RADIATION PROTECTION MANUAL

Issued by

The Radiation Hazards Subcommittee

of

The Executive Safety Council

THE DOW CHEMICAL COMPANY

MIDLAND MICHIGAN

EMERGENCY INSTRUCTIONS

FIRE - Dial 311

Give department, building and door number, state "radiation hazard."

INJURY - Dial 393

For ambulance, give department, building, and door number. State "radioactive contamination involved." Proceed to wash wound and contaminated skin with copious amounts of water until ambulance arrives. Spread edges of wound to insure thorough washing with water.

CONTAMINATION - Dial 8991

Environmental Research Laboratory, if the normal procedures as described in part VII fail to decontaminate adequately.

SPECIAL PROBLEMS - Dial 8991

Environmental Research Laboratory for more detailed information and assistance with any problems.

IMPORTANT:

AEC requires an immediate report of any incident involving overexposure or release of high concentrations of radioactive material. Please report any unusual "incidents" to the Environmental Research Laboratory at once.

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I. Purpose of Manual

This manual is to establish standards for radiation protection for the Midland facilities of The Dow Chemical Company. It should be used in conjunction with the Plant Safety Standard for Radiation Producing Equipment and Radioactive Materials (Appendix III); it supplies more detailed information on radiation hazards and their control.

II. Introduction

The high energy radiation given off by radioactive materials and radiation producing equipment such as X-ray machines produces deleterious effects upon living organisms. The human body is constantly subject to a small amount of radiation due to natural radioactivity and cosmic radiation, without visible effect. The body thus tolerates small amounts of high energy radiation just as it can tolerate a certain amount of direct exposure to sunlight. However, excessive exposure is injurious.

The purpose of radiation protection is to keep the amount of radiation to which a person is occupationally exposed to a low enough level that no ill effects will ever be obtained.

Radiation exposures are of two kinds.

(1) irradiation from a source external to the body

(2) irradiation of the body internally from radioactive materials swallowed, inhaled, or absorbed through the intact or broken skin.

X-ray machines are an example of a potential source of external radiation hazard. A sealed capsule of radioactive material presents only an external radiation hazard as long as the capsule does not leak.

A solution of radioactive material which could be swallowed or inhaled as tiny droplets is an example of a potential source of an internal radiation hazard. If the solution of radioactive material is an emitter of strong beta or gamma radiation, it is also an external radiation hazard. Some radioactive isotopes such as C-14, S-35, and H-3 have such low energy beta rays that they do not constitute an external hazard since the radiation is absorbed in the container or in the dead layer of skin.

III. Procurement and Storage of Radioactive Materials

The Midland Division Safety Standard for Control of Radiation Hazards has established procedures for procuring radioactive materials. It is imperative that the requirements set forth by this standard be followed if we are to keep proper control of radiation hazards.

A typical pattern for obtaining and storing radioactive materials follows:

1. A need for the purchase of some radioactive material arises.

A requisition must be written to the Purchasing Department requesting the purchase of this material. If an authorization is needed, a member of the Radiation Hazard Subcommittee must approve it.

2. The Purchasing Department will notify the Environmental Research Laboratory that it has received a requisition for this radioactive material. A copy of the Purchase Order is sent to the Environmental Research Laboratory and the Safety Department and the material is ordered from the supplier.

3. The Stock and Receiving Department is responsible for notifying the Environmental Research Laboratory of the arrival of the material. The package containing the material should then be sent to the purchaser unopened.

4. When the material is received, the purchaser will open and inspect the package. If the purchaser desires, he may call upon the services of the Environmental Research Laboratory to assist him in this operation.

5. Storage of the radioactive material by the plant group having control over it will depend on its radiation characteristics. Again, the Environmental Research Laboratory should be consulted. The Radiochemistry Laboratory has a vault specifically designed for the storage of radioactive materials that is available to other plant groups which do not have suitable storage facilities at their installation.

6. For proper disposal of radioactive materials, including by-products or waste products from radioactive materials, consult the section of this publication entitled, "Waste Disposal." Primarily, the job of disposal of radioactive materials is the joint responsibility of the Environmental Research Laboratory and The Waste Disposal Department.

Recommendations for the storage of radioactive materials. Any volatile radioactive materials must be stored in flame-sealed glass ampules. In the case of radioactive carbonate materials, measures must be taken to prevent moisture from contacting the material which

could result in an exchange of radioactive CO_2 with the CO_2 in the atmosphere.

1. <u>Storage of radioactive material classified as soft beta emitters, such as C^{14}, S^{35}, and H^3.</u>

These materials should be stored in sealed containers in a hooded area or an area designed for storage and do not normally require shielding. If the radioactive strength of the material exceeds 10µc, it should be handled in a hood at all times.

2. <u>Storage of radioactive material classified as hard beta emitters, such as P^{32}.</u>

This type of material should be handled in sealed containers under a hood and normally requires shielding as follows:

a. 3/8 inch plastic or glass or the equivalent is satisfactory to confine most hard beta rays.

b. Lead shielding may be necessary to confine secondary x-rays which might be produced. If the radioactive strength of the material exceeds 10µc, it should be handled in a hood at all times.

3. <u>Storage of radioactive material classified as gamma emitters.</u>

This class of radioactive materials must be stored in sealed containers with adequate lead shielding.

The amount of shielding will depend upon the strength of the source involved.

4. <u>Storage of materials which are especially harmful because of their deposition in vital organs, such as Sr^{90}, Cs^{137}, Fe^{55}, and alpha emitters.</u>

Radioactive materials in this classification require the same type of storage facilities as is used for hard beta emitters. If the radioactive strength of these materials exceeds .05 µc, they should be handled in a well ventilated hood at all times. Due to the nature of these materials, special handling equipment may be required for their use.

Natural uranium and thorium, although alpha emitters, are only moderately toxic and therefore do not require the stringent storage conditions of section 4, above. Thorium is used in production quantities and is safely stored in properly marked areas.

The storage of radioactive stock reagents will depend upon which of the above classifications best describes the material. Generally stock reagents can be stored in a hooded area with or without shielding depending upon the class of material. Under most

circumstances, counting samples will be of such low activity that they do not have to be handled in a hood.

Record keeping, as required by the Dow Midland Safety Standard for Control of Radiation Hazards, is very important and must be carefully executed as outlined. The cooperation of the individual user with the Environmental Research Laboratory is necessary to properly maintain these records.

IV. Maximum Permissible Dose
(ref. NBS Hb 59)

Permissible dose is defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime. A restriction on the permissible dose has recently been imposed as a result of genetic considerations.

The National Committee on Radiation Protection has proposed a cumulative whole-body exposure limit of 5r (roentgens) per year for each year of a person's age beyond eighteen. As long as a person's cumulative exposure remains below the limit for his age, the figures in Table I apply.

A formula for determining a person's permissible exposure is:

$$5\ (X - 18) = \text{permissible cumulative exposure in r.}$$

where X = age in years

TABLE I

Maximum Permissible Dose for whole body irradiation

X-rays and gamma rays	300 mr per week (7.5 mr per hr. for 40 hrs. per week)
Beta rays	1500 mrep per week 300 mrep to lenses of eye.
Thermal neutrons	2000 n/sq.cm./sec.
Fast neutrons	30 n/sq.cm./sec.

Maximum Permissible Concentrations of various radioisotopes in air and drinking water are given in Appendix I.

Definitions of terms and units are found in Appendix II.

TABLE II

GAMMA-RADIATION DOSE RECEIVED FROM VARIOUS ISOTOPES

Isotope	Half-life	Gamma-ray Energy (Mev)	Dosage at one ft. from 1 mc (mr./hr.)
Na^{24}	14.8h.	1.38, 2.76	20.6
Mn^{54}	310d.	0.84	5.2
Fe^{59}	47d.	1.30 (50%), 1.10 (50%)	7.0
Co^{60}	5.3y.	1.10, 1.30	14.0
Zn^{65}	250d.	1.14 (46%)	3.2
I^{131}	8.0d.	0.37, 0.08	2.8
Radium and Products	1600y.	2.5 (max.), 0.8 (mean)	10

(Most of these data taken from R. D. Evans, Nucleonics I, (2), 32-43 (1947), McGraw-Hill Publishing Company)

The values used in this manual for maximum permissible dosage are based on experimental evidence and experience gained by workers with X-rays and artificial radioisotopes over a number of years.

Gamma radiation is very penetrating and is exponentially absorbed in matter. The radiation intensity, like light, falls off as the inverse square of the distance from a point source. For example, referring to Table II, a 10 millicurie cobalt-60 source will produce 140 mr/hr at one foot, limiting working time to about 20 minutes per day. At ten feet from the source, the dose will be 1.4 mr/hr and working time will be unlimited. To obtain 1.4 mr/hr at one foot with this source, about 2.5 inches of lead shielding or 6 inches of concrete would be required around the source. The penetration of gamma radiation in the human body is of a similar order. One inch of muscular tissue will reduce the intensity of 1.5 Mev gamma rays about 6 or 7% and 8 inches about 40%. For lower energy gammas the absorption is greater.

Beta rays are much more easily absorbed by matter than gamma rays. The highest energy betas can be stopped in about 1/4 inch of aluminum. Sheet plastic,

3/8 to 1/2 inch thick, serves as a very effective shield for this type of radiation. Since all the energy of a beta particle is expended in a short distance, the biological damage is localized. For external beta irradiation, the damage is to the skin or eye.

Alpha particles have very low penetration and normally do not present an external radiation hazard since they do not penetrate the epidermal protective layer of the skin. When alpha emitting materials are taken into the body they constitute a very serious hazard because the alpha particles are then emitted in direct contact with the tissue and produce intense damage over a very short distance.

V. Radioisotope Laboratory Procedures

Protection from external radiation hazards is accomplished by: limiting the size of the source, shielding, limiting the time of exposure, and by controlling the distance between the source and personnel. In a radioisotope laboratory the first two of these measures are used in almost all situations.

Deposition of radioisotopes within the body may result from ingestion or inhalation of the materials,

or by their absorption through the intact or broken skin. In order to prevent such occurrences, bulk radioactive materials and sealed sources must be handled properly, and appropriate monitoring techniques must be utilized.

Work with radioactive materials should follow the careful laboratory practices that are normally used in handling toxic or corrosive chemicals. The primary aim is to know where the radioactive material is, and to confine it as closely as possible.

The amounts of activity handled in a radioisotope laboratory will range from 100 millicuries in stock solutions to 10^{-8} millicuries in counting samples. It is important to keep the laboratory free of contamination from two aspects. One is the health hazard involved in ingesting or inhaling radioisotopes. The second is the interference with low level counting work. With certain isotopes such as carbon-14 the health hazard is the less stringent of the two requirements, since a dose of 0.7 millicuries of carbon-14 is considered within permissible limits. The maximum permissible amount of strontium-90 in the body is, however, 1×10^{-3} millicurie or about 6×10^{-9} grams, and therefore, with this material, health protection dominates.

All radioactive materials except microcurie amounts of the less toxic isotopes should be handled in a good hood. Powdered materials should be handled with special care so as to avoid inhalation of the dust. Such powders can be handled most easily in a glove box.

A laboratory experiment should be set up in a definite space and the active material confined to that space.

Clean-up of spills or accidental contamination is greatly facilitated by using saran film with or without a layer of kraft paper to cover working surfaces.

Respiratory protection may be used for short periods of time when operations are being carried out that may lead to air contamination. Respirators for this purpose must be carefully chosen as several commercially available types are totally inadequate for protection against radioactive materials.

Surgical rubber gloves should be worn whenever working with radioactive isotopes. Good practice requires that wrists be covered by pulling the glove gauntlet over the sleeve of the laboratory coat.

Smoking, eating or pipetting by mouth are not permitted in a laboratory where radioisotopes are handled.

Hands should be thoroughly washed after working, and monitored with a thin window Geiger tube survey meter.

Gloves and tools can be easily monitored for contamination with a survey meter. Objects known or suspected to be contaminated, should be handled only with disposable tissue. During the course of the work a number of tissues, paper towels, etc., will be collected which may be contaminated. Step-lid garbage cans should be provided for disposal of such material. This type of disposal is meant for low-level contamination. Low level contamination is defined as less than 500 c/m (counts per minute) with a thin-window G-M Counter. In case of a spill of "hot" material the area must be cleaned up immediately and the clean-up materials put into a wide mouth can (1 or 2 qt. size) for disposal.

At the end of a working day the working area and tools should be cleaned and monitored. "Hot" materials should be placed in closed containers, labeled and left in the hood.

Rubber gloves which show 500 c/m after several washings with detergent should be discarded as contaminated.

Each person is responsible for the clean-up of the area in which he works and should leave the area clean and monitored after the work is completed.

In general, neatness and cleanliness are the best methods of preventing contamination of air, bench tops, or clothing.

VI. Decontamination and Clean-up (Ref. NBS - Handbook 48)

Every effort must be made to prevent contamination, or to control its spread. Therefore, personnel should be thoroughly familiar with all safety measures and good working habits such as are suggested in Section V of this manual and, in more detail in NBS - Handbook 48.

A. Personnel Contamination

Extreme personal cleanliness is the first rule in preventing contamination of the skin. Persons working with radioactive materials should wash exposed parts of the body thoroughly whenever leaving the active area, even though no known contact has occurred.

1. Permissible level of contamination:

Loose or easily removed contamination should not be tolerated at any level. "Permissible level" applies only to contamination which is difficult to remove.

0.1 mr/hr or 100 counts/minute as measured by a thin window Geiger tube of 2 sq. in. flat plate area is the maximum permissible level of bodily contamination.

Isotopes listed as Class IV Internal Hazard in Appendix IV must be <u>completely</u> removed from the skin.

2. Decontamination of skin:

Thorough washing with soap and water is the best general method for decontamination of the hands and other parts of the body, regardless of the contamination. The recommended procedures for general hand-washing are as follows:

(a) Wash for 2 to 3 minutes by the clock with a mild pure soap in tepid water with a good lather, covering the entire affected area thoroughly. Do not use highly alkaline soaps or abrasives. Repeat, as monitoring indicates, until the contamination is reduced

to desired level.

(b) If the above procedure is not sufficient, scrub the hands with a soft brush using a heavy lather and tepid water, with only light pressure on the brush. Repeat as necessary.

(c) If soap, water, and brush do not remove contamination, call the Environmental Research Laboratory, extension 8991.

3. Wounds:

A person should not be permitted to work with radioisotopes if there are open cuts, abrasions, or skin breaks of any kind on the body. In the event that the skin is broken in accidents while working with radioactive substances, wash the wound under large volumes of running water immediately, spread the edges of the gash to permit flushing action by the water, and call the ambulance, extension 393.

4. Internal:

Should a person have a reason to suspect that he may have tasted, swallowed, breathed, or absorbed any amount of radioactive material in his body, he should call the ambulance, extension 393 immediately.

B. Contamination of Clothing

Protective clothing should be worn as required by the nature of the hazard involved. In ordinary laboratory work this will consist of a laboratory coat, surgical

rubber gloves, safety glasses, and on occasion, air filter respirators. This equipment should be monitored routinely each day, or when one's work with the radioactive material is finished. In addition, as further precaution, exposed portions of street clothes, e.g., shoes, trouser cuffs, pockets, etc., should be monitored at the end of each day.

1. Permissible levels of contamination:

The same levels of maximum permissible contamination that were given in Section VI, A-1 should be applied to clothing as well as to the skin. That is, 0.1 mr/hr measured as the average near the surface of the garment. (This corresponds to approximately 100 counts/min when a thin window Geiger counter having a flat plate area of 2 sq. in. is placed against the garment.)

2. Decontamination procedures:

Clothing that is contaminated to a level less than the above may be released to public laundries (or the general Dow laundry.) If the level of contamination is greater than the above, the clothing may be:

(a) stored until the level of activity has decayed to below the maximum permissible level, at which time it may be released to the laundry.

(b) laundered separately in a special washing machine with effluent monitored.

(c) if the volume of washing is too low to justify (b), the clothing may be disposed of as dry radioactive waste (see Section IX of this manual).

Rubber gloves usually decontaminate readily by washing with plenty of suds and hot water, but excessive time cannot be justified in this operation because of the low replacement cost. Leather goods, e.g. shoes, cannot easily be decontaminated; therefore, if the risk of contamination is high, shoe covers or rubber overshoes should be worn. Mildly contaminated shoes may sometimes be cleaned by swabbing with paper tissue dampened with soap and water. Respirators and safety glasses may be decontaminated by washing with soap, a hot 20% solution of sodium citrate, or other similar agents. Contaminated air filters should be disposed of as "dry radioactive waste."

C. Laboratory Tools and Glassware

1. Permissible levels of contamination:

The same levels of maximum permissible contamination that were given in Section VI, A-1 of this manual should be applied to laboratory tools and glassware.

2. Decontamination procedures:

Equipment that is found to be contaminated should be placed inside a plastic bag and set aside in an isolated location, preferably in a hood, until more thorough decontamination procedures may be applied. Contaminated equipment shall

not be released from control of the laboratory for repair, or any other purpose, until the activity has been reduced to a safe level. When the half-life is short, it may be desirable to store equipment for decay of activity rather than to attempt to decontaminate it. In many cases, if the items are cheap or easily replaced, it may be simpler to dispose of such equipment in a recommended manner (see Section IX), and replace with new apparatus. Glass and porcelain articles may be cleaned with mineral acids, ammonium citrate, trisodium phosphate, or cleaning solution (chromic acid). When the glaze on porcelain is broken or when active solutions are heated to extreme dryness in glass, decontamination is very difficult, and usually it is more convenient to replace such items.

Metal objects may be decontaminated by dilute mineral acids (nitric), or a 10% solution of sodium citrate. Brass polish is an excellent decontaminant for brass. If all other procedures fail for stainless steel, use hydrochloric acid only as a last resort, because it etches the surface, making it less desirable for future use.

Plastics may be cleaned with ammonium citrate, dilute acids, or organic solvents.

In general, decontamination seldom exceeds 99.9% efficiency and usually runs about 98-99.5%. If the residual contamination indicates that the level of activity is

still greater than that specified as permissible, equipment shall be regarded as radioactive waste.

Glassblowing, welding, soldering, etc. should never be permitted on contaminated equipment, unless it is done in specially ventilated facilities, and unless special techniques are used to prevent the inhalation of radioactive dusts and fumes.

D. Decontamination of Laboratory Floors, Benches, Hoods, Etc.

A large variety of materials are in current use in laboratory walls and floors, as well as work benches, tables, and hoods. Decontamination will be simplified if recommended materials of construction are used (see NBS Handbook 48, p. 14 for a brief analysis), and working surfaces are covered with stainless steel trays, or sheets of absorbent paper with or without waterproof backing.

1. Permissible level of contamination:

The maximum permissible levels of contamination of materials used for the surfaces of laboratory walls, floors, work benches, hoods, etc. is about 500 counts/min. No loose contamination is permissible.

In areas where low level counting is done, the general background for satisfactory instrument operation may be such that decontamination to well below this maximum permissible level is required.

2. Decontamination procedures:

Floors and benches should be cleaned routinely by wet or oil mopping and dusting, never with a dry mop, since this may create a dust hazard. Cleaning equipment which is assigned to radiation areas shall not be removed or used elsewhere under any circumstances.

Linoleum may be decontaminated by swabbing with absorbent paper moistened with perchlorethylene, kerosene, ammonium citrate solution, or dilute mineral acids; care should be taken not to dissolve sealing compounds between cracks of the linoleum.

Ceramic tile may be decontaminated by the use of mineral acids, ammonium citrate, or trisodium phosphate.

Paint is sometimes successfully decontaminated by perchloroethylene or 10% hydrochloric acid; however, such treatment may partially dissolve the paint; in such

circumstances, the paint should be thoroughly removed and a new coating applied.

Concrete has been successfully decontaminated by the application of 32% hydrochloric acid. If this is not successful, no recourse is left except to remove the surface concrete with a chisel or by sandblasting, or if practical, covering the surface with another layer of fresh concrete.

Wood surfaces must be removed, sanded, planed, or, if the contaminant is an alpha emitter, covered over with paint.

Traps and drains may sometimes be decontaminated by the following procedure:

(a) Flush thoroughly with a large volume of water.

(b) Scour with rust remover.

(c) Soak in a solution of citric acid prepared by adding one pound of acid to one gallon water.

(d) Flush thoroughly with a large volume of water.

E. <u>Minor Spills</u>

In this category are considered only those minor spills that do not constitute a radiation hazard to personnel and would be cleaned up by the laboratory personnel. (For the procedure to be followed in the event of a major spill involving a radiation hazard or other emergency, consult section VIII, (p. 38) of this manual.)

1. Notify all other persons in the room at once.

2. Permit only the minimum number of persons necessary to deal with the spill into the area.

3. Confine the spill immediately

(a) Liquid spills:

Don protective gloves

Drop absorbent paper on spill

(b) Dry spills:

Don protective gloves

Dampen the material thoroughly, taking care not to spread the contamination.

4. Decontaminate by swabbing repeatedly with absorbent paper, taking care not to spread the contamination.

5. Monitor all persons involved in the spill and cleaning.

6. Permit no person to resume work in the contaminated area until a survey is made. The Environmental Research Laboratory (Ext. 8991) is available for such monitoring.

7. Prepare a complete history of the accident and subsequent activity related thereto for the laboratory records.

VII. Radiation Monitoring And Surveys (Reference: NBS Handbook 51)

Purpose

Radiation surveys and monitoring are undertaken to detect contamination in the air and on surfaces, to measure exposure of personnel and to evaluate procedures and techniques involved in handling sources of radiation. These aims are accomplished if suitable instruments are properly used and the results are interpreted intelligently. An initial survey is made of each new facility and periodic surveys are conducted as necessary.

General

Radiation injuries are prevented by knowledge and recognition of potential exposures and the application of the following basic protective measures. Internal exposure is prevented by excluding radioactive materials from the body. This is accomplished by enclosing all

radioactive materials, supplying air of assured purity, maintaining effective contamination control boundaries around all sources, using immaculate handling techniques, decontaminating when control has failed and enforcing a rigid system of accounting for all radioactive materials. External exposure is reduced to minimum by reducing the time of exposure, increasing the distance from the source and by using appropriate shields.

Air Monitoring

Laboratory air and effluent should be monitored for radioactivity if there is any possibility of airborne contamination at hazardous levels. Beta and gamma activity may be determined by collecting particulate matter on a filter paper and counting that material with a G-M counter. Determination of alpha activity is complicated by the presence of naturally occurring decay products of radon and thoron. Maximum permissible concentrations of alpha emitters are generally so low that special protective measures are usually required which include techniques and equipment that virtually eliminate airborne contamination.

Surface Contamination

Estimates of surface contamination are qualitative because of unknown factors such as self-absorption, geometry, and depth of penetration of the contamination. Wipe samples are taken by wiping part of the surface with a slightly moist filter paper and counting this with a G-M counter. They are useful in estimating contamination on surfaces and determining whether or not the contamination is likely to rub off. A wipe sample indicates contamination if its count is more than twice the background of the G-M counter. Normally a surveyor should know what type of contamination he is looking for; however, identification of the radiation types present can be made for a wipe sample by the use of filters. Alpha activity is completely stopped by a thin absorber such as paper; beta radiation is stopped by a thin metal absorber; gamma rays will be only slightly attenuated by the same absorber.

Personnel Monitoring

Every person whose safety depends upon proper operating technique and shielding shall wear a personnel monitoring device on his person at all times when exposure

is possible. Devices in use at Dow are film badges and pocket ionization chambers. Film badges are issued to persons who work regularly with radiation sources and are sometimes supplemented by pocket chambers. Either type of device is available from the Environmental Research Laboratory. When an unusual or potentially hazardous operation is to be performed special monitoring service should be requested from the Environmental Research Laboratory.

The limitations of personnel monitoring devices should be remembered in using them. They measure the exposure only at the spot where they are worn, which should be the part of the body expected to receive the largest exposure. Film badges and pocket chambers are normally worn in a breast pocket or at the belt since this region and the head are the most sensitive parts of the body to radiation. If the hands or feet might receive an unusual exposure, a second film badge or chamber should be attached to them. In this way, a record is kept of exposure to the extremities as well as that to the "whole body." A second limitation is that these devices do not accurately measure beta or low energy X-ray exposure unless specially calibrated.

Instruments

National Bureau of Standards Handbook 51 contains detailed information on instrument specifications. The most important general considerations are to pick the correct instrument for a particular job and to know its limitations.

G-M survey meters or "Geiger Counters" are used for detecting radiation at low levels. The Tracerlab SU-3 Laboratory Monitor and the SU-14 portable survey meter are used for detecting spills of radioactive materials, contamination on laboratory equipment and clothing, and for monitoring waste materials. G-M survey instruments should not be used for measuring high external radiation levels since they may "saturate" and produce a zero or low reading on the meter.

An ionization chamber instrument such as the Tracerlab SU-14, the Jordan Radector or NRD model CS-40, is used or measuring the level of external radiation from x-ray machines, Van De Graaff accelerators and gamma emitting isotopes such as Iodine 131, Radium 226 and Cobalt 60. These instruments (sometimes called "cutie pies") are calibrated quarterly by the Environmental

Research Laboratory with a reference source of known strength.

The aid of the Radiochemistry Laboratory or the Environmental Research Laboratory should be enlisted in choosing the proper instrument and in servicing and calibrating radiation survey instruments.

Survey Methods

A survey normally includes a study of the techniques and habits of individuals involved, the operating procedures, and the methods used in handling radioactive materials. The survey is conducted under typical operating conditions, and under conditions of greatest possible hazard. Instruments used for a survey should be checked for proper operation and calibration in the energy range to be encountered before the survey is started. Survey records should include all data and recommendations for corrective action in technique and shielding. Personnel monitoring should be recommended where it is needed, and a recheck made after corrective action has been taken.

Each location or operation must be surveyed individually because of the large number of variables involved. The

location and physical form of a radiation source, the type and energy of its radiations, its use, and the habits of the user are important factors. The time and intensity of exposures, the areas exposed, the biological effectiveness of the particular radiation, and the possibility of internal exposure are also important.

The first step in surveying operations involving radioisotopes is to determine what isotopes are present. This is usually known from the history of the operation, but cross-contamination may be a factor if other radioisotopes are being used in nearby areas. Airborne contamination is hazardous and spreads rapidly, so it receives attention first.

Air samples should be taken at the worker's breathing zone if possible. Surfaces should be thoroughly checked for contamination. Any possibly contaminated location should be scanned with a geiger counter, remembering that the response time of the instrument limits the speed of scanning, unless earphones or flashing lights are used as indicators.

Shielding and containers should be checked for contamination and radiation leaks; all handling techniques should be observed and dose rates for each operation checked, with time limits imposed where necessary; surrounding areas should be checked for contamination and radiation leaks; effluents, air and sewage should be assayed, and waste disposal practices checked. A program of routine and spot monitoring of radioisotope laboratories usually is desirable.

X-ray installations include radiographic, fluoroscopic, diffraction, diagnostic and therapy units, and electron microscopes. Special consideration is necessary with these units because of their directional beams and the variations in energy of radiations produced. Operating techniques and the operator's habits must be observed, with particular attention to the proper use of protective devices such as interlocks and shielding. Measurements of radiation levels at the operator's position and adjoining rooms and areas should be made to detect shielding leaks and scattered radiation. Normal operating conditions and worst possible hazard conditions should both be checked.

The dose rate, or intensity of radiation, adequate shielding and the user's knowledge of the potential hazard are important factors to consider in surveying the cobalt 60 sources, radium static eliminator bars, density gauges, hi-vacuum gauges, and the beta ray gauges used in the plant. The surveyor should measure the dose rate with a ionization chamber instrument, and calculate the safe working distance for a 40-hour week. If workers are required to be closer than the safe working distance, a time limit at the working distance can be calculated which will not allow over-exposure. All persons concerned should be advised of safe working distances and times. Sources should be wipe tested for contamination and leakage. Shielding should be provided to keep radiation levels as low as possible without interfering with the use of the source. All sources should be plainly marked to warn transients of their presence, and the sources should be registered with the Environmental Research Laboratory to provide a means of preventing their loss with possible harm to persons ignorant of the hazards involved.

VIII. Emergency Procedures And Fire Fighting

The introduction of radioactive materials within the plant area poses the following emergency problems: (1) fires and explosions in areas where radioactive materials are used or stored; (2) major spills with contamination of men and equipment by radioactive materials.

Individual departments handling radioactive materials will receive assistance and advice from the various technical groups on coping with the potential problems of radioactivity. However, here, as in the past, the responsibility for plant engineering, personnel safety, and education lies directly with the departmental supervisor.

Fire or Explosion

The Fire Department will be promptly advised of the location of all radioactive sources when they enter the plant. A personal visit will be made by a responsible officer of the Fire Department to acquaint himself with the building, type of material, its use and storage. At this time, a meeting will be held with the building supervisor and representatives of the Environmental Research Laboratory, Safety, Plant Protection and

Fire Departments to discuss the hazards that might be encountered from any possible emergency situation. Modes of specific action in case of emergency will be discussed and approved. Following this meeting the information will be relayed to all responsible personnel of the Fire Department and Plant Protection.

All groups using or storing potentially hazardous amounts of radioactive materials should periodically review an emergency plan in their group safety meetings. The plan will include the location of emergency equipment such as gas masks and fire extinguishers, and plans of action for all emergencies that can be foreseen, e.g. fire, explosion, minor wounds, major injuries, and release of radioactive materials to other areas by leakage, spill or other accidents. The Environmental Research Laboratory will aid in setting up emergency plans and conducting periodic reviews.

In the event of a fire where radioactive materials may be present, precaution must be taken to protect all personnel from injurious amounts of external radiation and to prevent contamination of men and equipment by radioactive materials. Upon reaching the scene of the

fire, all apparatus should be parked upwind, out of the smoke area if possible, and tools and equipment should be dispensed to fire fighters by a person who has not been contaminated.

The amount of external radiation in an emergency area will be determined by the Fire Department or Plant Protection personnel who are furnished with radiation detection instruments. These men will constantly survey the scene, and will warn others away from areas where the radiation intensity is at or above the danger level plainly marked on each meter.

In addition, each man entering the radiation area should have a dosimeter and a film badge on his person. Each film badge should be identified with a particular person by name or number. Dosimeters should be read before entering the area and the reading recorded. When a man is within the radiation area he should read his dosimeter at least every fifteen minutes, and <u>must</u> leave the area and report to the Fire Chief, building supervisor, or a member of the Environmental Research Laboratory when his dosimeter indicates an exposure of 5 roentgens (one division).

In order to avoid breathing radioactive material, each man entering the emergency area must wear a respirator until the wearing of such equipment has been deemed unnecessary by the building supervisor or a member of the Environmental Research Laboratory.

<u>Any</u> wound, however slight, must receive <u>immediate</u> attention as speed is necessary to prevent the entry of a hazardous amount of radioactive material into the body.

After the emergency, all personnel present must shower thoroughly and put on clean clothing (See section VI regarding personal decontamination). Final readings of all dosimeters should be made and recorded, and all film badges should be sent in for evaluation. All tools, hose, clothing, respirators, and other equipment used should be grouped for checking under the supervision of the Environmental Research Laboratory before re-use. All persons present at the scene of the emergency should report to the Medical Department following decontamination so that a record may be made of their exposure.

Major Spill, Contamination Of Personnel And Material

If a major spill of radioactive material occurs in an area, all persons in the area should be evacuated to a safe location. If the possibility of spread to adjacent buildings exists, personnel in such buildings should be immediately warned of the pending danger. The Environmental Research Laboratory and Plant Protection should be notified to give aid in isolating the area and in decontamination.

All personnel in the area of the spill should be checked by a member of the Environmental Research Laboratory for contamination of skin or clothing. If contamination is found or is suspected, that person must immediately remove his clothing, shower thoroughly with soap and water for 10-15 minutes and then should be brought to the Medical Department where he will be re-examined and a record will be made of his exposure. All contaminated clothing must be isolated so that it may be checked easily and disposed of at a later time.

In the event that an injury accompanies the exposure, the ambulance should be called and all clothing should be removed and decontamination of the skin begun by flushing the skin with large amounts of running water.

It should be remembered that any individual helping a contaminated injured person may himself become contaminated and should decontaminate himself as soon as possible. When transporting an injured person who has received possible contamination by radioactive materials in the ambulance, the person should be wrapped in a large sheet of saran film to be carried in all ambulances so that the ambulance itself will not become contaminated, thereby rendering emergency equipment useless for an extended period of time.

All personnel should stay out of the contaminated area until after decontamination is finished (See Section VI for the proper procedures to follow.)

IX. Radioactive Waste Management

All radioactive wastes are handled in accordance with the regulations of the Atomic Energy Commission and the Dow Standard for Control of Radiation Hazards. It is the responsibility of the Environmental Research Laboratory to assure that there is no hazard to Dow employees while handling waste materials and that no health hazard is imposed on the general public as a result of radioactive waste disposal. The Waste Disposal Department handles

the actual disposal and maintains a record of the burial of solids. The Environmental Research Laboratory keeps records of the disposition of all radioactive wastes and must account to the A.E.C. for all licensed material and for its disposal in accordance with A.E.C. regulations.

General

The term "waste management" has been used in the title of this chapter because there is at present no means of disposing ultimately of radioactive waste. It may be diluted, dispersed, buried or stored, but it is still radioactive and is still a potential health hazard.

The methods of management mentioned in this chapter are both expensive and difficult. For these reasons it is extremely desirable to minimize the amount of radioactive waste material that must be handled. This task is the responsibility of everyone using radioactive materials. The department generating the waste should identify the isotopes present, specify their chemical state if known, and estimate the amount of activity involved. The Environmental Research Laboratory will evaluate the health hazard involved in handling the waste. The most suitable method of disposal will be

decided upon by the Environmental Research Laboratory and the Waste Disposal Department.

There are two general techniques which are followed for the disposal of radioactive waste.

1. Whenever possible, dilution with stable isotopes is the first step in disposing of either liquids or solids.

2. If the contaminant has a short half-life, storage for a period of several half-lives may be desirable before final disposition of the waste.

Solids:

Incineration and burial are the two courses open for disposing of solid wastes. NBS Handbook 53 indicates the usefulness of incineration in disposal of Carbon 14 waste. Recommendations concerning isotope dilution, complete combustion and atmospheric dilution are easily satisfied for Carbon 14, but for very few other materials.

Phosphorus 32, because of its short half-life may be stored until its activity is low enough to allow incineration. Incineration of other isotopes should be considered only for very low activity waste, and when complete combustion of the waste is assured.

Solid wastes should be segregated into high level and low level waste by the originating group. Low level wastes such as paper tissue, filter paper, and glassware, should be placed in lined step-lid cans. High level wastes should be placed in wide mouth jars or else doubly wrapped in saran and sealed with tape. The Environmental Research Laboratory will pick up accumulated waste upon request.

Requirements for burial of solid waste are: controlled burial area (access restricted to authorized persons), no edible plant life, no pronounced erosion or leaching, burial depth not less than 4 feet, and restrictions on the concentration of radioactive material in the soil. A record of the location of all consignments is also required. Dow's burial ground satisfies the site requirements, and Waste Disposal and the Environmental Research Laboratory each maintain a record of burials.

Liquids:

At present, all liquid wastes are retained in polyethylene bottles and collected periodically by the Environmental Research Laboratory. They are turned over to the Waste Disposal Department after evaluation of

the health hazard involved and calculation of the necessary dilution. Liquids are mixed into a sewage canal at the entrance to the waste treatment plant at a rate that will insure adequate dilution before Dow loses control of the radioactive material. Dilution is sufficient at the point of mixing to eliminate any significant health hazard or damage to biological organisms within the waste treatment plant. The type of contamination, amount of activity and its chemical state and an estimate of the total dilution are included in the records of liquid waste disposal.

Summary:

This manual has presented much detail concerning radiation protection and much more is available from the technical groups mentioned and from the literature references. All of this information is useless unless each reader realizes that the primary and the ultimate responsibility for your safety rests with you alone.

APPENDIX I

Maximum Permissible Average Concentrations of Radioactive Materials in Air and Water

NOTE: In applying Table I, exposures in any week should be averaged over 40 hours. In applying Table II, concentrations of radioactive material should be averaged over one year.

Material	Half-Life (1) (Days)	Restricted (40 hrs./week) TABLE I Column 1 Air (2)	Column 2 Water (3)	Non-restricted TABLE II Column 1 Air (2)	Column 2 Water (3)
A^{41}	0.074	1.6×10^{-6}	1.4×10^{-3}	5×10^{-8}	5×10^{-5}
Ag^{105}	2.8	3.6×10^{-5}	5	1.2×10^{-6}	1.6×10^{-1}
Ag^{111}	2.1	1×10^{-4}	13	3×10^{-6}	4×10^{-1}
Am^{241}	890.	8×10^{-11}	4×10^{-4}	3×10^{-12}	1.3×10^{-5}
As^{76}	1.09	7×10^{-6}	6×10^{-1}	2×10^{-7}	2×10^{-2}
At^{211}	0.31	9×10^{-10}	6×10^{-6}	3×10^{-11}	2×10^{-7}
Au^{198}	2.6	3.4×10^{-7}	9×10^{-3}	1.1×10^{-8}	3×10^{-4}
Au^{199}	3.1	8×10^{-7}	2×10^{-2}	2.5×10^{-8}	7×10^{-4}
Ba^{140} + La^{140}	12	2×10^{-7}	6×10^{-3}	6×10^{-9}	2×10^{-4}
Be^{7}	48	1.5×10^{-5}	3	4×10^{-7}	1×10^{-1}
C^{14}	180	1.4×10^{-6}	1×10^{-2}	5×10^{-8}	3.6×10^{-4}
Ca^{45}	151	9×10^{-8}	1.5×10^{-3}	3×10^{-9}	5×10^{-5}
Cd^{109} + Ag^{109}	77	2×10^{-7}	2×10^{-1}	7×10^{-9}	7×10^{-3}
Ce^{144} + Pr^{144}	180	2×10^{-8}	1×10^{-1}	7×10^{-10}	3.6×10^{-3}
Cl^{36}	29	1×10^{-6}	7×10^{-3}	4×10^{-8}	2.4×10^{-4}
Cm^{242}	120	5×10^{-10}	2.7×10^{-3}	1.8×10^{-11}	1×10^{-4}
Co^{60}	8.4	3.4×10^{-6}	5×10^{-2}	1.2×10^{-7}	1.8×10^{-3}
Cr^{51}	22	2.4×10^{-5}	1.4	8×10^{-7}	5×10^{-2}

(1) Effective half-life in body.

(2) Air concentrations are given in microcuries per milliliter of air.

(3) Water concentrations are given in microcuries per milliliter of water. These figures also apply to foodstuffs in microcuries per gram (wet-weight).

(Continued) Appendix I

		Restricted (40 hrs/week) TABLE I		Non-restricted TABLE II	
Material	Half-Life (1) (Days)	Column 1 Air (2)	Column 2 Water (3)	Column 1 Air (2)	Column 2 Water (3)
Cs^{137} ≠ Ba^{137}	17	6×10^{-7}	4.5×10^{-3}	2×10^{-8}	1.5×10^{-4}
Cu^{64}	0.53	2×10^{-5}	2.5×10^{-1}	6×10^{-7}	8×10^{-3}
Eu^{154}	820	2×10^{-8}	1×10^{-1}	6×10^{-10}	3×10^{-3}
F^{18}	.078	3.5×10^{-4}	2.6	1.2×10^{-5}	9×10^{-2}
Fe^{55}	61	1.8×10^{-6}	1.3×10^{-2}	6×10^{-8}	4×10^{-4}
Fe^{59}	27	5×10^{-8}	3.3×10^{-4}	1.5×10^{-9}	1.1×10^{-5}
Ga^{72}	0.59	1×10^{-5}	26	3.4×10^{-7}	9×10^{-1}
Ge^{71}	3.9	1×10^{-4}	27	3.6×10^{-6}	9×10^{-1}
H^3(HTO or T_2O)	19	7×10^{-5}	5×10^{-1}	2.5×10^{-6}	1.6×10^{-2}
Ho^{166}	1.1	1×10^{-5}	70	3×10^{-7}	2.3
I^{131}	7.7	9×10^{-9}	9×10^{-5}	3×10^{-10}	3×10^{-6}
Ir^{190}	7.3	2.2×10^{-6}	4×10^{-2}	7×10^{-8}	1.3×10^{-3}
Ir^{192}	17	1.5×10^{-7}	2.7×10^{-3}	5×10^{-9}	9×10^{-5}
K^{42}	0.51	6×10^{-6}	4×10^{-2}	2×10^{-7}	1.4×10^{-3}
La^{140}	1.6	4×10^{-6}	3.4	1.4×10^{-7}	1.1×10^{-1}
Lu^{177}	3.2	1.5×10^{-5}	70	5×10^{-7}	2.4
Mn^{56}	0.106	8×10^{-6}	5×10^{-1}	3×10^{-7}	1.5×10^{-2}
Mo^{99}	2.8	5×10^{-3}	40	1.8×10^{-4}	1.4
Na^{24}	0.61	5×10^{-6}	2.4×10^{-2}	1.6×10^{-7}	8×10^{-4}
Nb^{95}	21	1.3×10^{-6}	1.2×10^{-2}	4×10^{-8}	4×10^{-4}
Ni^{59}	8	5×10^{-5}	7×10^{-1}	1.6×10^{-6}	2.5×10^{-2}
P^{32}	14	4×10^{-7}	6×10^{-4}	1.4×10^{-8}	2×10^{-5}

(Continued) Appendix I

Material	Half-Life (1) (Days)	Restricted (40 hrs/week) TABLE I Column 1 Air (2)	Restricted (40 hrs/week) TABLE I Column 2 Water (3)	Non-restricted TABLE II Column 1 Air (2)	Non-restricted TABLE II Column 2 Water (3)
Pb^{203}	2.16	2×10^{-5}	4×10^{-1}	6×10^{-7}	1.4×10^{-2}
Pd^{103} + Rh^{103}	4.4	2×10^{-6}	3×10^{-2}	7×10^{-8}	1×10^{-3}
Pm^{147}	140.	6×10^{-7}	3	2×10^{-8}	1×10^{-1}
Po^{210}(sol.)	40.	6×10^{-10}	9×10^{-5}	2×10^{-11}	3×10^{-6}
Po^{210}(insol.)	31.	2×10^{-10}	-	7×10^{-12}	-
Pr^{143}	11.	2.3×10^{-6}	1	7×10^{-8}	3.6×10^{-2}
Pu^{239}(sol.)	43000.	6×10^{-12}	4.5×10^{-6}	2×10^{-13}	1.5×10^{-7}
Pu^{239}(insol.)	360.	6×10^{-12}	-	2×10^{-13}	-
Ra^{226}+1/2 dr.	16000.	2.4×10^{-11}	1.2×10^{-7}	8×10^{-13}	4×10^{-9}
Rb^{86}	7.8	1.1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
Re^{183}	0.5	2.4×10^{-5}	2.4×10^{-1}	8×10^{-7}	8×10^{-3}
Rh^{105}	1.4	3×10^{-6}	5×10^{-2}	1×10^{-7}	1.6×10^{-3}
Rn^{222} + dr.	-	1×10^{-7}	6×10^{-6}	1×10^{-8}	2×10^{-7}
Ru^{106} + Rh^{106}	19	8×10^{-8}	4×10^{-1}	2.6×10^{-9}	1.3×10^{-2}
S^{35}	18	3×10^{-6}	1.5×10^{-2}	1×10^{-7}	5×10^{-4}
Sc^{46}	13	2×10^{-7}	1	7×10^{-9}	3.6×10^{-2}
Sm^{151}	39000.	4×10^{-8}	6×10^{-1}	1.3×10^{-9}	2×10^{-2}
Sn^{113}	44	1.7×10^{-6}	5×10^{-1}	6×10^{-8}	1.6×10^{-2}
Sr^{89}	52	6×10^{-8}	2×10^{-4}	2×10^{-9}	7×10^{-6}
Sr^{90} + Y^{90}	2700	6×10^{-10}	2.4×10^{-6}	2×10^{-11}	8×10^{-8}
Tc^{96}	2.1	8×10^{-6}	8×10^{-2}	3×10^{-7}	3×10^{-3}
Te^{127}	13	3×10^{-7}	8×10^{-2}	1×10^{-8}	3×10^{-3}
Te^{129}	10	1.2×10^{-7}	3.3×10^{-2}	4×10^{-9}	1.1×10^{-3}

Material	Half-Life (1) (Days)	Restricted (40 hrs/week) TABLE I Column 1 Air (2)	Column 2 Water (3)	Non-restricted TABLE II Column 1 Air (2)	Column 2 Water (3)
Th^{234}	24.1	2×10^{-6}	10	6×10^{-8}	3×10^{-1}
Th-natural (sol.)		5×10^{-11}	1.5×10^{-6}	1.7×10^{-12}	5×10^{-8}
Th-natural (insol.)		5×10^{-11}		1.7×10^{-12}	
Tm^{170}	59	1.5×10^{-7}	8×10^{-1}	5×10^{-9}	2.5×10^{-2}
U-natural (sol.)*	30	5×10^{-11}	2×10^{-4}	1.7×10^{-12}	7×10^{-6}
U-natural (insol.)*	120	5×10^{-11}		1.7×10^{-12}	
U^{233} (sol.)	300	4×10^{-10}	4.5×10^{-4}	1×10^{-11}	1.5×10^{-5}
U^{233} (insol.)	120	5×10^{-11}		1.6×10^{-12}	
V^{48}	12	3×10^{-6}	1.5	1×10^{-7}	5×10^{-2}
Xe^{133}	5.27	1.3×10^{-5}	1.3×10^{-2}	4×10^{-7}	4×10^{-4}
Xe^{135}	0.38	5×10^{-6}	4×10^{-3}	1.7×10^{-7}	1.4×10^{-4}
Y^{91}	51	1.2×10^{-7}	6×10^{-1}	4×10^{-9}	2×10^{-2}
Zn^{65}	21	6×10^{-6}	2×10^{-1}	2×10^{-7}	6×10^{-3}
Unidentified beta or gamma emitters or any undetermined mixtures of beta or gamma emitters		3×10^{-9}	3×10^{-6}	1×10^{-10}	1×10^{-7}
Unidentified alpha emitters or any undetermined mixtures of alpha emitters		1.5×10^{-11}	3×10^{-7}	5×10^{-13}	1×10^{-8}

*For enriched uranium the same radioactivities per unit volume as those for natural uranium are applicable. It should be noted that the contribution of U^{234} to the gross activity of enriched uranium is 20-40 times that of the U^{235}.

Appendix II - Definitions and Terminology

1. X-rays and Gamma rays are short wave length electromagnetic radiation.
2. Beta rays are high speed electrons ejected from radioisotopes.
3. Fast neutrons are neutrons with energy in range above one kilovolt.
4. Thermal neutrons have energy equal to about that of thermal kinetic energy of molecules - 0.025 electron volt.
5. Radioisotope is an isotope of an element giving off nuclear radiation.
6. Roentgen is that quantity of X- or gamma radiation which produces directly and indirectly, per 0.001293 gram of air, ions carrying one electrostatic unit of charge of either sign.
7. Rep or Roentgen equivalent physical is that amount of ionizing radiation that results in the absorption in tissue of 93 ergs/gram. mrep is a millirep or 0.001 rep.
8. Health Physics is that branch of industrial hygiene which deals with the protection of personnel from harmful effects of ionizing radiation.
9. Maximum Permissible Dose is that amount of radiation which a person may receive within a specified period of time without harmful effects.
10. Dose is that amount of energy delivered to a particular absorber. Dose can be expressed as roentgen for X-rays, r.e.p. for beta

rays. The absorber may be air, skin, an organ in the body, or the whole body.

11. Curie is that amount of a radioactive material which has a disintegration rate of 3.7 x 10^{10} atoms/second.

12. Dose rate is the dose delivered per unit time.

13. Radioactivity is a process in which atoms undergo spontaneous disintegration in which energy is liberated in the form of α, β, γ and X-rays.

14. Half-Life is the time in which a radioactive material will lose 1/2 its activity by decay.

Appendix III

SAFETY STANDARD

CONTROL OF RADIATION HAZARDS

THE DOW CHEMICAL COMPANY

MIDLAND MICHIGAN

AUG. 1, 1955

THIS COPY ISSUED TO ____________________

MADE:	THE DOW CHEMICAL COMPANY, MIDLAND, MICH.	SAFETY STANDARDS
CHECKED: A.W.W.	STANDARD FOR CONTROL OF RADIATION HAZARDS	
APP'D: B.B.H.		
DATE 8-1-55	REVISION DATE: 6-13-55	S-477

K&E 166 12-52a

STANDARD FOR CONTROL OF RADIATION HAZARDS

This original Standard was approved by the Executive Safety Council May 19, 1952, as the Standard for Purchase and Control of Radioactive Equipment. The following revision presented by the Radiation Hazards Committee was approved on June 13, 1955. This Standard establishes procedures for the control of all radiation hazards from the use of radiation producing equipment and materials.

I Definition of Terms

1. Radiation producing equipment is any equipment which can produce injurious amounts of emissions of alpha or beta particles, gamma or x-rays, or neutrons. For example: x-ray machines, electron microscopes, accelerators, or sealed radioactive sources.

2. Radiation producing material is any material not in a sealed source which can produce injurious amounts of emissions of alpha or beta particles, gamma or x-rays, or neutrons. For example: Carbon 14, Cobalt 60, Iodine 131 and other radioactive isotopes.

II Purchase of Radiation Producing Equipment and Materials

1. The Industrial Hygiene Laboratory will be notified by the Purchasing Department whenever a request is received for the purchase of any radiation producing equipment or materials. Copies of the purchase order will be sent to the Industrial Hygiene Laboratory and the Safety Department.

2. When the purchase order is written, instructions to the supplier will indicate each package containing any radiation hazard must be marked; "NOT TO BE OPENED BY ANYONE OTHER THAN________________ PHONE NO._____."

3. Further instructions should be given to the supplier to mark each piece of equipment as follows:

   A. When a series of items are purchased under a single Purchase Order Number, they shall each be identified by the name "DOW" and then the Dow Purchase Order Number followed by a dash -, and then numbered consecutively, 1, 2, 3, etc., to account for each item ordered.

   B. Static eliminator bars or other small sources should bear the name

"DOW" and then the Dow Purchase Order Number engraved on the encasement.

C. Larger pieces of equipment will have prominently displayed a suitable tag affixed by welding or metal screws bearing the name "DOW" and then the Dow Purchase Order Number.

D. Permanent radioactive sources contained in protective lead pigs will bear a suitable tag affixed to the pig bearing the name "DOW" and then the Dow Purchase Order Number.

III Receiving of Radiation Producing Equipment and Materials

1. The Stock and Receiving Department will notify the consignee and the Industrial Hygiene Laboratory when any package containing a radiation hazard is received. The package should then be released to the consignee. Notification and release should be accomplished without delay.
2. The Stock and Receiving Department will not open any package marked as in II-2. Furthermore, any package bearing either of the rectangular labels or radioactive identification symbol illustrated on Sheet 6, shall not be opened by the Stock and Receiving Department.
3. In the case of a damaged package containing a readiation hazard, the Industrial Hygiene Laboratory must be notified immediately, and the package must not be handled by anyone until instructions are received from the Industrial Hygiene Laboratory.

IV Registration of Radiation Producing Equipment or Materials

1. Any piece of equipment which can produce a radiation hazard, for example; x-ray machine and permanently sealed radioactive sources will be registered by the Industrial Hygiene Laboratory and assigned a Dow registration number as indicated on the Radiation Record Sheet (Sheet 7). Other pertinent data will be recorded as required to complete the form. Copies of the form will be sent to the consignee and the Safety Department.
2. Any unsealed source of radioactive material, for example; solutions of radioactive isotopes, will be registered on a Radioactive Materials

Record (Sheet 8) by the Industrial Hygiene Laboratory, when it is received. Copies of this form will be sent to the consignee and the Safety Department.

V Monitoring

1. At the time of registration of any radiation producing equipment or material, the Industrial Hygiene Laboratory will make an evaluation of the quantity of radiation produced and other pertinent data as indicated on the appropriate form. The Safety Department or other qualified departments may be called on for assistance.
2. At periodic intervals after the original registration and/or installation, the Industrial Hygiene Laboratory will make rechecks of each source of radiation. The Safety Department or other qualified departments may be called on for assistance.
3. The Industrial Hygiene Laboratory will make periodic surveys of general areas in which work is being done with equipment or materials that could represent a radiation hazard.
4. The Industrial Hygiene Laboratory will be responsible for supplying personnel monitoring service for areas in which a need for this type of monitoring is indicated.
5. On request, the Industrial Hygiene Laboratory will be available to do additional monitoring, or assist in any problems relating to radiation protection.

VI Education

1. The Industrial Hygiene Laboratory will assume the responsibility of properly informing all new personnel who are entering into the use of any equipment or material presenting a radiation hazard.
2. The Industrial Hygiene Laboratory will maintain source material for the use of personnel in promoting a better understanding of the radiation hazards.

VII The Disposal of Radioactive Wastes and Contaminated Equipment

1. The disposal of radioactive wastes or contaminated equipment will be handled by the Industrial Hygiene Laboratory, who will use the facilities and assistance, when needed, of the Waste Disposal Department.

2. The records of the burial grounds, including a detailed map, should be kept as in part IX.

VIII Responsibilities of Supervision Having Jurisdiction Over Radiation Producing Equipment or Materials

1. In any installation where equipment or materials representing a radiation hazard are used, supervision is responsible for safe installation and/or use of this equipment or material.

2. Supervision will see that adequate monitoring is done to assure -
   A. The safety of his workers and also transients who might be in a hazardous area.
   B. Freedom from radioactive contamination of all Dow products.

3. Supervision will notify the Industrial Hygiene Laboratory of any proposed changes in the location or use of radiation producing equipment or materials including -
   A. Any proposed shipment outside of the plant.
   B. Need for disposing of any potential source of radiation.

4. Supervision will properly identify any area or piece of equipment under their jurisdiction which presents a radiation hazard to man. Standard signs to be posted in areas and/or on equipment are available thru the Dow Paint Shop.

5. Supervision will keep up-to-date their copy of the registration forms sent to them by the Industrial Hygiene Laboratory.

6. Supervision will immediately notify the Industrial Hygiene Laboratory of any gross radioactive contamination of their area.

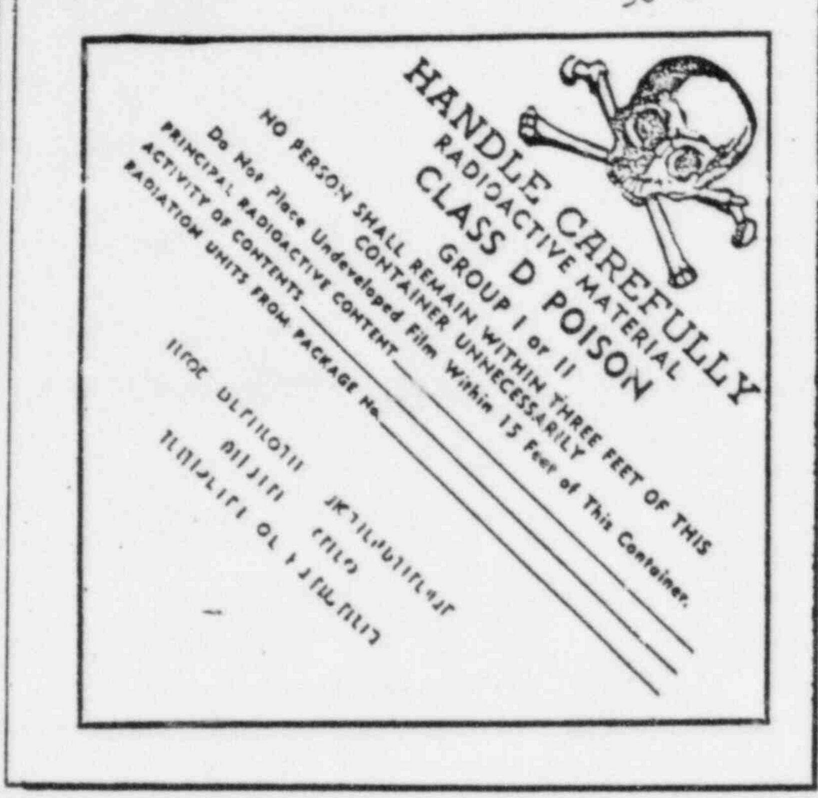
7. On any doubtful problems which might arise in regards to radiation hazards, the Industrial Hygiene Laboratory is to be consulted.

IX Records on Radiation Producing Equipment or Materials

1. The Industrial Hygiene Laboratory will keep the official records on all potential sources of radiation within the Midland Division.
2. Supervision and Safety Department will periodically check their records against those of the Industrial Hygiene Laboratory to keep them up-to-date.
3. Records of radiation exposures to all plant personnel will be kept-
   A. On an individual basis in the personnel health records by the Medical Department.
   B. By the Industrial Hygiene Laboratory on the individual but indexed by department name only.
4. A record of the burial of radioactive wastes and contaminated equipment will be kept by the Waste Disposal Department. A detailed map of the burial grounds will be part of this record. A copy of the record and map shall be kept by the Industrial Hygiene Laboratory.

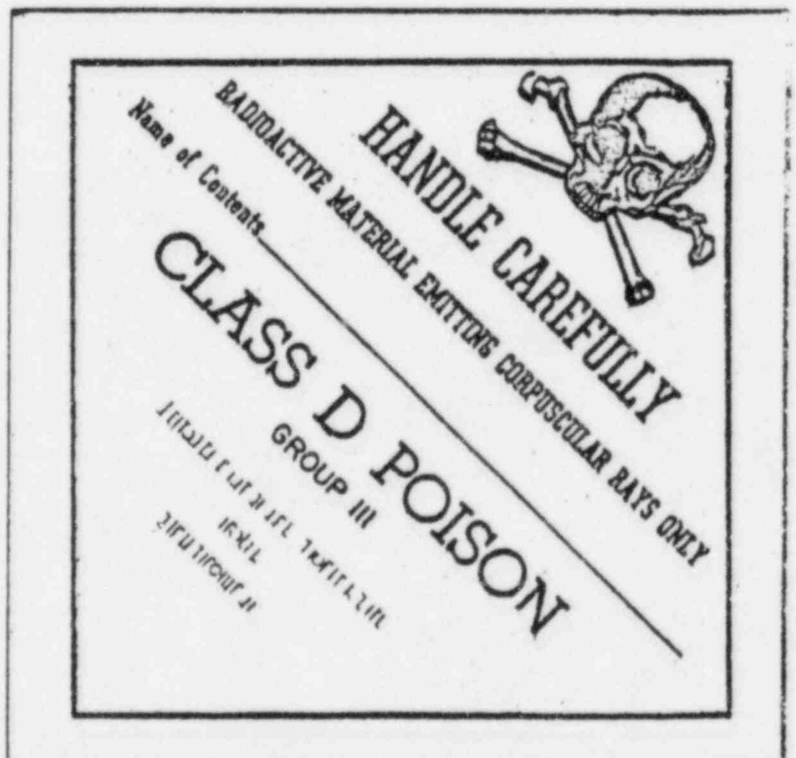
X Responsibilities of the Radiation Hazards Committee

1. The Radiation Hazards Committee will be available to make interpretations of this standard.
2. It will be the responsibility of the Radiation Hazards Committee to review the plans for proposed buildings or areas in which a radiation hazard might exist.
3. The Radiation Hazards Committee is directly answerable to the Executive Safety Council and will carry out such other duties as are assigned it by the Executive Safety Council.



RED PRINT ON WHITE

MAGENTA ON YELLOW



BLUE PRINT ON WHITE

SHEET 6 OF 8

MADE:	THE DOW CHEMICAL COMPANY, MIDLAND, MICH.	SAFETY STANDARDS
CHECKED: A.W.W.	STANDARD FOR CONTROL OF RADIATION HAZARDS	
APP'D.: B.B.H.		S-477
DATE 8-1-55	REVISION DATE: 6-13-55	

DATE	BLDG. NO.	MAN RESPONSIBLE	LOCATION IN BUILDING	USE	REMARKS	[illegible]		REFERENCE MEASUREMENTS mr/hr			
						[illegible]	[illegible]	[illegible]	CONTACT	[illegible]	[illegible]

TYPE OF SOURCE	AMOUNT OF SOURCE	PRINCIPLE RADIATION PRODUCED	SOURCE NO.

RADIATION RECORD SHEET

DATE THE INSTRUCTIONS WERE GIVEN					
WAS THE MAN INSTRUCTED TO TELL THE INDUSTRIAL HYGIENE LAB OF ANY MOVEMENT OF THE SOURCE?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WAS HE INSTRUCTED ON THE DANGER INVOLVED IN MOVING THE SOURCE?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WERE THE GENERAL HAZARDS ASSOCIATED WITH SOURCES OF RADIATION EXPLAINED?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WERE THE SPECIFIC HAZARDS ASSOCIATED WITH THE SOURCE THE MAN WILL BE WORKING WITH EXPLAINED?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
MAN'S NAME					
TITLE OR POSITION HELD BY MAN					
DATE THE INSTRUCTIONS WERE GIVEN					
WAS THE MAN INSTRUCTED TO TELL THE INDUSTRIAL HYGIENE LAB OF ANY MOVEMENT OF THE SOURCE?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WAS HE INSTRUCTED ON THE DANGER INVOLVED IN MOVING THE SOURCE?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WERE THE GENERAL HAZARDS ASSOCIATED WITH SOURCES OF RADIATION EXPLAINED?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
WERE THE SPECIFIC HAZARDS ASSOCIATED WITH THE SOURCE THE MAN WILL BE WORKING WITH EXPLAINED?	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO	( ) YES ( ) NO
MAN'S NAME					
TITLE OR POSITION HELD BY MAN					

RADIOACTIVE MATERIALS RECORD

AUTHORIZATION NO. ______________________

RADIOISOTOPE ______________________ HALF LIFE ______________________ RADIATION

ALPHA ______________________ MEV.

BETA ______________________ MEV.

GAMMA ______________________ MEV.

RECEIVED AS

DATE	REMARKS	AMOUNT RECEIVED	AMOUNT DISPENSED	BALANCE ON HAND	DISPOSITION

[illegible] PRINTED IN U.S.A. [illegible]

SHEET 8 OF 8

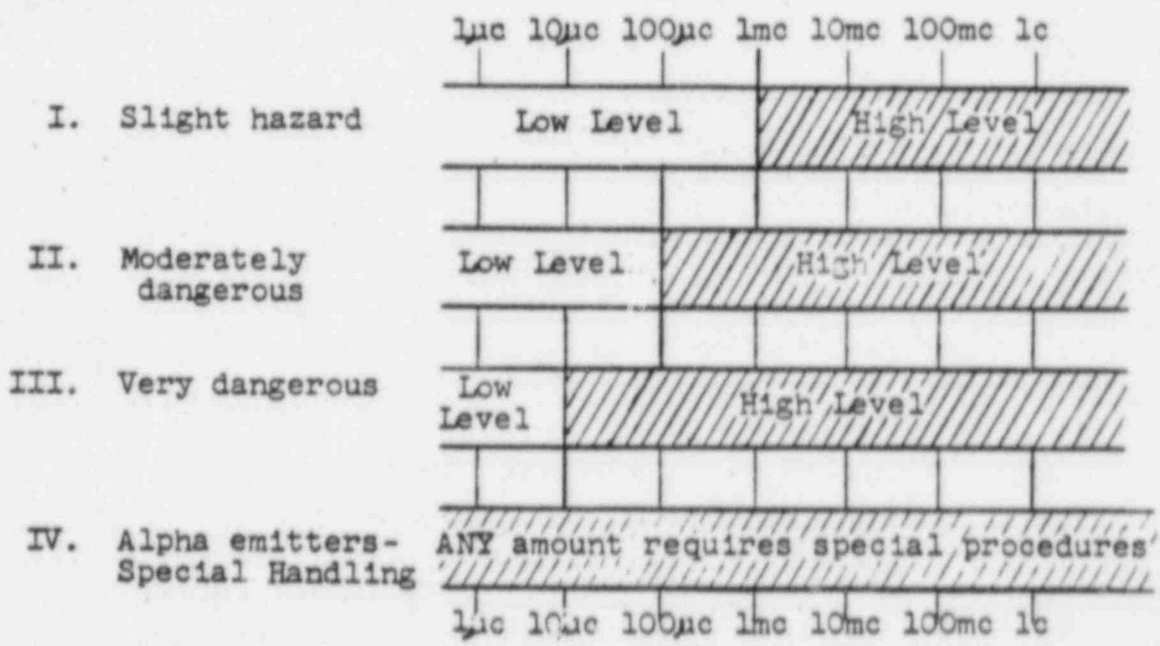
MADE:	THE DOW CHEMICAL COMPANY, MIDLAND, MICH.	SAFETY STANDARDS
CHECKED: A.W.W.	STANDARD FOR CONTROL OF RADIATION HAZARDS	
APP'D.: B.B.H.		S-477
DATE: 8-1-55	REVISED DATE: 6-13-55	

Appendix IV - Useful Information for Safe Handling of Radioisotopes.

The limitations stated below must be remembered in applying the information in this appendix.

<u>Footnotes</u>

1. h = hours, d = days, y = years.
2. Energies listed are those to be used in Appendix V in determining amount of shielding necessary.
3. Internal Hazard Groups are as follows:



The Environmental Research Laboratory, ext. 8991 should be consulted for special precautions and monitoring in all operations involving "high levels" of radioactivity.

Appendix IV (Contd.) - Useful Information for Safe Handling of Radioisotopes

Footnotes

4. This column applies to the maximum laboratory quantity of column 8 and is not valid for larger amounts. A working distance of 1/2 to 1 meter and a working time of 40 hours per week are assumed. A completely closed system is also assumed. A beta shield (usually 1/2 inch thick lucite) is required whenever radioisotopes are handled in open containers such as beakers.
5. The maximum laboratory quantity is the amount above which special monitoring by the Environmental Research Laboratory is required.
6. "Special Handling" means that any amount, no matter how small, requires unusual precautions and special monitoring by the Environmental Research Laboratory. Natural Uranium and Thorium are placed in this group because of the need for strict accountability to the AEC for these materials.

Appendix IV - Useful Information For Safe Handling Of Radioisotopes In The Laboratory

1 Isotope	2 Physical Half Life[1]	3 Radiation	4 Energy in Mev[2]	5 Permissible Body Burden in μc	6 Internal Hazard Group[3]	7 Shielding[4]	8 Maximum Laboratory Quantity in μc[5]	9 Point source γ dose rate at 1 meter in mr/hr per mc.
Ag^{105}	40 -d	γ	0.5	18	II	No	100	0.3
Ag^{111}	7.5-d	β γ	1.04 0.3	36	II	β	100	0.2
Am^{241}	470 -y	α γ	5.5 0.06	0.06	IV	Special Handling[6]		
As^{76}	26.7-h	β γ	1.14 0.6	10	I	β	1000	0.3
At^{211}	7.5-h	α γ	5.9 0.6	$6x10^{-4}$	II	No	100	0.3
Au^{198}	2.7-d	β γ	0.96 0.4	10	II	β	100	0.2
Au^{199}	3.2-d	β γ	0.3 0.2	28	II	No	100	0.04
Ba^{140}+ La^{140}	12.8-d	β γ	1.0 0.5	5	II	β,γ	100	1.2
Be^{7}	53 -d	γ	0.48	670	II	No	100	0.03
C^{14}	5570 -y	β	0.155	1500	II	No	100	0
Ca^{45}	160 -d	β	0.25	65	III	No	10	0
Cd^{109}+ Ag^{109m}	1.3-y	γ	0.16	40	II	No	100	0.08
Ce^{144}+ Pr^{144}	285 -d	β γ	0.33 0.134	5	III	No	10	0.005
Cl^{36}	$3x10^{5}$-y	β	0.71	200	II	No	100	0
Cm^{242}	163 -d	α γ	6.1 0.04	0.05	IV	Special Handling		
Co^{60}	5.7-y	β γ	0.31 1.1,1.3	3	II	γ	100	1.3
Cr^{51}	27.8-d	γ	0.3	390	II	No	100	0.02
Cs^{137}+ Ba^{137m}	30 -y	β γ	0.52 (92%) 1.2 (8%) 0.66	90	II	No	100	0.3
Cu^{64}	12.8-h	β γ	0.57 1.34 (0.5%)	150	I	No	1000	0.1
Eu^{154}	16 -y	β γ	1.5 1.1 (50%)	22	II	β,γ	100	0.6

1 Isotope	2 Physical Half Life[1]	3 Radiation	4 Energy in Mev[2]	5 Permissible Body Burden in μc	6 Internal Hazard Group[3]	7 Shielding[4]	8 Maximum Laboratory Quantity in μc [5]	9 Point source γ dose rate at 1 meter in mr/hr per mc.
F^{18}	1.9-h	β^+	0.65	670	I	No	1000	0
Fe^{55}	2.9-y	E.C.	0.21 cont. γ spectrum	1000	II	No	100	0
Fe^{59}	45 -d	β γ	0.46 1.1,1.3	11	III	γ	10	0.6
Ga^{72}	14.1-h	β γ	3.2 max. 2.5 max.	8	II	β,γ	100	1
Ge^{71}	12 -d	E.C.		67	I	No	1000	0
H^3(HTO or T_2O)	12.3-y	β	0.018	10^4	I	No	1000	0
Ho^{166}	27 -h	β γ	1.85 1.46 (11%)	17	II	β,γ	100	0.7
I^{131}	8 -d	β γ	0.8 0.36 (87%)	0.3	II	β	100	0.22
Ir^{190}	11 -d	γ	0.3	21	II	No	100	0.2
Ir^{192}	74.5-d	β γ	0.67 0.4	3.4	II	β	100	0.3
K^{42}	12.4-h	β γ	3.6 1.5	20	I	β	1000	0.15
La^{140}	40.2-h	β γ	2.26 1.6	24	II	β,γ	100	1.2
Lu^{177}	6.8-d	β γ	0.5 0.3	78	II	No	100	0.2
Mn^{56}	2.6-h	β γ	2.8 0.8	2	I	β,γ	1000	0.5
Mo^{99}	67 -h	β γ	1.2 0.2	50	II	β	100	0.1
Na^{24}	15 -h	β γ	1.4 2.7,1.4	15	I	β,γ	1000	1.84
Nb^{95}	35 -d	β γ	0.16 0.75	90	II	γ	100	0.5
Ni^{59}	$8x10^4$y	E.C.		39	I	No	1000	0
P^{32}	14.5-d	β	1.7	10	II	β	100	0
Pb^{203}	52 -h	E.C. γ	0.4	57	II	No	100	0.2

1 Isotope	2 Physical Half Life[1]	3 Radiation	4 Energy in Mev[2]	5 Permissible Body Burden in μc	6 Internal Hazard Group[3]	7 Shielding[4]	8 Maximum Laboratory Quantity in μc [5]	9 Point source γ dose rate at 1 meter in mr/hr per mc.
Pd^{103+} Rh^{103}	17 -d	E.C. γ	 0.04	6	II	No	100	0
Pm^{147}	2.6-y	β	0.23	120	III	No	10	0
Po^{210} (sol.)	138 -d	α	5.3	0.02	IV	Special Handling		
Po^{210} (insol.)	138 -d	α	5.3	$7x10^{-3}$	IV	Special Handling		
Pr^{143}	13.8-d	β	0.9	29	II	β	100	0
Pu^{239} (sol.)	24,300 -y	α	5.1	0.04	IV	Special Handling		
Pu^{239} (insol)	24,300 -y	α	5.1	0.008	IV	Special Handling		
Ra^{226+} 1/2 dr	1620 -y	α γ	4.8 0.2-2.5	1	IV	Special Handling		
Rb^{86}	18.6-d	β γ	1.8 1.1	60	II	β	100	0.05
Re^{183}	150 -d	E.C. γ	 0.2	35	II	No	100	0
Rh^{105}	36 -h	β γ	0.6 0.3 (5%)	9	II	β	100	0
Rn^{222+} dr	3 -d	α γ	5.5 complex		IV	Special Handling		
Ru^{106+} Rh^{106}	1 -y	β γ	3.5 0.5	4	II	β	100	0.3
S^{35}	87 -d	β	0.167	100	II	No	100	0
Sc^{46}	85 -d	β γ	0.36 0.9,1.1	6	II	Yes	100	1.1
Sm^{151}	80 -y	β γ	0.076 0.02	420	II	No	100	0.2
Sn^{113}	112 -d	E.C. γ	 0.4	80	II	No	100	0.3
Sr^{89}	53 -d	β	1.48	2	II	β	100	0
Sr^{90+} Y^{90}	28 -y	β	2.3	1	IV	β	Special Handling	0

1 Isotope	2 Physical Half Life[1]	3 Radiation	4 Energy in Mev[2]	5 Permissible Body Burden in μc	6 Internal Hazard Group[3]	7 Shielding[4]	8 Maximum Laboratory Quantity in μc[5]	9 Point source γ dose rate at 1 meter in mr/hr per mc.
Tc^{96}	4.3-d	E.C. γ	 0.8 (3 per dis.)	5	II	Yes	100	1.5
Te^{127}	9.3-h	β	0.7	4	II	β	100	0
Te^{129}	1.2-h	β γ	1.8 0.3,0.8	1.3	II	β	100	0
Th^{234}	24.1-d	β	0.2 0.09	120	II	No	100	0
Th-natural (sol.)	1.4×10^{10}-y	α	4.0	0.01	I	No	Special Handling	Increases with time since last separation,
Th-natural (insol.)	1.4×10^{10}-y	α	4.0	0.002	I	No	Special Handling	Usually low
Tm^{170}	125 -d	β γ	1.0 0.08	19	II	β	100	0
U^{233} (sol.)	1.6×10^{5}-y	α	4.8	0.04	IV	Special Handling		
U^{233} (in sol.)	1.6×10^{5}-y	α	4.8	0.008	IV	Special Handling		
U natural (sol.)		α		0.2	IV	Special Handling		
U natural (insol.)		α		0.009	IV	Special Handling		
V^{48}	16 -d	β+ γ	0.7 1.3	20	II	β,γ	100	1.0
Xe^{133}	5.3-d	β γ	0.35 0.08	300	I	No	1000	0
Xe^{135}	9.2-h	β γ	0.9 0.25	100	I	β	1000	0.04
Y^{91}	58 -d	β γ	1.5 1.2 (0.1%)	15	III	β	10	0
Zn^{65}	245 -d	E.C.	0.008 (98%)	430	II	No	100	0.3
		β+	0.325 (2%)					
		γ	1.1 (44%)					

Appendix V - Beta And Gamma Shielding

Beta-Ray Shielding

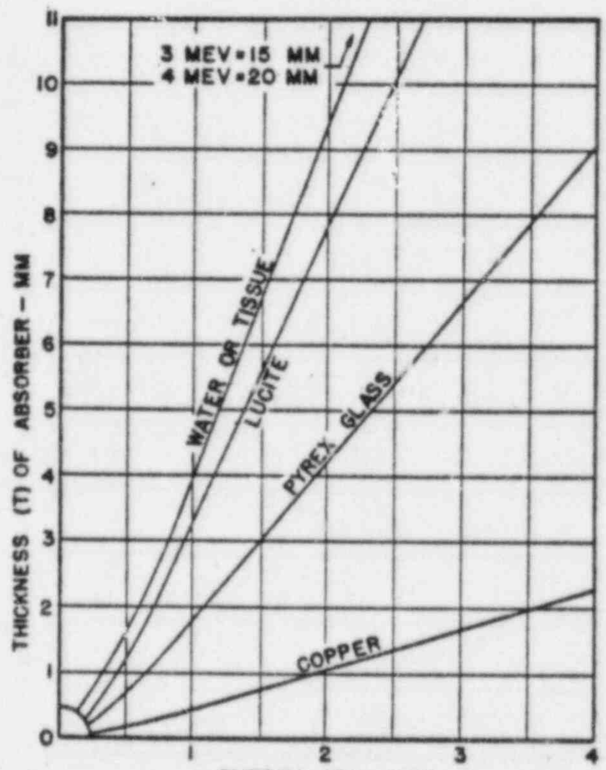


FIGURE 1.—*Thickness, T mm, of typical materials required to stop completely beta-rays of maximum energy, E MEV.*

Note: For Beta range in air, use "Lucite" curve and multiply Thickness (T) by 1000.

Appendix V Gamma-Ray Shielding

1. Required Shield Thickness

The table given below may be used to determine the required thicknesses for shielding from gamma-ray sources in the laboratory.

Select column for energy required (use next higher if exact value is not given). Entry gives thickness in centimeters of lead for different source strengths at 1 m for 8 hr/day to give 50 mr. *Add* algebraically the correction terms for other working ranges or times, and *multiply* by factor for shield material.

Example: An iron shield is required for the manipulation of 500 mc of radioactive material emitting 1.8-Mev gamma rays at a minimum working distance of 50 cm, and for 4 hr/day.

Shield thickness = $(\underset{(a)}{8.60} + \underset{(b)}{2.77} - \underset{(c)}{1.39}) \times \underset{(d)}{1.43} = 14.3$ cm of Fe, in which

a = basic entry.
b = correction for danger range = 50 cm.
c = correction for 4 hr/day.
d = conversion from Pb to Fe.

Activity	ENERGY (Mev)								
	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	4.0
10 mc	−0.14	−0.36	−0.27	−0.11	+0.37	+0.78	+1.15	+1.40	+1.70
20 mc	−.09	.00	+.41	+.76	+1.57	+2.16	+2.63	+2.91	+3.21
50 mc	−.01	+.47	+1.31	+1.90	+3.15	+4.00	+4.57	+4.90	+5.20
100 mc	+.06	+.82	+1.99	+2.77	+4.34	+5.38	+6.05	+6.41	+6.71
200 mc	+.10	+1.17	+2.67	+3.63	+5.54	+6.77	+7.52	+7.92	+8.21
500 mc	+.17	+1.64	+3.57	+4.78	+7.12	+8.60	+9.47	+9.91	+10.21
1 c	+.23	+1.99	+4.25	+5.65	+8.31	+9.99	+10.95	+11.41	+11.71
2 c	+.28	+2.35	+4.93	+6.52	+9.51	+11.37	+12.42	+12.92	+13.22
5 c	+.36	+2.81	+5.82	+7.66	+11.09	+13.21	+14.37	+14.91	+15.21
10 c	+.41	+3.17	+6.50	+8.52	+12.28	+14.59	+15.85	+16.42	+16.72
20 c	+.47	+3.52	+7.18	+9.39	+13.46	+15.98	+17.32	+17.93	+18.23
50 c	+.54	+3.99	+8.08	+10.54	+15.06	+17.81	+19.27	+19.92	+20.22
100 c	+.60	+4.34	+8.76	+11.40	+16.25	+19.20	+20.75	+21.43	+21.72
Danger range	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
20 cm	+0.26	+1.64	+3.16	+4.02	+5.55	+6.44	+6.85	+7.00	+7.00
50 cm	+.11	+.71	+1.36	+1.73	+2.39	+2.77	+2.95	+3.01	+3.01
1 m	.00	.00	.00	.00	.00	.00	.00	.00	.00
2 m	−.11	−.71	−1.36	−1.73	−2.39	−2.77	−2.95	−3.01	−3.01
5 m	−.26	−1.64	−3.16	−4.02	−5.55	−6.44	−6.65	−7.00	−7.00
10 m	−.37	−2.35	−4.52	−5.76	−7.94	−9.21	−9.80	−10.01	−10.01
Working time, hr/day	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus	Plus
1	−0.17	−1.06	−2.04	−2.00	−3.59	−4.16	−4.42	−4.52	−4.52
2	−.11	−.71	[illegible].36	−1.73	−2.39	−2.77	−2.95	−3.01	−3.01
4	−.06	−.35	−.68	−.87	−1.20	−1.39	−1.47	−1.51	−1.51
8	.00	.06	.00	.00	.00	.00	.00	.00	.00
24	+.09	+.[illegible]6	+1.08	+1.37	+1.99	+2.20	+2.34	+2.39	+2.29
Absorber	Times	Times	Times	Times	Times	Times	Times	Times	Times
Pb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	[illegible].00
Fe	5.60	2.88	1.[illegible]3	1.74	1.49	1.43	1.47	1.48	[illegible].59
Al[1]	41.67	9.80	6.18	5.33	4.83	5.00	5.28	5.68	6.39
H_2O	106.84	21.54	13.42	11.59	10.36	11.11	11.19	12.11	12.78

[1] Or concrete.

NOTES

(1) Source activity is quoted in millicuries or curies, where 1 curie is that amount of radioactive material that disintegrates at the rate of 3.7×10^{10} disintegrations/second. However, the table is computed on the further assumption that each disintegration yields one gamma photon of the selected energy. This will lead to inaccuracies whenever the disintegration is complex. More accurate calculations can be made by obvious methods when the disintegration scheme is known.

(2) The tabulation ignores the increased effective transmission of shields under wide beam irradiation.

(3) This form of shielding table (prepared by C. C. Gamertsfelder) is intended to form a guide to rapid erection of temporary shielding structures in the laboratory. Where permanent installations of maximum economy are planned, more detailed calculations by conventional methods are required.