverse, is an unavoidable consequence of the various activities conducted in laboratories. Laboratory management has the responsibility to limit the quantities of such chemicals that must be disposed of as waste and to provide financial resources and personnel to ensure safe and legal disposal of unneeded chemicals. The disposal of such chemicals would be facilitated by regulatory recognition of the difference between waste generated in laboratory operations and waste resulting from large-scale industrial operations.

Academic institutions can provide a valuable service by incorporating features of waste handling and disposal into their curricula. New generations of scientists need to be trained in sound practices for the disposal of hazardous chemicals, and from these scientists may come concepts of new ways to dispose of or destroy hazardous chemicals.

References and Notes

1. Committee on Hazardous Substances in the Laboratory, National Research Council Assembly of Mathematical and Physical Sciences, *Prudent Practices for Disposal of Chemicals from Laboratories* (National Academy Press, Washington, D.C., 1983).
2. The committee included Robert A. Alberty, Massachusetts Institute of Technology, chairman; Edwin D. Becker, National Institutes of Health; Larry I. Bone, Dow Chemical U.S.A.; Alain DeCleve, Stanford University; Margaret C. Etter, 3M Company; Irving H. Goldberg, Harvard Medical School; Clayton Hathaway, Monsanto Co.; Blaine C. McKusick, Wilmington, Del.; John F. Meister, Southern Illinois University; William G. Mikell, E. I. Du Pont de Nemours & Co.; Adel F. Sarofim, Massachusetts Institute of Technology; William P. Schaefer, California Institute of Technology; Alfred W. Shaw, Shell Development Co.; Fay M. Thompson, University of Minnesota; P. Christian Vogel, BASF Wyandotte; Kenneth L. Williamson, Mount Holyoke College. William Spindel, National Research Council, was study director. This committee evolved from one that earlier issued a report on handling hazardous substances in laboratories [see B. C. McKusick, *Science* **211**, 777 (1981)].
3. Application for this exemption (DOT-E 8129) can be made to the Associate Director of Hazardous Materials Regulations, Materials Transportation Bureau and Special Programs Administration, U.S. Department of Transportation, Washington, D.C. 20590.
4. For EPA regulations, see 40 CFR, chapter 1; for DOT regulations, see 49 CFR, chapter 1.

Stress Hormones: Their Interaction and Regulation

Julius Axelrod and Terry D. Reisine

The constancy of the "milieu interieur" is the condition of a free and independent existence.

—Claude Bernard (*1*)

The body responds to increased physical or psychological demands by releasing adrenocorticotropin (ACTH) from the anterior pituitary, glucocorticoids from the adrenal cortex, epinephrine from the adrenal medulla, and norepinephrine from sympathetic nerves. These hormones serve to adapt the body to stressors ranging from the mildly psychological to the intensely physical by affecting cardiovascular, energy-producing, and immune systems. It was the 19th-century physiologist Claude Bernard who recognized the importance of adaptive mechanisms with one of the most cogent statements (cited above) framed by a biological scientist (*1*). Walter Cannon referred to the complex biological responses necessary to maintain a steady state in the body as homeostasis (*2*). In a series of landmark experiments during the early part of the 20th century, Cannon recognized the importance of the sympathomedullary system in reacting to stressful events evoked by acute physical or psychobiological stressors (*3*). He observed that the tissues liberate a humoral agent which he termed "sympathin." This was later identified as epinephrine (adrenaline) and norepinephrine (noradrenaline) (*4*).

In 1936 Selye reported that diverse noxious agents cause an enlargement of the adrenal cortex as a consequence of the "stress syndrome" (*5*). During the following three decades many investigators observed that a variety of stressful events cause a release of ACTH from the anterior pituitary (*6*). The secreted ACTH stimulates the synthesis of corticosteroids in the adrenal cortex. The elevated corticosteroid levels in plasma then inhibit the further release of ACTH from the pituitary. In a series of elegant experiments, Harris demonstrated that the release of ACTH from the pituitary is regulated by a corticotropin-releasing factor (CRF) from the hypothalamus (*7*). The CRF synthesized in the hypothalamus reaches the pituitary by a private portal blood supply. It then stimulates the secretion of ACTH from the pituitary. After a long period of intensive investigations CRF was isolated and purified, and its structure was characterized as a 41 amino acid peptide by Vale and co-workers (*8*). CRF was thought to be the major if not the sole means of releasing ACTH from the pituitary. Recent experiments indicate that ACTH can also be released and regulated by catecholamines and other hormones.

Catecholamines, Glucocorticoids, and Sympathoadreno Activity

A variety of stressors cause an increased activity of the sympathetic nervous system and adrenal medulla (*2*). This activity results in a discharge of epinephrine and norepinephrine into the blood stream and changes in the activity of enzymes that synthesize catecholamines and in the concentrations of norepinephrine and epinephrine in the brain. With prolonged stress, marked compensatory changes in the activity of the catecholamine biosynthetic enzymes tyrosine hydroxylase, dopamine β-hydroxylase, and phenylethanolamine *N*-methyltransferase (PNMT) occur. These changes in enzyme activity are regulated to varying degrees by glucocorticoids, ACTH, and neuronal activity.

When mice are subjected to psychosocial stressors through competition for food and living space, they show increases in blood pressure, adrenal weight, and catecholamine concentrations in the adrenal medulla (*9*). The biosynthetic enzymes tyrosine hydroxylase and PNMT are both increased in mice experiencing excessive social stimulation. Forced immobilization of rats

The authors are members of the Section on Pharmacology, Laboratory of Clinical Science, National Institute of Mental Health, Bethesda, Maryland 20205.