NFPA No.

801

File: 800 Series
Radioactive Materials

Recommended Safe Practice for LABORATORIES HANDLING RADIOACTIVE MATERIALS

MAY 1955

Reprint 1958

NATIONAL FIRE PROTECTION ASSOCIATION
INTERNATIONAL
60 Batterymarch St., Boston 10, Mass.

PRICE: 50 CENTS
(Discount for quantities)

2M-11-58-FP (4M)

Printed in U.S.A.

National Fire Protection Association

International

Executive Office: 60 Batterymarch St., Boston 10, Mass.

The National Fire Protection Association was organized in 1896 to promote the science and improve the methods of fire protection and prevention, to obtain and circulate information on these subjects and to secure the cooperation of its members in establishing proper safeguards against loss of life and property by fire. Its membership includes two hundred national and regional societies and associations (list on outside back cover) and seventeen thousand individuals, corporations, and organizations. Anyone interested may become a member; membership information is available on request.

This pamphlet is one of a large number of publications on fire safety issued by the Association including periodicals, books, posters and other publications; a complete list is available without charge on request. All NFPA standards adopted by the Association are published in six volumes of the **National Fire Codes** which are re-issued annually and which are available on an annual subscription basis. The standards, prepared by the technical committees of the National Fire Protection Association and adopted in the annual meetings of the Association, are intended to prescribe reasonable measures for minimizing losses of life and property by fire. All interests concerned have opportunity through the Association to participate in the development of the standards and to secure impartial consideration of matters affecting them.

NFPA standards are purely advisory as far as the Association is concerned, but are widely used by law enforcing authorities in addition to their general use as guides to fire safety.

Definitions

The official NFPA definitions of shall, should and approved are:

SHALL is intended to indicate requirements.

SHOULD is intended to indicate recommendations, or that which is advised but not required.

APPROVED refers to approval by the authority having jurisdiction.

Units of measurements used here are U. S. standard. 1 U. S. gallon = 0.83 Imperial gallons = 3.785 liters.

Approved Equipment

The National Fire Protection Association does not "approve" individual items of fire protection equipment, materials or services. The standards are prepared, as far as practicable, in terms of required performance, avoiding specifications of materials, devices or methods so phrased as to preclude obtaining the desired results by other means. The suitability of devices and materials for installation under these standards is indicated by the listings of nationally recognized testing laboratories, whose findings are customarily used as a guide to approval by agencies applying these standards. Underwriters' Laboratories, Inc., Underwriters' Laboratories of Canada and the Factory Mutual Laboratories test devices and materials for use in accordance with the appropriate standards, and publish lists which are available on request.

Recommended Safe Practice for Laboratories Handling Radioactive Materials

NFPA No. 801

This, the first edition of Recommended Safe Practice for Laboratories Handling Radioactive Materials, was prepared by the NFPA Committee on Atomic Energy and adopted by the National Fire Protection Association on May 17, 1955.

RECOMMENDED SAFE PRACTICE FOR LABORATORIES HANDLING RADIOACTIVE MATERIALS

NFPA No. 801 — 1955

This text is written to provide for the fire protection specialist certain information about laboratories handling radioactive materials and for the designers and operators of these laboratories some guidance on practices necessary for fire safety.

There are at least three phases of the use of radioactive materials which, for convenient consideration of the fire protection problems, are separate. These are

(1) Radioisotopes as used in chemical and other laboratories.

(2) Radiation machines (particle accelerators).

(3) Nuclear reactors for research and power.

Discussions in this text are confined principally to the first listed of the above and are basically confined to laboratories handling radioactive materials in small quantities (1 curie or less). Some paragraphs are included containing information about both radiation machines and reactors, as both of these types of equipment may be associated with the same plants which operate radiochemical laboratories, but the text does not attempt to treat comprehensively either of these subjects.

The Joint Fire and Marine Insurance Committee on Radiation has issued two publications which are additional sources of material for reference on these subjects:

Report on Radioactive Materials. 16 pages. 1951.

Fire Protection for Particle Accelerator Installations. 64 pages. 1953. $1.00.

The Joint Fire and Marine Insurance Committee on Radiation is made up of the Factory Insurance Association, the Associated Factory Mutual Fire Insurance Companies, the National Board of Fire Underwriters, the Associated Reciprocal Exchanges, the Board of Underwriters of New York, the Improved Risk Mutuals and the Inland Marine Underwriters Association. Copies of the above publications may be obtained from these organizations or from the National Fire Protection Association.

A Selection of Additional Reference Material

There are the following references dealing with phases of this problem of concern to public fire departments, prepared and published by International Association of Fire Chiefs, Martinique Hotel, New York 1, N. Y.

Radiation Hazards of Radioactive Isotopes in Fire Emergencies. 16 pages. 1950.

Radiation and Monitoring Fundamentals for the Fire Service, 50 pages. Revised edition, 1955.

The following is available as a pamphlet reprint from the National Fire Protection Association:

Combating Fires Involving Radioisotopes. By George G. Manov. No. Q48-7, reprint from Quarterly magazine, October 1954 (Vol. 48, No. 2, page 173). 12 pages. 25 cents.

The U. S. Atomic Energy Commission has the following publications which contain information pertinent to the radiation problem associated with radiochemical laboratories. These publications can be obtained from the U. S. Superintendent of Documents, Washington 25, D. C.

Control of Radiation Hazards in the Atomic Energy Program. 244 pages. July 1950. 50 cents.

Handling of Radioactive Wastes in the Atomic Energy Program. July 1950.

The National Bureau of Standards has issued a number of handbooks dealing with various phases of the atomic radiation problem. These may be obtained from the U. S. Superintendent of Documents, Washington 25, D. C. The principal handbooks of importance in connection with the problems covered by this text are the following:

No. 42. Safe Handling of Radioactive Isotopes. 36 pages. 1949. 20 cents.

No. 48. Control and Removal of Radioactive Contamination in Laboratories. 28 pages. 1951. 15 cents.

No. 51. Radiological Monitoring Methods and Instruments. 40 pages. 1952. 15 cents.

No. 52. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. 52 pages. 1953. 20 cents.

No. 59. Permissible Dose from External Sources of Ionizing Radiation. 88 pages. 1954. 30 cents.

Specific reference is made in the text to the following publications of the National Fire Protection which are available as separate pamphlets and are also published in the National Fire Codes (Six volumes, published annually. $6.00 each volume). A complete list of NFPA publications with further details about the National Fire Codes and other publications is available on request.

No. 325. Fire Hazard Properties of Certain Flammable Liquids, Gases and Volatile Solids. 84 pages. 1951. 75 cents.

No. 325A. Flammable Liquid Trade Name Index. 84 pages. July 1954. $1.25.

No. 49. A Table of Common Hazardous Chemicals. 32 pages. 1950. 50 cents.

Specific reference is also made in the text to the following standards of the National Fire Protection Association which are published in National Fire Codes Vol. III, Building Construction and Equipment, and by the NFPA and the National Board of Fire Underwriters, 85 John Street, New York 38, N. Y., with the same identifying number. A list of the standards in this series and other publications of the National Board of Fire Underwriters may be obtained from the above address.

No. 90. Standards for the Installation of Air Conditioning, Warm Air Heating and Ventilating Systems (NFPA edition, June 1952. 36 pages. 35 cents; NBFU edition, August 1952. 36 pages).

No. 91. Standards for the Installation of Blower and Exhaust Systems for Dust, Stock and Vapor Removal and Conveying (NFPA edition, 1949. 20 pages. 25 cents; NBFU edition, November 1949. 28 pages).

The following additional references may be useful where copies are available or in personal or library files.

Radiation Safety in Industrial Radiography with Radioisotopes. By P. M. Frazier and others, in ISOTOPICS, a publication of the U. S. Atomic Energy Commission at Oak Ridge, Tenn., January 1955 issue.

Design of Radioisotope Laboratories for Low and Intermediate Levels of Activity. By George G. Manov and Oscar M. Bizzell. ASTM Special Technique Publication No. 159, reporting a Symposium on Radioactivity, June 30, 1953. American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

BRAB Conference Report No. 3. Proceedings of a Conference on Laboratory Design for Handling Radioactive Materials, November 27 and 28, 1951. Building Research Advisory Board, 210 Constitution Avenue, Washington, D. C. 144 pages. 1952. $4.50.

Problems Associated with the Transportation of Radioactive Substances. Paper by the National Research Council. Publication No. 205 of the National Academy of Science, Washington 25, D. C. 1951.

Surveying and Monitoring of Radiation from Radioisotopes. By G. W. Morgan in NUCLEONICS magazine. McGraw-Hill Publishing Co., Inc., 330 West 42nd Street, New York 36, N. Y. March 1949 issue.

Fire Problems in Radiochemistry. Quarterly of the National Fire Protection Association, October 1947 (Vol. 41, No. 2, page 98).

RECOMMENDED SAFE PRACTICE FOR LABORATORIES HANDLING RADIOACTIVE MATERIALS

CONTENTS

PART 1. RADIOACTIVE MATERIALS

Radioactive elements and chemical compounds have fire and explosion properties identical with those of the same materials when not radioactive. The property of radioactivity can cause injuries, loss of life, damage to and extended loss of use of other materials, equipment and buildings, because its hazards are added to the normal ones. Laboratories handling radioactive materials must be designed and operated in accordance with good practice for any laboratory, but with specific emphasis on the added properties of radioactivity.

The effects of the presence of radioactive substances upon the extent of loss caused by fire, explosion or other perils are:

(1) Possible interference with manual fire fighting due to the fear of exposure of fire fighters to harmful radiation.

(2) Possible increased delay in salvage work and in resumption of normal operation following fire, explosion, or other damage due to loss of control over radioactive substances and the consequent need for decontamination of buildings, equipment and materials.

1.1. The Fire Problem of Radioactive Materials

Radioisotopes are forms of various elements which may emit radiation as described in Paragraph 1.5. With the exception of rare naturally-occurring radioactive elements, they are produced commercially in particle accelerators and reactors and are available from respective government-owned agencies or authorized distributors and private laboratories. The use of radioisotopes has steadily increased in medical therapy and radiography applications for which radium and X-ray equipment has been used for years. Radioisotopes are finding application as industrial controls. They are used in the automatic control of chemical, metallurgical, and other processes. They make possible instruments of new types to measure liquid levels, thickness of materials, or density of products.

For most of the uses, except for radiography and X-raying, the amounts of these radioactive materials, at any one point, are small. However, there are locations where materials with high radiation intensity exist. Laboratories handling radioactive materials, while usually involving small amounts, may in some cases have substantial quantities as measured in terms of their radioactive strength. One installation using cobalt-60, for example, provides a source of radioactivity equivalent to several times that of the total amount of radium under human control in the entire world.

Radioactive materials, depending upon the particular nature of the parent element or the compound in which they are present, may be expected to melt, vaporize or oxidize under fire conditions. None of these alterations would slow down or halt the radioactivity. It is conceivable that certain radioactive materials under fire conditions might be converted to radioactive vapor or oxidized to a radioactive dust or "smoke:" This dust or smoke might be carried by air currents and subsequently deposited on other parts of the burning buildings or even on neighboring buildings or lands.

Fire might be very destructive to some types of shielding material but much less so to others. For example, lead, which melts at 622 degrees Fahrenheit, might rapidly be rendered useless as a shielding material by fire but a material such as reinforced concrete, although less effective as a shielding material, at normal temperatures would be much more durable than lead under fire conditions. This disadvantage of lead as a shielding material is largely overcome by encasing it in steel which will maintain the geometric configuration and shielding ability of the lead even at high temperatures when it has become molten.

In view of the possibility of the spread of radioactive materials during a fire, certain precautions and procedures are indicated in connection with fire-fighting operations.

For example, users should advise fire departments of the location and general nature of radioactive materials at hand so that fire fighters may function at maximum efficiency without exposing themselves inadvertantly to harmful radiation and without allowing small amounts of radioactivity to interfere.

Also, it appears highly desirable that fire-fighting personnel at a fire be protected with suitable clothing and suitable gas masks or other respiratory protective equipment. They must be assured of services to monitor radioactivity at the scene. During the fire, bystanders should be kept at a safe distance, as is always desirable.

Attention should be given to the method by which the fire is attacked. Properly selected fire extinguishers, chosen to suit the location, may be used to control small fires. It appears likely that in some cases the use of low-pressure water spray will be particularly advantageous for fighting fires in radioactive areas as it is less likely to stir up and unnecessarily spread the radioactive materials than would solid streams. Moreover, water spray might tend to settle any radioactive dusts in the atmosphere.

After a fire, fire-fighting personnel and their clothing and equipment should be monitored for radioactivity and, if necessary, be decontaminated.

Courtesy U. S. Atomic Energy Commission (Lord)

Various gummed labels and tags are used on the containers in which radioactive materials are handled. The above are some in use by the U. S. Atomic Energy Commission.

These conditions make necessary the good practice recommendations herewith presented with respect to laboratories handling radioactive materials. In the construction of such laboratories, the use of fire-resistive building components and equipment is highly desirable, particularly in areas where radioactive materials are to be stored in relatively large quantities. Some form of automatic protection, such as sprinklers, would be highly advantageous. Later portions of this text contain specific recommendations to fire protection.

The observance of measures which would be good practice in any occupancy will operate to prevent the release or loss of control of radioactive materials by fire or during fire extinguishment, with resultant potential life hazard and contamination of property involving large loss of the materials or both of these complications. Measures for fire prevention and protection are therefore treated in sections following, both generally and with specific concern for the property of radioactivity.

1.2. Extent of Use of Radioactive Materials in Laboratories

Radioactive materials are being used to a sufficient extent to demand attention. Shipments of radioisotopes by the U. S. Atomic Energy Commission alone are currently exceeding 10,000 a year and those of Atomic Energy of Canada, Limited, are over 1,500 a year. These figures are only a rough indication of the fact that radioactive materials are widely used and because the number of these shipments has increased to at least ten times what they were five years ago that the use of these materials is rapidly increasing.

A representative list of the radioisotopes in most common use would include those given in an accompanying tabulation.

COMMON RADIOISOTOPES

Radioisotope	Beta-emitters	Gamma-emitters	Half-life
Carbon-14	Carbon-14		5,740 years
Sodium-24	Sodium-24	Sodium-24	14.9 hours
Phosphorus-32	Phosphorus-32		14.3 days
Sulphur-35	Sulphur-35		87.1 days
Potassium-42	Potassium-42	Potassium-42	12.44 hours
Calcium-45	Calcium-45		180 days
Iron-55			2.91 years
Iron-59	Iron-59	Iron-59	46.3 days
Cobalt-60	Cobalt-60	Cobalt-60	5.3 years
Strontium-89	Strontium-89		53 days
Strontium-90	Strontium-90		25 years
Iodine-131	Iodine-131	Iodine-131	8 days
Gold-198	Gold-198	Gold-198	2.69 days

Of the radioisotopes listed, the most common in terms of numbers shipped are iodine-131 and phosphorus-32. They are far ahead of all the others. Individual shipments of these are usually very small as measured in curies. On the basis of curie activity, the important radioisotope is cobalt-60 by a wide margin.

By far the most frequent laboratory use of radioisotopes is in "tracer" experiments. In this work, the path of travel of a radioisotope during an experiment is followed by measuring radiation emitted by the radioisotope with sensitive detection instruments. If, for example, it was desired to determine the path of travel of iodine after absorption in a plant, this may be done by feeding the plant mildly radioactive iodine in a suitable chemical form and then following the path of travel of the iodine within the plant through the use of external radiation detection instruments. Most of the work with tracers is conducted in plant or animal research laboratories in individual experiments involving very low levels of radioactivity in the range of millionths of a curie. Tracer experiments of any type requiring use of radioisotopes in quantities exceeding a few millicuries are infrequently encountered.

Other laboratory uses of radioisotopes in microcurie or millicurie quantities include certain types of internal medical treatment, manufacture of radioactive devices for measuring thickness of materials or level of liquids in tanks, manufacture of devices for eliminating static electricity, and for research in corrosion, wear, or detergency effectiveness.

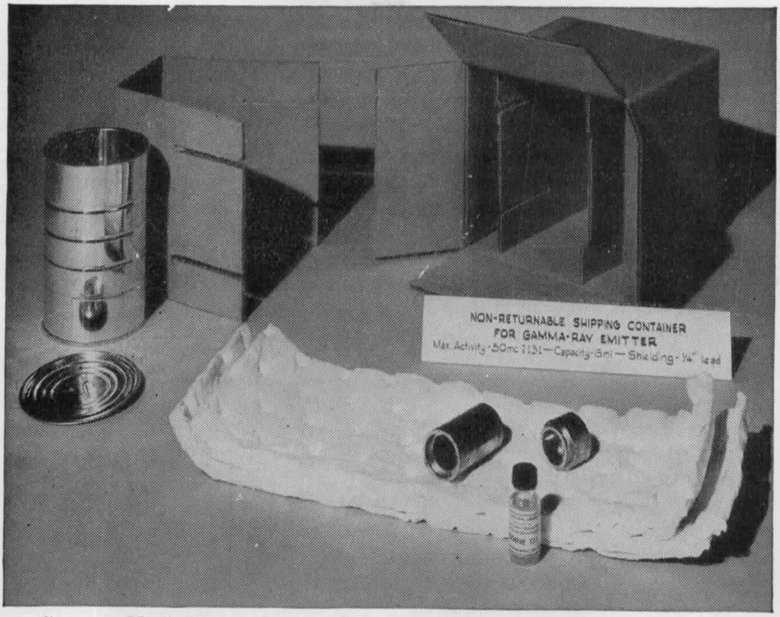
Radioactive sources used for X-ray of castings may range from roughly 100 millicuries to 2 curies while similar sources for medical X-ray therapy may range from 200 to 2,000 curies. Quantities of radioactive materials larger than 1,000 curies may be encountered in laboratories using atomic piles (reactors) or in experimental work on food sterilization by means of radiation exposure.

Quantities of beta or gamma emitting radioactive materials in amounts exceeding a few millicuries are frequently stored in heavy sealed containers or in special heavily constructed vaults. While the inherent nature of most tracer work results in controlled dispersal of a radioactive material, the quantities of radioactive materials involved are generally quite small. Where larger quantities of radiation are required for a particular use (such as in X-ray of castings), the radiation source can be kept intact. Many of the largest manufactured radiation sources involve cobalt-60 in the form of a metal.

Of the many radioisotopes, iodine-131 is significant in considering fire situations. It is a beta and gamma emitting radioisotope that is selectively absorbed in the thyroid gland. It is in widest use, the number of orders for iodine-131 far exceeding those for other radioisotopes.

Fire exposure will cause the material to vaporize. Rapid diffusion of the vapor in air may be expected. On the positive side, it should be noted that good ventilation reduces the hazard from the volatilized material by dilution, that the material has a comparatively short half-life of 8 days, and that gas masks or self-contained breathing apparatus may be used to obtain adequate respiratory protection in the event of an emergency.

Iodine-131 in quantities not exceeding 50 millicuries is commonly shipped in non-returnable containers of the type shown in photograph on page 801-11. Most shipments are by air express because of the short half-life. While the hazards from potential human ingestion of iodine-131 should not be minimized, it is also important to note that the medical profession routinely administers doses of this material in amounts up to 50 millicuries in making thyroid "uptake" studies of patients.



Courtesy U. S. Atomic Energy Commission

Relatively low hazard isotopes are shipped in non-returnable containers of which the one illustrated here is typical.

The properties of cobalt-60 are of interest because of the relatively long half-life (5.3 years), the fact that it is an energetic gamma emitter, and above all, the fact that although cobalt-60 shipments are relatively small in number (less than one percent of the total), they involved nearly 90 percent of the total activity involved in all shipments. Cobalt-60 is almost exclusively shipped and used in solid metallic form.

The physical size of a typical cobalt-60 source (for x-ray work this may approximate the size of an eraser on the end of a pencil) is generally dwarfed when compared with the physical size of the very heavy shielding necessarily provided to furnish adequate protection of personnel from gamma radiation exposure. Hazards associated with cobalt-60 usage are almost exclusively connected with the possibility of accidental over-exposure of personnel to external gamma radiation.

The larger quantities of radioactive materials, such as those in sealed teletherapy sources, may have as much as 1,000 curies or more of cobalt-60 or cesium-137 properly shielded to reduce radiation to a permissible value. Large sources of this type are required to be installed in concrete walled rooms containing a minimum amount of combustible material.

A recently prepared 1,540 curie source of cesium-137 intended for teletherapy use in cancer research has been described as being "in the form of two small pellets about the diameter of a half dollar, half an inch thick and weighing a little more than an ounce. The pellets of compressed cesium chloride are sealed inside double jackets of stainless steel to ensure against leakage."

In general, radioisotopes cannot be simply purchased over a counter nor arbitrarily resold, traded, or indiscriminately disposed of. A few natural occurring radioactive materials, of which radium and polonium are examples, are not under government jurisdiction, but the U. S. Atomic Energy Commission and Atomic Energy of Canada, Limited, both federal government agencies, have jurisdiction and, in general, can confine radio-

Courtesy U. S. Atomic Energy Commission

Except by special arrangement, there are limitations on the quantity of a radioisotope which may be shipped in a special container. For example, U. S. Interstate Commerce Commission usually limits these amounts to a maximum of 2 curies. This illustrates a typical container for such shipments. A lead shield within the cylindrical steel jacket shown may range from ½ inch to 2½ inches depending on the shielding necessary for a particular shipment.

isotopes to users known to possess adequate facilities and personnel trained in their use. These federal agencies will probably continue some measure of control over the distribution of radioactive materials, even under the conditions where private agencies may be able to produce radioisotopes in privately operated reactors or radiation machines.

At present, it is the usual practice of the federal agency to give to the state or provincial department of public health, or some such similar agency in each state or province, a list showing the names and addresses of isotope users, together with the quantity and type of material shipped to each. One of the purposes of furnishing this kind of information is to enable the state or provincial agency to inform local public health departments, and others concerned. One of the purposes of this information is to enable the location of dangerous radioactivity to be properly placarded. It is possible for the state or provincial fire marshal's office to get this information and channel it to local fire departments. Routine flow of information through this readily available channel is not yet the case in all jurisdictions. In cases where it is established, as in Ontario, notification of radioactive shipments is extended to the fire department concerned. The fire department makes an inspection on the premises so that they know the particular room in which the radioactive material may be. It is thus possible for the fire fighters from the nearest fire station to be familiar both with the location, which is placarded, and to determine the protective measures that should be taken in connection with fire fighting at that location.

1.3. Radiation Machines

Radiation machines or particle accelerators are variously described as Van de Graaff, linear accelerators, cyclotrons, synchrotrons, betatrons, or bevatrons. The machines are used, as the name implies, to accelerate the variously charged particles of which the atoms are composed to tremendous speeds and consequent high energy. They furnish scientists with copious quantities of atomic particles, in the form of a beam, from which extremely high energy X-rays or gamma rays may be derived for research, radiography or therapy, in much the same fashion as radium, radioisotopes or X-ray machines have been used.

These machines emit a large flux of radiation while in operation and attempts to extinguish a fire in the immediate vicinity of the machine should be delayed, where possible, until the main power supply, except for lights and other important services, can be turned off. Certain "target" materials become highly radioactive when bombarded by an accelerator and, for this reason, a monitor should be available to estimate the radiation hazard, even when the machine has been made inoperative, especially if the target receptacle has been visibly damaged.

Some types present certain fire hazards by virtue of the high voltage and complicated electrical equipment associated with them. Like transformers and generators, some of the equipment employs oil for insulating and cooling, requiring heat exchangers, tanks, pumps and related devices. Large installations used for research, as in universities and research laboratories, include intricate and expensive control apparatus, vacuum-producing and other machinery embracing the fire hazards usual in such equipment.

While most of the installations of these radiation machines have been made in universities or large research institutions, commercial types of accelerators are being marketed for industrial and medical work. Industrial applications include chemical activation, acceleration of polymerization in plastics production and the sterilization and preservation of packaged drugs.

Fire prevention and protection measures for these machines consist of proper housing (in detached buildings of at least noncombustible construction and preferably fire-resistive construction) and the use of as little combustible material and equipment as possible in connection with the installation. Proper automatic extinguishing systems should be provided for hazardous areas or areas having appreciable amounts of combustible material or equipment, and special protection for any air-cooling or high-voltage electrical equipment. Fire in and around accelerators should be treated as electrical and flammable liquid fires according to the equipment associated with the machines.

1.4. Reactors

Nuclear reactors are in use or in various stages of design, construction and testing by governmental agencies and private interests for research purposes, production of radioisotopes and compounds and nuclear weapons, propulsion of ships, railways and aircraft, and electric power generation.

The heat produced within the reactor by nuclear reactions will be extracted by means of some heat transfer medium, fed to steam generators or boilers which operate turbine generators in the usual manner. If present day methods of heat transfer are employed, such hazardous heat transfer media would be encountered as potassium, sodium, lithium, and the like, at high temperature and perhaps in large quantities.

There is to be expected an extensive search for materials of construction to withstand the temperatures, corrosion, and nuclear reactions produced in the reactors and there will be fire problems as well as other engineering problems in the design of equipment to handle radioactive and hot fluids at high pressure as safely as that can be done.

1.5. Review of Radiation Hazards

All of the atoms of most chemical elements are not identical, but differ slightly in mass and in nuclear stability. The different forms of atoms of the same element are called "isotopes." The term "isotope" is derived from two Greek words "iso" and "topos," meaning "same" and "place" respectively, and is used to name elements which occupy the same position in the Periodic Table of Chemical Elements. In more technical aspects, it refers to any two or more very nearly alike forms of a chemical element, the general chemical and physical properties being identical, but exhibiting slight variations in their atomic weights or masses, each element consisting of as many isotopes as its atoms have different masses.

Some isotopes are stable, some are radioactive and are changing continuously into other elements. Some isotopes occur naturally; others are produced artificially. Because of their radioactive emissions, radioactive isotopes may be readily detected and measured, often in very minute quantities, by various instruments. Since a radioactive isotope behaves almost exactly as other isotopes of the same element in chemical and physical reactions, a known quantity of a radioactive isotope may be mixed with the more common isotope of the same chemical elements and its progress followed, by instruments, as it takes part in chemical or physical activity. Such an isotope, whose progress may thus be followed, is termed a "tracer."

For brief definitions of some of the terms used, "radioactivity" may be defined as the spontaneous emission of rays or particles during change of an atom's nucleus. "Radioactive decay" means the disintegration of a nucleus of the atom during radioactivity. Each radioactive isotope has a "half-life" — a period of time, characteristic of the particular isotope, in which the intensity of nuclear radiation, ascribable to that isotope, progressively decreases by half. However, products formed by the radioactive decay of the original isotope may in turn be radioactive.

The unit for measuring the quantity of radioactivity in the source material is the curie; also the millicurie (one one-thousandth curie) and the microcurie (one one-millionth curie). The term curie was originally designated as the standard to measure the disintegration rate of radioactive substances in the radium family (reported as 3.7×10^{10} atomic disintegrations per second per gram of radium). It has now been adapted to all radioisotopes and refers to the amount of the isotope that has the same disintegration rate as 1 gram of radium.

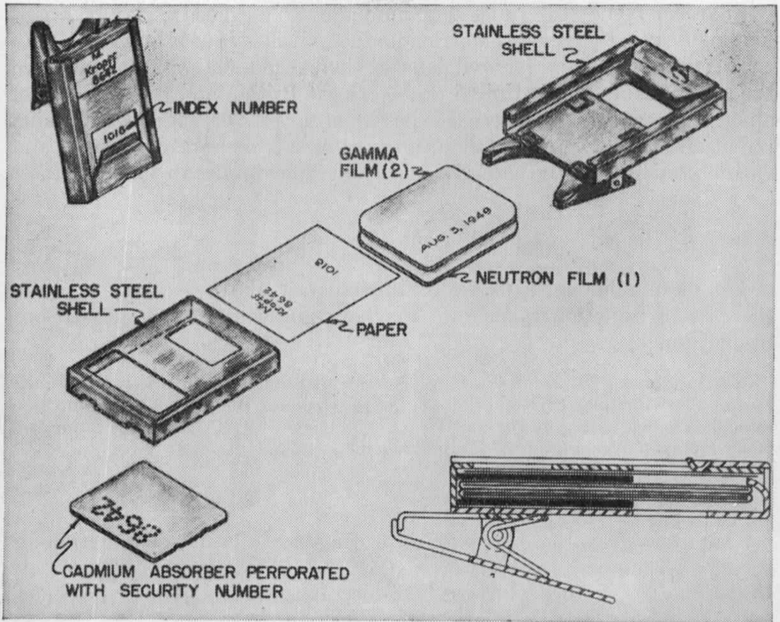
Radioactive emissions are undetectable by the human senses and reliance must be placed entirely on instruments. Among the radiations likely to be encountered are alpha-particles, beta-particles, gamma rays and neutrons. The first three come from many radioactive materials, but

Courtesy Brookhaven National Laboratory, Upton, New York

A gamma survey instrument, one type of which is illustrated, is used for general monitoring in areas where hot experiments are in progress.

neutrons are likely to be most dangerous in the vicinity of nuclear reactors or accelerators only while they are in operation, or from certain special neutron source materials. Neutrons, alpha particles and beta particles are small bits of matter, smaller than an individual atom. Gamma rays (and X-rays) are electromagnetic radiations (like radio waves but with much shorter wave lengths).

All radioactive emissions are capable of injuring living tissue, and of causing death to the individual if the injury is sufficiently severe. The fact that these radiations are not detectable by the senses make them very insidious, and serious injury may be done without the recipient of the injury being aware of it at the time. Because of their relatively high penetrating power, gamma rays and neutrons may be a serious external hazard (*i.e.*, may be very dangerous even when arising from a source outside of the body). Beta-particles, being less penetrating, can be somewhat of an external hazard if approached within inches but are mainly an internal



Courtesy U. S. Atomic Energy Commission

Diagram showing the component parts of a film badge. This shows how special films are employed to record gamma and beta radiation to which the individual wearing the badge has been exposed.

hazard; while alpha-particles, because of their extremely low penetrating power, are entirely an internal hazard (*i.e.*, can only injure the body if emanating from a source in the body after having entered the body in some manner, except where the external exposure is over a long period of time).

These radiations are measured in roentgens, a unit representing the amount of radiation absorbed or which will produce a specified effect. The ultimate effect upon the human body will depend on how and where the energy is expended. For peace-time industrial purposes, a total exposure of 300 milli-roentgens (*i.e.*, 0.3 roentgens) of gamma radiation per week or equivalent for continued exposure, has been established as a permissible limit by the International Commission on Radiological Protection.

The latest authoritative work in this field is Handbook 59 of the U. S. National Bureau of Standards, entitled "Permissible Dose from External Sources of Ionizing Radiation" (88 pages. 1954. U. S. Superintendent of Documents, Washington 25, D. C. 30 cents).

In an emergency case, this maximum allowable exposure may be raised for single dosages without incurring undue risk of serious injury. For both the armed services and for civil defense, there is unanimity of opinion from the governments of the United States, Great Britain and Canada that in an emergency, a single external exposure of up to 25 roentgens of gamma radiation can be incurred without any decrease in operating efficiency and with no serious risk to the individual. This rule applies to the fire fighter for a single emergency.

See NBS Handbook 59, pages 69 and 70.

The permissible exposure stated immediately above does not apply in the case of radiation taken into the body for which the limits are extremely small.

See Handbook No. 52 of the U. S. Bureau of Standards, entitled "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water" (52 pages. 1953. U. S. Superintendent of Documents, Washington 25, D. C. 20 cents.)

1.6. Protection of Personnel

"Monitoring" is the process of measuring the intensity of radiation associated with a person, object or area. It is done by means of instruments which may be photographic or electronic. Instruments used by personnel for radiation detection or measurement include:

Film badge — a piece of photographic film which records gamma and beta radiation.
Pocket dosimeter — which measures gamma radiation.
Geiger-Muller counter — measures beta and gamma radiation.
Scintillation counter — measures alpha, beta, and gamma radiation.
Ionization chamber — measures alpha, beta and gamma radiation.
Proportional counter — measures alpha radiation.
Gamma survey meter — measures intensity of gamma radiation.

Common effects of excessive (200 roentgens or more) nuclear radiation on the body include vomiting, fever, loss of hair, loss of weight, a decrease in the blood count and a general weakness to disease. Radioactive materials absorbed into the body often tend to accumulate at a particular location (*e.g.*, plutonium and strontium tend to collect in the bone), and the radioactivity, concentrated in a particular organ, gradually destroys the cell tissue so that the organ is no longer capable of performing its normal function, and the entire body suffers.

Radiation injury requires prompt highly specialized treatment. Instruments must be provided to detect radiation contamination in clothing or on the skin. There must be a routine monitoring of the degree of exposure to the various particles and rays. Personnel working in the laboratory

Courtesy Brookhaven National Laboratory, Upton, New York

The hand and foot counter illustrated is standard equipment in most laboratories where radioactivity is present.

should be required to wear pocket radiation meters or indicators which are examined daily and records of the exposure kept for future reference.

The practice of placarding dangerous areas is for the protection both of regular laboratory personnel and of those who, like fire fighters, may have to deal with an emergency situation. If fire fighters are to have the best protection, they must expect to inspect, long before they are called to any fire, the premises where there may be radiation hazards to consider during fire operations. Also, by frequent follow-up inspections, they must reach a meeting of minds with the scientists or other personnel directing the laboratory facilities, as to steps to be taken in case of fire.

Fire fighters who may attend fires in properties where there are hazards of radioactivity should be given special training in what to wear for protection and what to do by way of clean-up or decontamination of their persons, clothing or equipment afterward. In all cases, they should either have suitable radiation monitoring equipment themselves or have monitoring specialists with them. Fire fighters should not let themselves get in the position of having to face a possible unknown radiation exposure, but in such cases radiation detection or monitoring equipment can be used. Without instruments, the only practical advice to fire fighters is to keep out of areas of unknown hazard, unless one of the scientists who may know the particular hazard is prepared to go alongside the fire fighter.

Protection from External Radiation. The dosage, and hence the injury therefrom, in the case of external nuclear radiation, may be kept to a minimum in several ways.

First, the smallest possible portion of the body may be exposed (*e.g.*, the hands, rather than the entire body).

Second, by efficient organization of the work procedure, the time spent in the hazardous area and, thereby, the time of exposure, may be kept to a minimum.

Third, the intensity of radiation during exposure may be minimized by maintaining the greatest possible distance (*e.g.*, by using long-handled tools for manipulating radioactive materials), and by the use of suitable materials interposed between the source and the person for shielding. It is important to remember that the intensity of the nuclear radiation varies inversely as the square of the distance from the source.

Protection from Internal Radiation. The possibility of radioactive materials entering the body may be reduced by the wearing of protective face masks and clothing while in a hazardous area. These masks should fit properly and be of a type which will prevent the entry, into the lungs or digestive system, of the particular radioactive materials encountered. Clothing should be of such a nature as to prevent the entry of radioactive materials into the body through wounds, scratches or skin abrasions. Eating, drinking, smoking and chewing should be avoided while in, or while awaiting decontamination after being in, radioactive areas.

Personnel working with radioisotopes are commonly subjected to routine biomedical checks for possible ingested radioactivity. Where applicable, routine checks are also made to show that permissible concentration of radioactive material in the body, the air or elsewhere, is not exceeded.

Biomedical checks are promptly conducted whenever human ingestion of dangerous quantities of radioactive materials is suspected for any reason. When workers dealing with an emergency or fire fighters are exposed to radiation and there is any doubt as to the severity of the exposure, they should be given this kind of routine biomedical examination.

PART 2. TYPES OF LABORATORIES HANDLING RADIOACTIVE MATERIALS

2.1. Laboratories for Research and Routine Application

After each new use for a radioactive material is discovered and perfected in a research laboratory, the demand for this material increases rapidly as other laboratories request it for routine application. Most research laboratories are, in their very purpose, characterized by temporary and expedient equipment, a minimum of safeguards and an extra degree of hazard. Once the feasibility of a particular procedure or operation has been proved, the widescale adoption in industrial or medical laboratories can be of a more permanent nature with provisions for the necessary safeguards.

Many of the routine applications of radioactive materials for testing and analyzing take place outside the confines of the laboratory although they still remain the responsibility of laboratory personnel. Radiographic inspection of metal castings, measurement of film thickness and tracking the flow of liquids through pipe lines are examples of applications taking place primarily outside the laboratory. Thus it is important to know if the activities of a laboratory are experimental or routine in nature and whether the radioactive materials are being used in the laboratory or in the field.

2.2. Classification of Laboratories by Field of Endeavor

The study and use of radioactive materials has had a marked effect in eliminating much of the customary division of laboratories into groups based on the basic subjects of chemistry, physics and biology. Many of the projects now being developed can be completed successfully only by a team with representation from each of the basic sciences working with members of the medical or engineering professions.

This is especially evident in the following breakdown of the types of laboratories authorized to use radioisotopes.

Industrial firms	42%
Medical institutions	33%
Educational institutions	11%
Government laboratories	11%
Others	3%

The present position of industry in this table is the result of a recent rapid surge of activity. The trend indicates that, by far, the greatest single group of laboratories to be considered in the future will consist of those working with industrial application. No industry has ignored the possibilities of radioisotopes. Leading industrial groups in this advance are petroleum, metals, textiles and plastics.

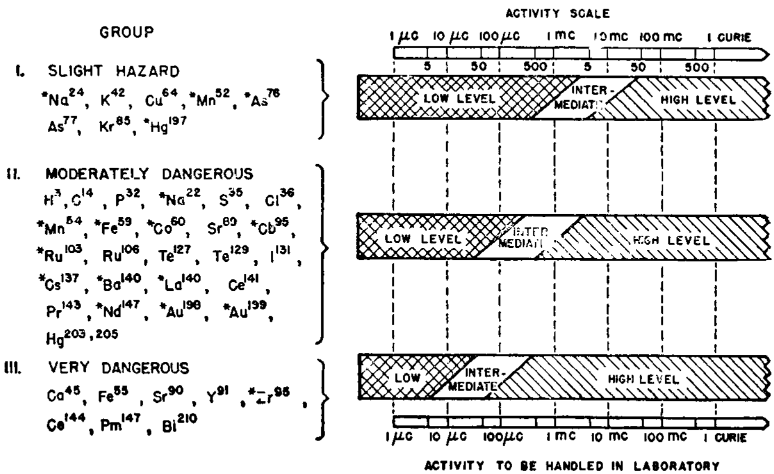
2.3. Classification of Laboratories by Level of Total Radioactivity Handled

Another method of classifying the laboratories is to group them according to the total amount of radioactivity necessary for the work being undertaken.

The following table and accompanying notes are from Handbook 48 of the U. S. National Bureau of Standards entitled, "Control and Removal of Radioactive Contamination in Laboratories." 28 pages. 1951. U. S. Superintendent of Documents, Washington 25, D. C. 15 cents. Table 1, page 4.

HAZARD FROM ABSORPTION INTO THE BODY

Selected radioisotopes grouped according to relative radiotoxicity, with the amounts considered as low, intermediate, or high level, in laboratory practice.



NOTES

Effective radiotoxicity is obtained from a weighting of the following factors:

- Half-life.
- Energy and character of radiations.
- Degree of selective localization in the body.
- Rates of elimination.
- Quantities involved and modes of handling in typical experiments.

The slant boundaries between levels indicate border-line zones, and emphasize that there is no sharp transition between the levels and the associated protection techniques.

The principal gamma-emitters are indicated by asterisk (e.g., $^*Na^{24}$). The above level system does not apply to the hazards of external irradiation.

Considerable attention has been called to that fact that one private research laboratory is handling a cobalt-60 source of radioactivity rated at 5,000 curies and equal in effect to $100 million worth of radium. College laboratories may be expected to use similar sources rated as high as 10,000 curies. At the opposite extreme are the millicurie and microcurie levels of activity more commonly found in radiochemical and radiobiological experiments. Average shipments to a radioisotope laboratory are reported to be between 50 and 100 millicuries per month exclusive of the few large deliveries of cobalt-60.

Actually, the curie rating alone does not indicate the half life of the material, the radiation characteristics, the amount of material, or the relative radiotoxicity of the source. However, it does offer a possible method for roughly classifying radioisotope laboratories. For the present purpose, quantities of any radioactive material may be defined as follows: up to approximately 1 millicurie as a "very low" level of activity, from approximately 1 to 10 millicuries as a "low" level, and from 10 up to 500 millicuries as an "intermediate" level. It should be understood that, because of differences in the radiation energy of the isotopes employed and differences in the kind of radiation emitted (beta, gamma, etc.), no definite line of demarcation is possible between these ranges.

This method of classification is from an article by George G. Manov and Oscar M. Bizell entitled "Design of Radioisotope Laboratories for Low and Intermediate Levels of Activity" from ASTM Special Technique Publication No. 159, reporting a Symposium on Radioactivity, June 30, 1953 (American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.) See also an article, "Combating Fires Involving Radioisotopes," by George G. Manov, U. S. Atomic Energy Commission, in the NFPA Quarterly, Volume 48, Number 2, October, 1954, pages 175–180. (Available as a pamphlet reprint from National Fire Protection Association, 60 Batterymarch St., Boston 10, Mass. No. Q48-7. 12 pages. 25 cents.)

PART 3. CONSTRUCTION DETAILS OF LABORATORIES HANDLING RADIOACTIVE MATERIALS

3.1. Room Arrangement

The location and arrangement of work areas in which radioactive materials are handled must be based upon consideration of the need for segregation of activity levels, isolation of work involving radioactivity from other operations and flexibility. Grouping and segregating the various projects according to the levels of activity facilitates the problem of shielding, waste disposal and ventilation.

When only tracer levels are being used the need for segregation and isolation is slight and the work may be carried on in a single room.

In installations such as the Processing Area at Oak Ridge National Laboratory, several small individual buildings are needed to segregate the various types of radioisotope development according to activity level. Even in a small laboratory arrangements can be made to segregate the areas for (1) receiving and storing radioisotopes (2) actual work with these materials and (3) measurement and counting.

The Oak Ridge Laboratory is also a good example of effective isolation. All service facilities are controlled from a single detached building used for no other purpose. Employees' lockers and showers are centrally located in another building. Cleaning and maintenance of laboratory equipment are centralized in still another building. This use of separate buildings assists in the prevention of the spread of radioactive contamination. Even though the radiation hazard may be less serious, this same principle of centralization of each phase of laboratory operations can be effectively applied in smaller installations.

Flexibility of operation in a radioisotope laboratory is especially necessary because of variations in shielding requirements and remote control handling techniques brought about by changes in the levels of activity being used. In general, the worker handling radioactive materials may require as much as 50 per cent more area than the worker handling stable materials. The modular system of planning helps to meet this need. A module is a unit of work space, the dimensions of which are determined by a use factor. By this method a large area can be divided into a number of small rooms of equal size, each with service facilities. When necessary, it can also be used as one large room.

For further discussion of modular dimensions see BRAB Conference Report No. 3, being the Proceedings of a Conference on Laboratory Design for Handling Radioactive Materials, November 27 and 28, 1951, condensed by the Building Research Advisory Board, 210 Constitution Avenue, Washington, D. C. (144 pages, 1952. $4.50) pages 7 to 8.

Most health-physics authorities recommend that locker facilities be provided for the storage of street clothing and that work clothes and coveralls which are used on the job be stored separately in an adjacent area. A washroom between the two locker spaces enables personnel to wash up after leaving the job before donning their street clothes.

Where large quantities of highly radioactive materials are involved, the arrangement of rooms in relation to corridors should permit safe movement of personnel even though a radioactive spill may have occurred in a particular room.

Emergency means of egress, in addition to doorways for normal use, are advisable where there is danger of flash fire or accidental release of strong radiation.

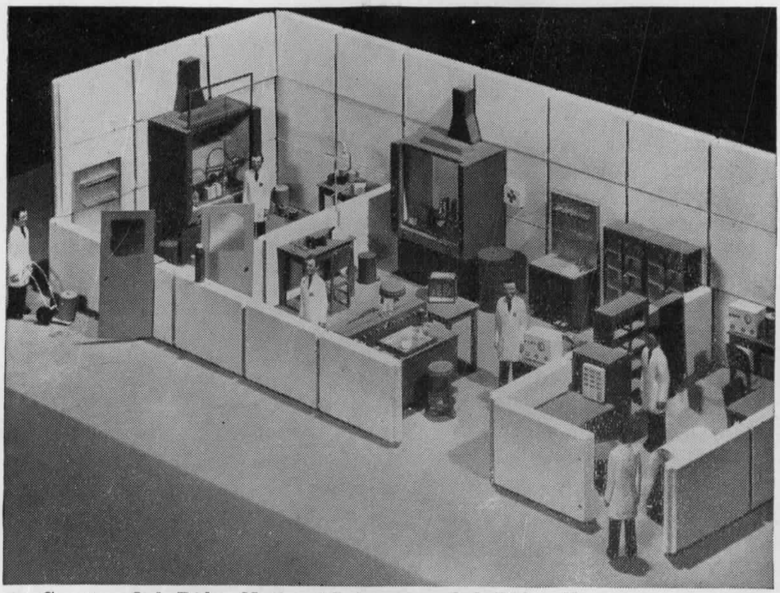
Courtesy U. S. Atomic Energy Commission

The picture shows one of the rooms at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, in which a person working with radioactive materials can determine if his body or clothing have become contaminated. The workman has just entered the room and is monitoring himself with a "frisker." Note that he is wearing a film badge and a pocket dosimeter.

materials used for shielding purposes the flooring must also be able to withstand heavier than normal loads.

One type of floor which meets most of the requirements consists of a concrete base covered with waterproof paper or metal foil and a top surface of rubber or plastic flooring materials in sheet or tile form. The floor must be waxed to fill the cracks in divisions and to provide the required surface continuity.

Experiments have shown that there is a considerable difference in susceptibility to radioactivity contamination among the many commercial floor materials. In one laboratory in which a dangerous spill of radioactive materials occurred it was necessary to decontaminate the painted concrete



Courtesy Oak Ridge National Laboratory, Oak Ridge, Tennessee

This photograph of a model of a three-room laboratory shows the components of an arrangement dictated by the particular needs of the work carried on in such rooms. This laboratory unit has a high-level room on the left, a low-level room in the center and a radiation counting room on the right. This arrangement prevents random radiations from the high-level laboratory from registering false "counts" on the counting room instruments and minimizes the possibility of spreading contamination. Trays are used in the hoods on the laboratory benches to catch any spilled materials. Lead in the hoods and lead storage containers on the floor beside the hood protect investigators from the penetrating gamma radiations. Shipping containers are received and amounts to be used are removed and processed in the high-level room at the left. The center room is used in the experimental investigation.

3.2. Floors

Selection of floor materials for any laboratory must meet the demands of comfort, appearance, cost, ease of maintenance and resistance to wear, corrosion, fire and water. In addition, the particular work in a laboratory may require that the floor be electrically-conductive and non-sparking. To all of these requirements the radioisotope laboratory adds the requirements that the floors have a continuous surface, that they have a low porosity and that they can be easily replaced. Because of the weight of and wood floors by heating the surfaces with an oxyacetylene torch followed by scraping and vacuuming. New linoleum was effectively cleaned by scouring, but old linoleum with a cracked surface had to be carefully disposed of as radioactive waste.

The use of metal sidewalk gratings for flooring has been found efficient in many laboratories where the equipment was multi-story in extent. However, this procedure is hazardous in laboratories handling radioactive materials. A spill on one of the upper levels can result in a radioactive shower on the areas below.

3.3. Walls and Partitions

Fixed walls and partitions are used for corridors, offices, and other main divisions of the laboratory building. Movable partitions may be used to separate laboratory modules of work space, but their use should be restricted to those areas in the building where the need for future flexibility is evident. Such area dividers yield the flexibility so often needed in a radioisotope laboratory and permit erection of temporary radiation shields as needed. Should the partition become contaminated, it can be removed and replaced quickly with a clean unit.

Use of the common partition surface of plaster for radioisotope laboratories is avoided except where sanitation or health-physics considerations require impervious surfaces that cannot be obtained more economically by other finishes. All plaster surfaces should be painted and, where contamination is probable, a smooth non-porous paint or one of the strippable plastic paints should be used. Unprotected porous surfaces are susceptible to contamination and in the removal of such a wall, plaster dust may spread the contamination throughout the building. Metal partitions, preferably with vitreous enamel surfaces, are probably the most easily handled of the materials. A concrete block wall with a special smooth hard surface coating will reduce porosity to a satisfactory degree.

3.4. Ceilings

Laboratory ceilings serve as the support for service pipes, heating and ventilating ducts and light fixtures in addition to their normal functions. Structural framing, duct work and piping runs should be planned to obviate the need for suspended ceilings. Where suspended ceilings are justifiable for providing certain conditions of cleanliness, lighting and ventilation, gypsum board with taped joints, removable metal panels, or plaster, painted, may be used. If the ceiling is merely the exposed lower side of the floor above, it should be given a smooth, non-porous finish.

3.5. Special Coverings and Coatings

The problem of surface contamination which was touched upon previously is of considerable importance to both the health of the laboratory worker and the accuracy of his measurements. To solve this problem the designer can use either materials which are expensive but easily cleaned, or materials which are inexpensive and easily replaced. Metal with a vitreous enamel coating is a good example of the first group, strippable paint is typical of the second. Ordinary paint is usually too porous to prevent contamination and it has been found that most of the organic paints tested under intense radiation tend to blister and check.

Low-porosity surfaces for application to various wall constructions can be obtained through the use of certain commercially prepared coatings including high gloss enamel, plastic paints and heat-reacting varnish. These materials have been found to provide satisfactory surfaces where spills are unlikely.

The use of removable sheeting or strippable coatings is being adapted for surfaces directly exposed to contamination. These coatings are plastic solutions which can be applied with spray guns to specially prepared bases and removed without great difficulty. The use of spray guns for applying materials containing a flammable solvent is not without danger, especially in small areas or rooms. Care should be taken to provide plenty of forced ventilation in the area and to remove all sources of ignition to avoid a possible fire or explosion. Certain plastic adhesive tapes are also being used for this same purpose.

An important characteristic of a strippable coating is its low ash content. Contaminated strippable coatings cannot be carelessly thrown away but rather they must be retained as radioactive waste until they can be disposed of without danger to health. By carefully reducing the coating to an ash the bulk remaining to be stored and disposed of can be brought to a minimum.

PART 4. EQUIPMENT USED IN LABORATORIES HANDLING RADIOACTIVE MATERIALS

4.1. Benches and Hoods

Laboratory benches and tables which are used in processing radioactive materials require non-porous continuous surfaces, preferably a seamless metal sheet with a high lip on all four sides. The use of stainless steel in radiological laboratories should be limited to bench trays as much as possible. It is not recommended for hoods because stainless steel, especially that having a polished finish, does not stand up well under repeated decontamination cycles. A layer of desk blotter or other absorbent paper reduces the spread of liquid spills and facilitates quick cleanup. Extra and unnecessary drawers and shelves are possible accumulation points for dust and contamination.

Porcelain and soapstone sinks are not entirely satisfactory for radioisotope laboratories. Coated steel is more resilient and reduces the possibility of glass breakage, an extra serious mishap when handling radioactive materials. The use of foot or knee operated controls for the drains and faucets leaves the hands free to concentrate on the handling of dangerous materials. Similarly operated controls are available for refrigerators.

The ratio of hooded bench area to open bench area is much higher than in an ordinary laboratory. The hood must have extra strength to support the weight of shielding materials, it must have a minimum of extra equipment and outlets and its design should permit easy and frequent cleaning. One hood now in use for work with a 1-curie source has a floor consisting of an 8-inch slab of steel. The back surface is a concrete wall 2 feet thick and the front shield is a lead barrier 8 inches thick plus lead bricks as needed. The ventilation ducts are made of chemical stoneware and are equipped with water flushing facilities.

4.2. Cabinets and Mounted Apparatus

Not all sources require such shielding and more often the process can be handled in gloved-box enclosures. These boxes have glass or lucite windows and the operator works with his hands in gloves which are an integral part of the unit. For more intense radiation the window is made of thick leaded glass and operations are performed with remote control tongs.

Special storage facilities must be provided not only for new and unused shipments but also for waste materials. The concentration of all radioactive sources in a single room with heavily shielded walls produces excessive exposure hazards inside the room. A preferable plan is to distribute the radioactive sources over a large area and provide individual shields of concrete block or lead brick. Often the concrete or lead shipping container will serve as a satisfactory storage container if it is placed in a location where it will not be subject to fire, explosion or other mishap. Suitable isotope vaults have been used which consist only of a concrete block pierced by a series of holes containing aluminum bottles. Storage of very high energy sources of cobalt-60 (2000 curies and upward) are presently being contained in stainless steel tubes, immersed in water tanks at a depth of 12 feet or more.

In one laboratory a highly radioactive source is used for routine study of hollow steel castings. The source is stored in a floor well of the exposure room and the well is covered with a heavy lead plug. Operations are carried on by remote control through a system of cables and pulleys.

4.3. Special Facilities

Ease of maintenance, cleaning and replacement are requirements which can be applied to all equipment used in radioisotope experiments. However, it is often possible to use commercially-produced standard equipment with minor changes. The radioactive animal can be segregated in a commercial cage which has been sprayed with strippable paint to permit easy decontamination. Other phases of the work may require such special equipment as shielded syringes, electric stirrers or even remote-controlled pipettes to insure the proper conditions.

Deluge type safety showers for emergency use should be installed in all areas where chemicals are handled.

PART 5. SERVICE FACILITIES OF LABORATORIES HANDLING RADIOACTIVE MATERIALS

(See also Part 7, Safeguards and Fire Protection)

5.1. Heating and Ventilating

The design of the heating and ventilating system must insure that the radioactivity of the building atmosphere is well within the limits of safety. The choice of either a central system of ventilation or a system of individual units is dependent upon the particular building and the processes or procedures it houses. A basic principle which must be followed is that there can be no reverse flow of radioactive gases or dusts from "hot" areas into areas of low or normal activity. If the "hot" area can be maintained at slightly below atmospheric pressure, the flow of air will have the proper direction.

Fume hoods serve as the primary means of air removal from laboratory areas. Estimates for the proper face velocity of a hood range from 50 feet per minute to 150 feet per minute and it is evident that every situation must be considered individually. Blower equipment should be located outside the exhaust stream to reduce the possibility of contamination. All hoods in a single area should be controlled by a master-switch so that contamination will not be drawn into the room from an unused hood.

The degree of contamination of the exhaust stream may be such as to require filtration, washing or electrostatic precipitation before discharge to the outer atmosphere. *Recirculation in the building is not acceptable under any circumstance.* Safe disposal of the filter, wash solution or precipitant is itself a problem. Dry filters such as glass wool combined with cellulose-asbestos paper have been found effective.

The use of combustible filter permits easy disposal as an ash, but introduces a fire hazard into the venting system and requires automatic sprinklers or special fire protection measures. In the absence of sprinklers within the ducts, fires in combustible filters are extremely difficult to extinguish.

The use of washing solutions results in large amounts of radioactive liquids which cannot be easily disposed of.

Self-cleaning filters which pass through a viscous liquid yield a radioactive sludge to be disposed of, and the liquid may require additional fire protection because of its flammable nature.

Electrostatic precipitators produce a high degree of dust removal but require periodic cleaning, usually by washing.

Air conditioning for an entire laboratory is an expensive proposition because of the large volumes of air which must be supplied. The heavy protective clothing and gloves which are often required for radioisotope techniques are uncomfortable and a conditioned atmosphere can reduce the possibility of face and neck contamination which is a result of this discomfort.

5.2. Waste Disposal

Disposal of liquid wastes from a radioisotope laboratory requires three systems of sewer drains. The sanitary sewers and the drains from the "cold" areas are little different from those in any laboratory. The third system leads from "hot" laboratory areas to retention tanks where radioactive substances having a short-half life can become less active and where a check of the radioactivity levels can be made. If the level is beyond the limits of safety the liquid must be processed for disposal in one of several ways.

It can be evaporated to a small volume and combined with cement for fixed entombment and burial in the ground or ocean. The contaminated liquid can be diluted sufficiently to reduce the radioactivity to the desired level. A third method uses chemical precipitation to remove the radioactive elements.

Solid waste and trash can be carefully separated into combustible and noncombustible lots by laboratory personnel. The combustible trash is burned in an incinerator and the ash is stored with the materials which cannot be burned in some remote location. The incinerator at one laboratory cost $25,000 to build and maintain because of the necessity to prevent discharge of radioactive smoke and gases into the atmosphere. In some locations it is less expensive to bale the combustibles and store them until radioactivity has decayed sufficiently for safe disposal by burial or burning.

Special attention should be given to the prompt disposal of combustible waste, particularly such waste as absorbent paper and rags that have been used to clean up radioactivity contaminated surfaces. It becomes especially important if the waste has been used to apply nitric acid or other oxidizing chemical that is subject to spontaneous heating. Waste that is collected during normal activity should be stored in metal containers having tight self-closing covers, and should be removed from the laboratory at the end of each day's work.

5.3. Light and Power

Good lighting for the radioisotope laboratory is necessary because of the hazardous nature of the materials being handled and because many of the procedures are remote-controlled operations. The use of a recessed fixture with a glass cover affords a surface which can be easily cleaned and decontaminated. A somewhat similar idea is the hung ceiling made of corrugated translucent plastic panels with all lighting fixtures above. The panels are easily cleaned or replaced.

Lights, ventilation and operation of much remote control equipment are dependent on a reliable source of electrical power. Location of transformers, switches and control boards well away from "hot" areas of the laboratory insures that maintenance work can be done without danger of exposure to radiation.

The need for effective ventilation during and immediately after an emergency such as a fire is urgent in radioisotope laboratories. An auxiliary power system should be available in the larger laboratories to provide temporary lighting and ventilation in these situations.

5.4. Stock Supplies and Storerooms

With the exception of small amounts needed for immediate or continuous use chemicals, materials and supplies should be in separate storerooms and not in areas where work with radioactive materials is carried on.

The presence of radioactive materials in a laboratory structure accents the need for every precaution in the storage of any materials which are hazardous because of flammability, combustibility, and tendency to explode. Cylinders containing compressed gases should be securely mounted in locations not subject to high temperatures.

In many laboratories it has been found desirable to establish dual storerooms. One room is assigned for new, unused equipment and the other contains equipment which has been used and possibly contaminated, but which may still be satisfactory for certain purposes.

PART 6. FUNDAMENTAL FIRE CHARACTERISTICS

This part discusses fundamental fire and explosion characteristics which the property of radioactivity does not change and which may affect design and operation of laboratories. Part 7, Safeguards and Fire Protection, relates these general characteristics to the special problem of laboratories handling radioactive materials.

6.1. Terms and Principles

Fires and explosions are, for the most part, the same fundamental phenomenon, the difference being in the time factor. Fire may be defined as rapid oxidation with the evolution of light and heat. In its broader sense, combustion includes not only the process of chemical combination with oxygen but also combination with chlorine and various other substances.

So-called spontaneous heating is usually one which starts with a slow chemical reaction or slow oxidation. This is due to inherent characteristics of materials which cause an exothermic (heat producing) chemical action to proceed without exposure to external heat. (See Section 5.2.)

In the burning of most substances, the actual combustion takes place only after the solid or liquid fuel has been vaporized or decomposed by heat to produce a gas. Visible flame is the burning gas. In the case of solid fuels, which do not evaporate or decompose to form gas at ordinary temperatures, combustion also takes place by direct combination of the fuel with oxygen. An example is the glowing combustion of charcoal. A few materials, such as pyroxylin plastic, contain enough oxygen, chemically combined, so that partial combustion or decomposition may occur without oxygen from the air.

Ignition of a combustible material occurs when there is a sufficiently high temperature and a sufficient quantity of heat to initiate self-sustained combustion. Where the pieces of combustible material are small, there is very little absorbing capacity and a smaller quantity of heat will cause ignition. This is illustrated by the ready ignition by a single match flame of ordinary wood shavings. Where the combustible material is still more finely divided, in the form of a dust cloud in the air, ignition can occur from an even smaller heat source. The same thing is true in the case of flammable gases and vapors (such as gasoline vapor) where the combustible material is divided into its individual molecules.

Explosions are of four principal kinds: (1) release of heat energy by rapid oxidation (gasoline vapor-air explosion), (2) release of energy by decomposition (dynamite explosion), (3) release of energy by release of pres-