NFPA No.

801

FACILITIES HANDLING RADIOACTIVE MATERIALS 1970

Seventy-five Cents

NATIONAL FIRE PROTECTION ASSOCIATION
International
60 Batterymarch Street, Boston, Mass. 02110

4M-6-70-FP
Printed in U.S.A.

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Recommended Fire Protection Practice for

Facilities Handling Radioactive Materials

NFPA No. 801 — 1970

This edition of Recommended Fire Protection Practice for Facilities Handling Radioactive Material was prepared by the NFPA Committee on Atomic Energy and officially adopted on May 19, 1970 at the NFPA Annual Meeting in Toronto, Ont.

Not only has the format been revised, but the entire publication has been up-dated to reflect current thinking and practices. It has also been expanded to apply to all locations, exclusive of nuclear reactors, where radioactive materials are stored, handled, or used.

Origin and Development of No. 801

The Committee on Atomic Energy was organized in 1953 for the purpose of providing the fire protection specialist with certain fundamental information about radioactive materials and their handling, and to provide designers and operators of such laboratories with some guidance on practices necessary for fire safety. The first edition of No. 801, whose coverage was limited to laboratories handling radioactive materials, was adopted at the 1955 NFPA Annual Meeting.

Committee on Atomic Energy

SCOPE: To develop standards for the safeguarding of life and property from fires in which radiation or other effects of nuclear energy might be a factor.

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Recommended Fire Protection Practice for

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INTRODUCTION

The nature of radioactive materials is such that their involvement in fires or explosions can act to impede the efficiency of fire-fighting personnel, thus resulting in increased potential for damage by radioactive contamination.

This text deals with practices aimed at reducing the risks of fires and explosions at facilities handling radioactive materials and also with certain methods for minimizing damage by radioactive contamination resulting from fire or explosion. The recommendations are applicable to all locations, exclusive of nuclear reactors, where radioactive materials may be stored, handled or used, including hospitals, laboratories, and industrial properties.

Further, this text outlines to the fire protection specialist, basic information concerning radiation protection methods and provides some guidance on fire protection practices to those persons responsible for the design or operation of facilities which involve the storage, handling, or use of radioactive materials.

Additional specific recommendations for nuclear reactors are described in NFPA No. 802, Recommended Fire Protection Practice For Nuclear Reactors.

All other applicable NFPA Codes, Standards and Recommended Practices should be followed.

PART I

SOURCES OF RADIATION — THE NATURE OF THE FIRE PROBLEM

1.1 General.

Radioactive materials are substances which spontaneously decay emitting energetic rays or particles in the process. Certain elements occur in more than one form. The various forms are chemically identical, but differ in their atomic weights. These different forms of the same elements are called isotopes. Those which are radioactive are called radioactive isotopes. It is possible for an element to have one or more nonradioactive (stable) isotopes and one or more radioactive isotopes (radionuclides). Each of the radioisotopes emits a definitive type or types of radiation. In discussing radioactive material, therefore, it is always necessary to use the terminology which identifies the particular isotope, such as Uranium-238 or alternatively 238 Uranium.

Some radioisotopes occur in nature and may be separated by various physical or chemical processes and others are produced in particle accelerators or nuclear reactors.

Emissions from radioactive materials cannot be detected directly by any of the human senses. Of themselves, radioactive materials present no unusual fire hazards as their fire characteristics are no different from the fire characteristics of the nonradioactive form of the same element.

Their presence may complicate a fire-fighting situation by presenting hazards of which the fire fighter may be unaware and may cause real or imagined hazards to fire fighters which may inhibit normal fire-fighting operations. The dispersal of radioactive materials by fumes, smoke, water or by the movement of personnel, may cause a radiation contamination incident which may contribute greatly to the extent of damage, complicate cleanup and salvage operations, and delay the restoration of normal operations.

1.2 Fire Problems.

Facilities handling radioactive materials should be designed and operated in accordance with the usual good practices, but with special recognition given to the properties of radioactive materials. 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 radiation.

(2) Possible increased delay in salvage work and in resumption of normal operations following fire, explosion or other damage due

to radioactive contamination and the consequent need for decontamination of buildings, equipment and materials.

(3) Possible increase in the total damage resulting from contamination of buildings and equipment to the point that they are unusable.

Radioactive materials may be expected to melt, vaporize, become airborne, or oxidize under fire conditions. None of these alterations will 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 could be carried by air currents and subsequently deposited on other parts of the burning buildings or even on neighboring buildings or land. These loss and personal injury aggravating characteristics of radioactive materials justify a high degree of protection against fire and explosion at those facilities where this potential exists. The use of fire resistive building components and equipment is highly desirable in those areas where radioactive materials are to be stored or used. Some form of automatic protection, such as automatic sprinklers, would be highly advantageous wherever combustibles are encountered since this makes it less necessary for personnel to expose themselves to possible danger, automatically begins the fire control process and sounds an alarm and makes efficient use of the water available.

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

The property manager should keep the local fire department advised of the locations and general nature of radioactive materials on hand. Preemergency planning is most necessary in order that fire fighters may function at maximum efficiency without exposing themselves to harmful radiation on the one hand and without causing unwarranted fears of radiation hazard to inhibit the fire-fighting effort on the other. Specific provision should be made where necessary by the property manager and the fire department for monitoring service, protective clothing and respiratory protective equipment, the need for which is determined by the nature of the specific hazard. The radiation hazard can usually be anticipated in preemergency planning studies (see Part V, Protection Against Fire and Explosions).

1.3 Radiation Hazards and Protection Methods.

Radiation exposure may be either chronic or acute. Chronic exposure includes the genetic effect of radiation exposure received by large segments of the population. Regulations for the control of day-in and day-out exposures which produce the chronic exposure are not significant under emergency short-term exposure conditions. Under emergency conditions the levels of radiation exposure which can cause acute injury or death become significant. This distinction should be understood by fire fighters in order that they will understand that radiation exposures which are tolerable in the event of a fire or other accident, especially where rescue operations are called for, are unsuitable for day-in, day-out exposure.

Aided whenever practical by the Plant Health Physics Group, the level of radiation risk to be assumed should be decided by the officer in charge of the fire-fighting operation just as he decides the level of all other risks to be assumed by his men. He should take into account the degree of risk based upon his knowledge and the importance of the operation to be accomplished.

(a) **Nature of the hazard of radioactivity.** In order that fire-fighting personnel may understand how to effectively protect themselves against dangerous amounts of radiation, it is necessary that they be familiar with the basic nature of radiation and the safeguards which are generally provided under normal operating conditions at those facilities where this hazard is to be found. While quite brief and simplified, the following paragraphs should assist in identifying for the fire fighter those areas of concern:

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 spontaneous disintegration of a nucleus. Each radioactive isotope has a "half-life" — a period of time that is a 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.

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 neutrons are likely to be present 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, makes them 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 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 within the body after having entered the body in some manner).

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. In industry safeguards are provided for the purpose of keeping radiation exposure to personnel to a practical minimum and under certain amounts.

In an emergency case, such as a necessary rescue operation, it is considered acceptable for the exposure to be raised within limits for single dosages. The National Committee on Radiation Protection has recommended 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 may be applied to the fire fighter for a single emergency. Internal radiation exposure may be guarded against by adequate respiratory equipment.

(b) Personnel Protection Methods. "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 should be provided to detect radiation contamination in clothing or on the skin. There should be a routine monitoring of the degree of exposure to the various particles and rays. Personnel working in the facility will generally be required to wear pocket radiation meters or indicators which are examined periodically and records of the exposure kept for future reference.

The practice of placarding dangerous areas is for the protection both of regular operating personnel and those who, like fire fighters, may have to deal with an emergency situation. If fire fighters are to have the best protection, they should 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 should reach a meeting of minds with the scientists or other personnel directing the 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 cleanup 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.

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 fourth, by the use of suitable materials interposed between the radiation 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 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 biomedical examination.

1.4 "Sealed" and "Unsealed" Radioactive Materials.

For purposes, of this publication, a "sealed" radiation source is one which is tightly encapsulated (or the practical equivalent by bonding or other means) and is not intended to be opened at the facility. An "unsealed" source is one which is not so sealed and/or is intended to be opened at the facility.

The protection of properties against the spread of radioactive contamination as the result of fire or explosion is considerably simplified by the fact that many radioactive materials are shipped, stored, and in some cases used without ever exposing the radioactive material itself to air. In many cases the shipping containers, or even used containers, may have sufficient integrity to withstand a fire or an external explosion. Examples are: Metallic Cobalt 60 sources tightly encapsulated in steel and sealed sources used in Beta gage thickness and measuring devices. It may be noted that there have been several instances of stainless steel encapsulated Beta gage sources surviving appreciable fire exposures without release of the radioactive isotope contained therein.

The principal reason radioactive materials are sealed is to prevent spread of contamination. In some cases the manufacturer of the container may not thoroughly consider fire resistance and it is important to remember that a sealed source may burst if its contents are subject to thermal expansion as a result of exposure to fire.

Unsealed sources, such as may be found in laboratories during transfer and use, may be readily spread about during a fire or an explosion.

1.5 Applications

The specific application for ionizing radiation is somewhat governed by the physical makeup of the source, whether it is in the "unsealed" or "sealed" form, and sometimes by its radiation intensity.

Most of the thousands of scientific and industrial uses of radioactive materials take advantage of one or more of the types of radiations emitted, i.e., alpha, beta, gamma rays, and neutrons. Certain radioisotope applications take advantage of the ultrasensitive detection capability of certain instruments for extremely small amounts of radioisotopes. Other uses take advantage of the ability of radiation to penetrate matter; while the extremely energetic sources have the ability to bring about biological, chemical and physical changes.

The most common nuclear radiation applications can be grouped into the following categories:

1. Radioisotope "tracer" applications utilize small amounts of short-lived, unsealed sources, involving easily detectable radiation emissions of the particular radioisotope employed. Such applications have found wide use in medical diagnosis, biological and agricultural explorations, water surveys, irrigation control, underground leak and seepage detection, atmospheric pollution, flow and transport rates in processing operations, lubrication and wear measurements, and rapid chemical analysis for continuous process control, including the new "activation analysis" technique, which is finding special use in criminal investigations and toxicology.

2. Radioactive gages and process control instruments utilize the more penetrative types of radiation from sources which are sealed to prevent the radioactive material from leaking out. The radioactive material in no way enters into the system or process. This includes a wide range of operations from gaging of thickness or density to monitoring height and levels in storage and process equipment, which can be automatically controlled by coupling with various servomechanisms.

3. Certain of the more intensive sources of radiation have the ability to ionize gases. One of the important applications is to prevent accumulation of static electricity on moving machinery. Here the ionized air effects an "atmospheric grounding" and prevents buildup of static charges (Radium and Polonium as low-

penetrating alpha emitters have been used along with the more penetrating beta-emitter Krypton-85). These sources are also being used as activating agents with self-luminous (phosphorescent) paints and coatings for various markings and emergency lighting, and instrument panels. The automotive industry has used ionized air (with Polonium-210) to remove dust and lint from surfaces to be painted.

4. Radioactive materials are being employed in the development of atomic batteries (as "isotopic power fuels"). The small currents generated are utilized in low-current demand microcircuits; also, the liberation of thermal energy during radioisotope decay is converted into useful electricity through thermoelectric couples or thermionic systems. The sources include some fission products and some of the radioactive materials obtained by neutron-irradiation of special target materials.

These auxiliary isotopic power systems (called SNAP — Systems for Nuclear Auxiliary Power — devices) are now being used to power navigational satellites in space and meteorological satellites, remote automatic weather stations (both in the North and the South Poles), and navigational buoys and undersea electronic equipment.

5. Powerful sources are finding wide use in industrial radiography and nondestructive testing of critical process equipment. The leading industrially used isotope of high-energy emission is Cobalt-60 which is obtained by the activation of Cobalt in a reactor.

The industrial radiographer has a choice of X-ray machines or radioisotopes. In many cases the latter offers the most advantages. The increased availability of Cobalt-60 has expanded its use greatly in more extensive radioagraphic inspection as a routine testing procedure. Steel thicknesses of from ½ inch to 6 inches can be radiographically evaluated and many companies are now licensed to provide such examination services.

Other radioisotopes which have less energetic gamma ray emissions than Cobalt-60, are coming into wider use for lighter materials such as aluminum, copper and zinc and thin sections of steel.

6. Powerful sources of high intensity radiation such as from Cobalt-60 are finding applications in food preservation, deinfestation processes and in radiological sterilization of pharmaceutical and medical supplies. Research and development indicate considerable promise in polymerization of plastics, vulcanization of rubber, improvement of wood properties, graft polymerization of plastics, and in catalyzing chemical reactions.

1.6 Nuclear Reactors.

Nuclear reactors present special problems which require individual study. They are used for electric power generation, research purposes, production of radioisotopes and ship propulsions.

The general fire protection recommendations for nuclear reactors are published in NFPA Pamphlet No. 802 entitled "Recommended Fire Protection Practice for Nuclear Reactors."

1.7 Nuclear Reactor Fuel Element Manufacture.

Certain radioactive nuclides are fissile (fissionable). Neutrons absorbed by such nuclides emit additional neutrons plus energy, largely in the form of heat. Because more neutrons are emitted than are absorbed, a self-sustained nuclear chain reaction is possible when certain conditions are met. These conditions include a minimum quantity of fissile material (critical mass) and other factors such as shape, geometry, reflection and moderation (or slowing down of neutrons). Fissile materials to be used in a nuclear reactor are arranged in specific arrays using fuel elements in order to optimize conditions for fission to take place. When a nuclear chain reaction takes place where it was not intended, a "criticality" accident is said to have occurred.

The external radiation hazards present during fabrication of Uranium-235 fuel elements is of a low order. Uranium-233 and Plutonium-239 present severe inhalation hazards to personnel, therefore an enclosed protection system must be used. These systems are called "glove boxes." They may be extensive with appreciable glass or transparent plastic areas and present fire protection problems, some of which have not yet been solved. Under normal conditions, the radiation hazard, although present, can be largely protected against. On the other hand, if a "criticality" incident should occur, the type and quantity of radiation emitted create grave hazards to personnel. Even a small fire within a "glove box" can produce serious consequences if not properly controlled. Fire control systems and procedures for "glove boxes" should be carefully developed and applied before the boxes are used. Generally such protective systems are custom-designed for each particular application (see Paragraph 4.4).

In handling fissile materials, precautions should be taken not only to protect against the normal radiation hazard, but also against the "criticality" hazard caused by the assembly of a "minimum critical mass." Since water is a reflector and a moderator of neutrons, concern for a "criticality" hazard sometimes leads to the unjustified and unevaluated exclusion of fire protection water from the area where fissile materials are stored or handled. The possibility of water moderation and reflection bringing about a "criticality" accident can be calculated in advance. If, in fact, such a hazard exists, combustible material which would require the use of water for fire fighting should be eliminated. If combustible materials are unavoidably present in quantity sufficient to constitute a fire risk water or other suitable extinguishing agent should be provided for fire fighting purposes. The fissile materials should be so arranged that water moderation and reflection will not present a hazard. In many facilities fissile materials are stored and handled in sprinklered areas.

In addition to the hazards of radiation and the potential for accidental "criticality," fuel element manufacture will often involve the use of combustible metals such as Uranium and Plutonium and combustible cladding material such as zirconium. The prevention and control of fires involving combustible metals requires special techniques (see NFPA Nos. 48, 481 and 482M).

It is important to remember that nuclear fuel elements are extremely valuable and extraordinary precautions may be necessary to protect them from the effects of an otherwise inconsequential fire.

1.8 Nuclear Fuel Reprocessing.

Reactors are generally capable of utilzing only a very small part of the fuel in its elements and as a result it is economical to recover the remaining fuel by reprocessing the so-called "spent" elements in specially designed facilities. These plants contain huge inventories of radioactive materials (fission products) extracted from spent nuclear fuel elements which were produced as by-products during nuclear fission. Processing operations usually will involve large quantities of flammable and/or corrosive liquids. Fire and explosion hazards will be present and the possibility of an accidental criticality incident, although guarded against and remote, will also be present.

The large quantities of highly radioactive materials present require massive shielding for personnel safety and most chemical processing and maintenance operations are conducted entirely by remote controls. Fire hazards are present during the sawing and chopping of fuel elements containing combustible metals, either in the form of fuel or cladding. Specially designed fire detection and control systems — arranged for remote control — are used to protect this operation as well as the chemical processing operation. Ventilating systems should be so arranged as to maintain their integrity under fire conditions. Such facilities handling large quantities of highly radioactive materials warrant the application of a high degree of fire protection planning in all areas.

1.9 Particle Accelerators.

Radiation generators 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 various charged particles of which atoms are composed to tremendous speeds and, consequently to high energy levels. Radiation machines furnish scientists with atomic particles, in the form of a beam, which may be utilized for fundamental studies of atomic structure. In addition, they furnish high energy radiation which may be utilized for radiography, therapy, or chemical processing.

These machines emit radiation only while in operation and attempts to extinguish a fire in the immediate vicinity of the machine should be delayed until the machine power supply can be disconnected.

However, certain "target" materials become radioactive when bombarded by atomic particles and for this reason monitoring equipment should be used during fire-fighting operations to estimate the radiation hazard. The usual hazard presented by particle accelerators is largely that of electrical equipment. There are, however, some important exceptions to this. Some of the more modern installations may use such hazardous materials as liquid hydrogen or other flammable materials in considerable quantities. Large amounts of paraffin are sometimes used for neutron shielding purposes. Another factor is the possible presence of combustible oils used for insulating and cooling. Especially important is the fact that these devices are usually one of a kind and the values involved are large in proportion to the volume occupied.

Industrial applications include chemical activation, acceleration of polymerization in plastics production, and the sterilization and preservation of packaged drugs and sutures. The general fire protection and prevention measures for these machines should include the use of fire resistive or noncombustible housing, noncombustible or slow-burning wiring and interior finishing, and the elimination of as much other combustible material as possible. Automatic sprinkler protection should be provided for areas having hazardous amounts of combustible material or equipment and special fire protection should be provided for any high voltage electrical equipment.

The practice of constructing highly combustible structures, or the use of house trailers with combustible interior finish for the housing of experimental equipment, provides the fuel for a hot fast fire which can do serious structural damage to an unprotected steel building, and extensive damage to the accelerator. Even in a sprinklered building the loss may be severe. Such structures should be built of noncombustible or fire retardant materials, or should be provided with automatic sprinklers, even if the building in which they are located is sprinklered.

PART II

ARRANGEMENT OF FACILITIES HANDLING "UNSEALED" RADIOACTIVE MATERIALS

2.1 Special Considerations.

There are special considerations which should be applied in the arrangement of facilities handling radioactive materials. The radioactive materials themselves may or may not present special fire characteristics, but the combating of a fire may be inhibited by the presence of radioactive materials and the restoration of the property after the fire has been extinguished may be complicated by the problem of radioactive contamination. It should be recognized that radioactive contamination may be the most costly element in a fire loss; therefore, the control of a fire loss is inextricably related to the control of radioactive contamination. Some of the important features to be considered in this connection are:

1. Grouping of facilities handling significant quantities of unsealed radioactive materials facilitates air cleaning, fire and process control procedures, and decontamination.

2. Where the probability of radioactive contamination is a serious matter, the design of many other building components may become critical. Light fixtures, electric conduits, ceilings, heating and cooling systems and operating equipment should be designed and installed with the view of facilitating decontamination.

It should be noted that the possibility exists, under certain circumstances, that radioactive contamination might be so costly to clean up that it would be cheaper to abandon a valuable building. Consideration should be given not only to the immediately proposed uses, but to those that are reasonably foreseeable, bearing in mind that all successful facilities usually expand their operations.

2.2 Location With Respect To Other Buildings and Within Buildings.

Facilities having quantities of radioactive materials that might become airborne or waterborne in case of fire, explosion, windstorm, earthquake, flood or other accident should be located well away from other important buildings or operations where contamination could interfere seriously with plant operations or where radioactive substances could come in contact with materials susceptible to damage.

In general, facilities handling radioactive materials should be so located that there is no *through* or *cross* traffic.

Particular attention should be given to the location of intakes and outlets of air cleaning systems. A breakdown in an air cleaning system can be more serious if the discharged air can immediately be drawn into another system. General isolation of radiation facilities from all other plant facilities causes an increase in both construction and operating costs, but should be undertaken if a study of the possible results of a contamination incident indicates that this is justified. In order to avoid unnecessary complication of accidents, such facilities should be located away from those handling explosives, or exceptionally flammable materials.

2.3 Planning for Decontamination.

The extent to which decontamination might be necessary depends upon the amount of radioactive material being handled, its half-life, type of radiation emitted, and its chemical and physical form. Taking all of these into account, a realistic assumption should be made as to the extent of a possible contamination incident. When decontamination is necessary, it is accomplished by hand, often by personnel not skilled in the work of clean-up, but highly paid because of their other skills, and often in a hurry. All these factors tend to raise costs and thus justify capital expenditures to reduce them to a minimum through good preemergency planning procedures. The basic purpose is to provide construction which will confine a contamination incident as closely as possible and which also will include easily cleaned surfaces.

2.4 Construction.

Buildings in which radioactive materials are to be used should preferably be of single story height without basements or other below-grade spaces. Construction should be fire resistive or noncombustible, including interior finish, acoustical or insulating treatments, and partitions.

(a) **Floors.** Selection of floor materials for any facility should meet the demands of comfort, appearance, cost, ease of maintenance, and resistance to wear, corrosion, fire and water. In addition, the particular work may require that the floor be electrically conductive or nonsparking. To all of these requirements the radioisotope facility adds the requirements that the floors have a continuous surface, that they have a low porosity and that they can be easily cleaned or replaced. Because of the weight of materials used for shielding purposes, the floor may be required 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 impervious flooring materials in sheet or tile form. The floor should be waxed to fill the cracks in divisions and to provide the required surface continuity.

Experiments have shown that there is considerable difference in susceptibility to radioactivity contamination among the many commercial floor materials. In one laboratory in which a serious spill of radioactive materials occurred, it was necessary to decontaminate the painted concrete 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 open grating for floors should generally be avoided as a spill on an upper level may result in a contaminated shower on the floors below.

(b) **Walls and Partitions.** The use of partition surfaces of plaster for radioisotope laboratories should be avoided except where sanitation or health-physics considerations require impervious surfaces that cannot be obtained more economically by other finishes. All such plaster surfaces should be painted and, where contamination is probable, a smooth nonporous 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 contaminants 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 generally reduce porosity to a satisfactory degree.

(c) **Ceilings.** 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 or removable metal panels may be used. If the ceiling is merely the exposed lower side of the floor above, it should be given a smooth, nonporous finish.

(d) **Protective Coatings.** Through the proper selection of materials the designer can economically facilitate decontamination efforts. Materials which are expensive but easily cleaned, or materials which are inexpensive and easily replaced may be used. 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 of the base material and it has been found that most of the organic paints tested under intense radiation tend to blister and check.

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

The use of removeable sheeting or strippable coatings is being adapted for surfaces directly exposed to contamination. These coatings are plastic solutions usually containing flammable solvents which can be applied with spray guns to specially prepared bases and removed without great difficulty. The use of spray guns for applying such materials may be hazardous, 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 purpose.

Care should also be used in removing and disposing of these coatings. Not only should their contaminated nature be considered, but some, when burned, liberate corrosive vapors which can cause extensive damage to sensitive equipment.

PART III

SERVICE FACILITIES

3.1 Special Considerations.

The design and installation of such service facilities as light and power, heating and ventilation, storage, and waste disposal at facilities not handling radioactive materials usually present no major problems. The introduction of radioactive materials into a plant presents additional hazards to both personnel and property which warrants special considerations of these services. Inadequate attention to the design features of service facilities has unfortunately contributed to the extent of decontamination found to be necessary following accidents. It is considered good practice to analyze the design of each service for the purpose of determining what effect the service would have upon the spread of contamination following an accident. An appraisal of the seriousness of contamination spread may then be used to determine the necessity for modifying the design of the service facility under consideration.

3.2 Heating and Ventilating.

The design of the heating and ventilating system must insure that airborne radioactivity of the building atmosphere is within permissible limits. The choice of either a central system of ventilation or a system composed of individual units is dependent upon the particular building and the processes it houses. A basic principle which should 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 area of high activity can be maintained at slightly below atmospheric pressure, the flow of air will have the proper direction to minimize the spread of contamination should an accident occur.

Fume hoods serve as the primary means of air removal from some facilities. Estimates for the proper face velocity of a hood range from 50 feet per minute to 150 feet per minute. Such variable conditions require that every situation be considered individually. Electric motors driving ventilating equipment should be located outside the exhaust stream to reduce the possibility of their being contaminated. No part of the exhaust system within the building should be under positive pressure. All hoods in a single area should be controlled by a master-switch in order that contaminants 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 of air within an area wherein dangerous radioactive materials are handled should not be permitted under any circumstances. Careful attention should be given to the disposal of filters — especially if they are loaded with materials having any significant degree of combustibility. The use of combustible filters introduces a serious fire hazard into the ventilating system and requires automatic sprinklers or other special fire protection. In the absence of protection systems within the ducts and for the filter banks, fires in combustible filters become extremely difficult to extinguish.

In addition, the accidental burning of combustible filters carrying radioactive contaminants may create a serious contamination exposure situation which could involve large areas as the radioactive material is discharged from the exhaust system.

Self-cleaning filters which pass through a viscous liquid yield a radioactive sludge to be disposed of, and the filter system may require additional fire protection because of the flammable nature of the liquid. Such systems should generally be avoided in areas wherein radioactive materials are handled.

Electrostatic precipitators produce a high degree of dust removal but require periodic cleaning, usually by washing, with the result that a large amount of radioactive liquid waste must be disposed of. Such filters should be cleaned regularly in order to prevent the buildup of possibly combustible lint and dust which could present a fire hazard.

The use of filters of low combustibility — such as those which comply with Underwriters' Laboratories Standard No. 586 — is recommended. Their use considerably reduces the likelihood of the spread of contamination by fire. Roughing filters, when necessary, should be constructed of materials which will not contribute to the fire hazard.

The location of fresh air inlets for ventilating systems should be very carefully chosen. Such inlets should be located where it would be most unlikely for radioactive contaminants to be present. For example, they should not be located near storage areas of combustible radioactive waste material which upon ignition could discharge radioactive combustion products which may be picked up by the ventilating system.

3.3 Light and Power.

Good lighting for facilities handling radioactive materials is highly desirable because of the hazardous nature of the materials being handled and because some procedures require remote-controlled operations. Lights, ventilation and operation of much remote-controlled equipment are dependent upon a reliable source of electrical power. Location of transformers, switches and control panels well away from "high activity" areas insures that maintenance work can be done without direct exposure to radiation from such areas. The need for effective ventilation during and immediately after an emergency such as a fire is of considerable importance. An auxiliary power system should be available to provide temporary lighting and ventilation in those facilities wherein the radioactive materials being handled are potentially dangerous to personnel.

It is important that electrical equipment be selected for its ease of decontamination and early restoration to service in those areas wherein a contamination incident is considered likely. Electrical conduits leading from "hot" areas should be sealed to prevent entrance of radioactive materials even under conditions of normal use.

Cable trays carrying electrical conductors should be discouraged in those areas subject to either normal or accidental release of contaminants due to decontamination difficulties. Experience has shown that cable trays can, under certain conditions, present a fire hazard of considerable magnitude. Upon burning certain types of insulation will release corrosive gases which can cause severe damage to sensitive equipment. In general, wiring in conduit is preferred to cable trays in such areas.

3.4 Storage.

With exception of those 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 conducted.

The presence of radioactive materials accents the need for the exercise of every precaution in the storage of materials which are hazardous because of flammability, combustibility, or reactivity. Automatic sprinkler protection provides the best means for controlling fires involving combustible occupancies and should be provided unless it can be shown that their operation will definitely create a situation more hazardous than that brought about by uncontrolled fire. It is very important that radioactive materials not be stored in the same area as other materials, especially if either are flammable or combustible in nature.

Special consideration should be given to the storage of radioactive compressed gases as their release under accidental conditions can result in a severe loss by contamination. Storage facilities for such gases should be designed with the peculiar characteristics of the gases in mind. Special noncombustible storage facilities located remotely from the main facility may be necessary in some cases.

3.5 Waste Disposal.

The disposal of liquid radioactive waste usually will present no fire hazards unless the liquids are combustible. Such combustible liquids should be handled with recognition to their fire hazard as well as to their radioactivity. Some facilities may find it less expensive to concentrate their radioactive wastes and either store them until the radioactivity has decayed to a safe level before disposal or contract with a commercial radioactive waste disposal organization for its removal.

Special attention should be given to the prompt disposal of combustible waste, particularly such waste as absorbent paper and rags which have been used to clean radioactive contaminated surfaces. It becomes especially important if the waste has been used to apply nitric acid or other oxidizing chemicals that are 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 operating areas of the facility at the end of each work day.

Care should be exercised in selecting the locations for the storage of radioactive waste material. Large concentrations of such combustible waste should not be allowed to accumulate. Such material should not be located near the fresh air intakes to the air-conditioning systems nor the air intakes for air compressors. Should the products of combustion of waste materials containing long-lived radioactive materials be dispersed through air-conditioning or compressed air systems, a decontamination problem of serious magnitude could result.

PART IV

EQUIPMENT FOR HANDLING AND PROCESSING RADIOACTIVE MATERIALS

4.1 General.

The type of equipment used to process radioactive materials depends not only upon the work to be performed but also upon the degree of hazard associated with the material and the process it is to undergo. Materials having low levels of radioactivity and having little or no inherent fire or explosion hazards require less protective equipment than others. For purposes of personnel protection, the amounts and kinds of shielding required will depend upon the types of radiation emitted as well as the activity involved. In addition, the chemical and physical nature of the radioactive materials will dictate the degree of containment necessary, as well as the construction materials used in the containment system. All equipment to be used for handling and processing radioactive materials should be designed to minimize fire and explosion potentials as well as to protect personnel against harmful radiation exposure and damage to property by contamination. There are many types of equipment and systems for handling radioactive materials but most may be classified as either benches, hoods, glove boxes, or "hot" cells.

4.2 Benches.

Benches are generally used for handling relatively small amounts of alpha or beta emitting materials requiring little or no shielding with handling by gloved hands or tongs. No special ventilation for the bench is provided in most instances and its use is thereby restricted to materials which will not easily become airborne.

Benches should be of noncombustible construction with a nonporous continuous working surface which may easily be decontaminated. One or two layers of blotting paper on the bench top to absorb small spills will usually not materially increase the fire hazard.

4.3 Hoods.

Hoods -- sometimes referred to as "Fume Hoods" — are similar to benches but with the addition of an enclosure and an exhaust system for removing vapors. The nature of the operations conducted within the hood may require a filter system to prevent the spread of radioactive materials. If such are used, they should have a low degree of combustibility (see Paragraph 3.2).

4.4 Glove Boxes.

The term "glove box" is used broadly to describe a system designed to contain materials, generally alpha-radiation emitters, which present little or no external radiation hazard but would present a serious problem if they became airborne. Such boxes may be large and used to conduct a wide variety of operations involving flammable liquids and gases, combustible solids, and toxic materials. The sides are fitted with long rubberlike gloves which permit manual operations to be conducted without personal contact with the hazardous materials. Special ventilation and fire protection systems are usually considered to be necessary.

(a) **Construction Materials.** Construction materials should be noncombustible. Combustible construction materials or materials which are noncombustible but lacking fire integrity introduce special problems. All surfaces should be nonporous and easy to decontaminate. Surface coatings are often used to provide a ready means for the removal of contamination but the fire hazards connected with their application should be guarded against.

Care should be exercised when handling combustible metals within such enclosures. It is possible that low-melting point alloys — such as iron-plutonium — may be formed which are often more pyrophoric than the parent materials.

(b) **Materials Handled in Glove Boxes.** All materials to be introduced into these boxes, as well as the construction materials used, should be viewed as to their compatibility in order to preclude the possibility of an explosion, fire, or uncontrolled exothermic chemical reaction. The confinement provided by the boxes together with often near static air conditions are conducive to the production of explosive mixtures of flammable vapors and gases with air.

The quantity of combustible materials within glove boxes should be kept to an absolute minimum. Special extinguishing agents or systems, compatible with the materials being handled, should be provided within glove boxes in order to avoid the delay and hazard inherent in introducing the extinguishant from outside.

(c) **Equipment Used in Glove Boxes.** Electrical equipment including motors and heat producing devices such as ovens, hot plates, soldering irons and direct flame devices such as torches and burners present special hazards which should be safeguarded.

The small volume and low air velocity conditions provide for less than normal heat removal. The vulnerability of rubber gloves to melting or burning through as a result of very brief contact with heat sources requires that glove port covers be kept immediately available for instant use.

(d) **Ventilating Systems.** Glove boxes are usually connected to a special ventilating system and are normally under constant air flow. Fire dampers are not often installed because of interference with contamination control. Insofar as practical the design of the ventilating systems should be such as to constantly maintain a negative pressure within the boxes under fire conditions. In this connection, consideration should be given to two principal problems.

1. Smoke and soot from burning material can quickly clog roughing and high efficiency filters in the exhaust system. This may cause rapid spread of the radioactive materials outside the box as a result of pressure created by the fire.

2. The flexible connections, if any, between the glove boxes and the exhaust system should be of fire resistive materials for the same reason.

(e) **Containment and Fire Control.** The containment system may lose its integrity due to fire or explosion originating in or outside the glove box. For fire originating outside the glove boxes, automatic sprinklers are commonly used and are quite effective for conventional fire control and extinguishment. Fire occurring within the glove boxes may involve materials of construction or combustibles within the boxes. These situations may be difficult to control unless advance consideration has been given to the specific fire problem which may develop under the specific conditions of glove box use. Where such hazards exist, serious consideration should be given to an automatic fire detection and control system within glove boxes. This system should sense and control the fire before it destroys the glove box integrity or creates smoke which clogs the filters. Where explosion possibilities exist within a glove box, provision should be made for venting by a predetermined path to a safe area.

It is important that under the most serious credible accident conditions, fire protection be such as to preclude airborne contamination spread beyond the confines of the room or building in which it originated. This indicates the need for the most efficient and prompt suppression of fire by all practical means. Fears may be expressed as to the possible spread of contamination by water. On the contrary, to the extent that water from the sprinkler system cleanses the air of airborne contamination, it can reduce a serious three dimensional airborne contamination problem to a much more manageable two dimensional waterborne contamination problem.

(f) **Fire Prevention.** Fire prevention may be improved by the conventional techniques of reducing to a minimum the amount of combustible materials, by eliminating or safeguarding sources of ignition or by inerting the glove box with a gas such a sargon, helium or nitrogen. In some cases, dry air may be used to prevent the formation of combustible and sensitive metal hydrides.