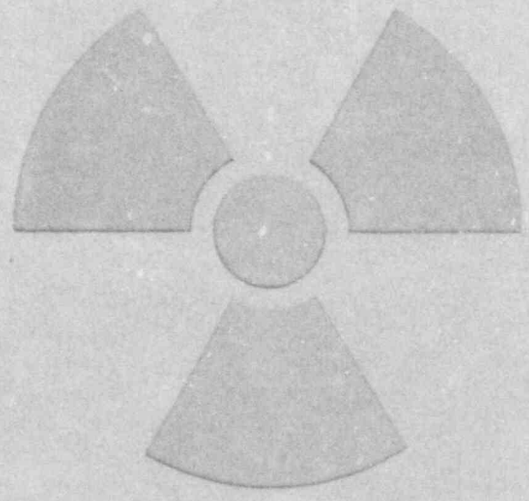

RADIATION SAFETY MANUAL

UNIVERSITY HEALTH SERVICES
OFFICE OF ENVIRONMENTAL HEALTH AND SAFETY
UNIVERSITY OF MASSACHUSETTS AT AMHERST

ML10

PART I

RADIONUCLIDE USE

POLICY AND PROGRAM

Prepared by the Division of
Environmental Health & Safety
University Health Services
July 1977

UNIVERSITY OF MASSACHUSETTS
AMHERST · BOSTON · WORCESTER

OFFICE OF THE CHANCELLOR
WHITMORE ADMINISTRATION BUILDING
AMHERST, MASSACHUSETTS 01002

The University of Massachusetts Amherst campus is using radionuclides under a specific license of broad scope issued by the U.S. Nuclear Regulatory Commission. Possession of this license carries strict responsibilities governing use and ultimate disposal. The University considers the N.R.C. regulations as minimum requirements, and has broadened local controls to include radiation sources not under N.R.C. surveillance.

The procedures in this manual are designed to permit maximum beneficial use of radiation sources with the minimum exposure to personnel. Knowledge of and adherence to these procedures is the responsibility of every individual who utilizes radioactive materials or radiation producing machines in any way.

Failure to follow the recommended procedures could result in a serious radiation overexposure and/or a suspension or revocation of our license. Moreover, all users shall cooperate fully with the Radiation Safety personnel of the Division of Environmental Health and Safety, University Health Services, who will assist in the implementation of these procedures.

Randolph W. Bromery
Chancellor

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RADIONUCLIDE USE POLICY AND PROGRAM

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I. PURPOSE

This manual sets forth the University of Massachusetts, Amherst campus, policy and program for personnel protection from unwarrented radiation exposure while using radioactive material.

II. SCOPE

A. This manual delineates the requirements for procuring, receiving shipping, using, transporting, maintaining or disposing of radioactive material.

B. The provisions of this manual apply to all departments, employees of the University, visiting scientists, and personnel from other organizations working at the University.

III. POLICY

All operations involving the use of radionuclides in any chemical or physical form, will be conducted in such a manner as to ensure that exposure to radiation is "as low as is reasonably achievable." Operations involving the use of RADIOACTIVE MATERIAL SHALL BE PLANNED so that the limits established by the Nuclear Regulatory Commission for personnel exposure and radioactive material effluent releases are not exceeded.

IV. RESPONSIBILITIES

A. RADIOISOTOPE USE COMMITTEE

The committee is responsible to the Chancellor thru the Dean of the Graduate School for insuring the safe use of radioactive materials on campus. All departments engaged in the use of radioactive materials are entitled to representation on the committee.

1. Responsibilities of this committee will include:
   a. Establishing policies on the safe use, handling, storage, transport, receipt, shipment, and disposal of radioactive materials.
   b. Reviewing the radiation safety aspects of proposals for the procurement and use of radioisotopes and for the modification of existing operating procedures involving the use of radioactive materials.
   c. Reviewing applications for Nuclear Regulatory Commission licenses.
   d. Reviewing and approving the qualifications of users of radioisotopes (see application for use Part B).
   e. Reviewing reports of accidents and incidents involving the use of radioisotopes to determine the cause and taking the necessary corrective action to prevent reoccurance.
2. Meetings - meetings will be scheduled at least quarterly by the chairman, but more often if necessary to attend to new proposals for radioisotope use or other matters pertaining to the safe use of radioisotopes.

B. DIVISION OF ENVIRONMENTAL HEALTH AND SAFETY

The Division of Environmental Health and Safety is organizationally situated within Student Affairs reporting thru Health Services. The Radiation Protection Officer reports to the Director of EH&S who in turn reports to the Director of Health Services.

		(day)	(night)
Barry W. Averill	Director Health Services	549-2671	369-4043
Donald A. Robinson	Director EH&S	545-2682	367-2039
James Tocci	Radiation Protection Officer	545-2682	323-5087

Radiation Protection Officer, as a staff member of the Division of Environmental Health and Safety, University Health Services, will perform as an integral part of the overall U. Mass. radioisotope use program the actions required to establish and maintain preventive measures to safeguard personnel from harmful effects of ionizing radiation.

1. Responsibilities of the Radiation Protection Officer will include:
   a. Providing the RUC and individual users with advice and assistance on all matters pertaining to the safe use of radioisotopes.
   b. Reviewing radioisotope use procedures to determine compliance with Nuclear Regulatory Commission regulations and approved procedures.
   c. Maintaining accurate records of U. Mass. radioisotope inventory, radiation surveys, bioassays, personnel dosimetry, solid waste disposal, leak test of sealed sources, effluent releases of radioactive material into the sanitary sewer system and into the atmosphere, calibration of instruments and any others necessary for NRC compliance.

d. Performing radiation surveys or causing such surveys to be performed.

e. Assuring that radiation detection instruments are properly calibrated.

f. Investigating accidents and incidents involving the use of radioactive material.

g. Collecting and disposing of solid wastes containing radioactive material.

h. Performing bioassay analysis on researchers as necessary.

2. The Radiation Protection Officer will act as secretary to the Radioisotope Use Committee.

C. AUTHORIZED USERS

Authorized users of radioactive material are responsible to the RUC for assuring the safe use of radioactive material in his/her area or lab. The responsibilities of an authorized user include:

1. Complying with and enforcing the radiation safety requirements prescribed in this manual and in his authorization by the RUC.
2. Assuring that his personnel are properly instructed in safe procedures for working with any radioactive material in his charge.
3. Assuring that required monitoring devices, protective clothing and equipment, and contamination control methods are used.
4. Reviewing in advance all lab procedures to be used by his personnel in carrying out research work involving radioactive material for probability of spills, explosion, implosion or fires.
5. Assuring the integrity of vacuum systems, cryogenic systems, pressure vessels or equipment to be used in conjunction with radioactive material.
6. Assuring that any new and/or complex procedures to involve the use of radioactive material are thoroughly tested in a "dry run" before attempting an actual use.
7. Maintaining control of visitors.
8. Maintaining an up-to-date record or log book showing all receipts and disposals (by any method) of radioisotopes.

D. THE INDIVIDUAL USER

The individual user is responsible for:

1. Keeping users daily exposures to radiation as low as is reasonably achieveable (Refer to page 14.19).
2. Wearing prescribed monitoring devices and protective clothing.
3. Using prescribed or approved techniques and facilities only in operations involving the use of radioactive material.
4. Reporting incidents or accidents involving radioactive material promptly to this supervisor and the Environmental Health and Safety Office.
5. Posting warning signs, properly labeling waste containers, and otherwise controlling radiation hazards for which he is responsible.
6. Cleaning up any contamination he generates using prescribed procedures. (Refer to page 11.5).
7. Keeping effluent wastes (i.e. liquids down the sink or air borne releases in or out of labs) containing radioactive material below prescribed (NRC 10CRF20) concentration limits and recording each disposal or release.
8. Properly storing and handling radioactive material.
9. Complying with restrictions on eating, drinking, and smoking.
10. Complying with all sections of this manual and with posted NRC regulations.
11. Opening and inspecting packages containing radioactive material delivered to them by Environmental Health and Safety personnel (who will observe and/or assist in this process if necessary, Refer to page 14.18).

V. APPLICATION FOR USE

Proposals to utilize radionuclides will be submitted to the RUC through the Environmental Health and Safety Office on approved forms obtainable at the Environmental Health and Safety Office.

The applicant may be requested to be present at the RUC meeting in which his application will be reviewed for more detailing of his propcsal prior to Committee action.

When an application has been approved, one copy will be given to the applicant to serve as his authorization. A second copy will be retained by the Environmental Health and Safety Office for compliance records. (Refer to pages 14.15 - 14.17).

VI. CONTROL/ACCOUNTABILITY OF RADIOACTIVE MATERIAL

A. ORDERING OF RADIOACTIVE MATERIAL

The actual ordering of radioactive material will be performed by authorized users or individuals working for authorized users, after securing verbal authorization from the Environmental Health and Safety Office. The Environmental Health and Safety Office will assure that the user is authorized type and quantity of radioactive material being requested. The following restrictions will be observed:

1. The amount of each radionuclide ordered, or the total when added to the present inventory of that radionuclide, will not exceed the maximum allowed by the RUC.
2. Only the type and chemical or physical forms authorized by the RUC will be ordered.

B. DISPOSITION OF RADIOACTIVE PACKAGES

All packages containing radioactive material will be delivered to Morrill Science Building-North, Room N407. The packages will remain there until logged in and checked for external contamination, leakage probability, external radiation levels, and proper labelling by the Environmental Health and Safety Office before being delivered to the purchaser.

C. INVENTORY OF RADIOACTIVE MATERIAL

A radioisotope inventory, showing all receipts and disposals, will be maintained by each authorized user. The Environmental Health and Safety Office will maintain an overall UMass radioisotope running inventory.

D. WASTE DISPOSAL

Radioactive waste will be disposed of by the following methods:

1. Properly labelled and quantified solid form wastes (or liquids

solidified in kitty litter or vermiculite) in glass, plastic, or metal containers will be collected by the Environmental Health and Safety Office once each week. Request for waste pick-up may be made by phoning the EH & S Office (5-2682).

2. Liquids containing radionuclides may be disposed of via sinks, subject to restrictions prescribed in authorizations by the RUC.
3. All radioactive materials containing infectious agents shall be autoclaved or otherwise deactivated before being presented for disposal.
4. Incineration or burial of any material containing radionuclides is not permitted under the University's license.

VII. TRANSPORTATION

A. On Campus

All radioactive material will be delivered to authorized or individual users by Environmental Health and Safety personnel in original shipping containers. Movement of radioactive material between laboratories will only be permitted if authorized in specific procedures by the RUC.

B. Off Campus

Any user contemplating off campus movement of radioactive material to another organization should make specific application to the RUC through the Environmental Health and Safety Office for prior approval and prescribed procedures for the transition.

VIII. RADIATION SURVEYS

The Environmental Health and Safety Office is responsible for performing radiation surveys and ensuring that radiation surveys are performed by others in accordance with the following:

A. INITIAL SURVEYS

An initial survey will be made by the RPO of areas where radioactive material will be used and/or stored before operations are initiated or changes approved, to assure the facilities are adequate.

B. ROUTINE SURVEYS

Areas where radioactive material are used and/or stored shall be surveyed on a monthly basis. A physical survey of locations of radioactive material and equipment, levels of radiation and/or concentration of radioactive material in and around the site will be performed. Locations of the monitoring points with results, statement of any hazard present, any recommendation as to decontamination, shielding, procedural changes, etc. will be recorded and filed.

C. USER SURVEYS

Authorized or individual users will evaluate their laboratory areas on a daily basis to insure that radiation levels are kept as low as is reasonably achievable.

D. SPECIAL SURVEYS

The RPO is responsible for performing the following special surveys:

1. Leak Tests. Leak tests of sealed sources will be performed once every six months as required by NRC license conditions.
2. Termination of Use Areas in which radioactive material will no longer be used will be surveyed to determine that no contamination exists and that sources of radiation are properly disposed of.

IX. CALIBRATION OF INSTRUMENTS

The Environmental Health and Safety Office will collect and calibrate all radiation detection and measurement instruments every 3 months. Instruments requiring maintenance and/or repair will be the responsibility of the user.

X. EMERGENCY PROCEDURES

A. In view of the complicating factors that may arise in an emergency, it is impossible to establish simple rules to cover all situations of a radiation emergency. The University is too large, and in the habit of many irregular work hours, for the Environmental Health and Safety Office to maintain sole responsibility in an emergency situation. Key emergency personnel, properly trained and equipped to cope with radiological emergencies should be established, and names posted in all use areas.

B. Emergencies will probably be of the following types:

1. Spill of radioactive material
2. Explosion in or near RAM use area
3. Fire in or near RAM use area
4. Overexposure of radiation to personnel
5. Injury to personnel
6. Loss of a radioactive source
7. Vehicular accident during transport of RAM

In all of the above cases primary concern must always be the protection of personnel from radiation hazards. Confinement of the contamination to the immediate environment of the accident should be a secondary concern.

C. EMERGENCY ACTION - GENERAL

1. Notify all persons not involved with the incident to vacate the area.
2. Notify Health Services if there are any injured personnel involved.
3. Notify Fire Department in the event of an accident involving fire.
4. Notify the Radiation Protection Officer as soon as possible:

Jim Tocci, RPO

Office: 545-2682

Home: 323-5087

Francis Roy, Asst. Health Physicist, 1st Alt.

Office: 545-2682

Home: 549-5131

Donald Robinson, 2nd Alt.

Office: 545-2682

Home: 367-2039

D. EMERGENCY ACTION - SPECIFIC

1. Spills or uncontrolled spread of contamination

   a. If spill is liquid and the hands and clothing are protected, right the container and take steps to contain the spillage.

   b. If the spill is on the skin, flush thoroughly

   c. If spill is on the clothing, discard outer or protective clothing at once.

2. Fire and other major emergencies

   a. Attempt extinguishment of fires with readily available type extinguishers if a radiation hazard is not immediately present.

   b. Efforts should be made to prevent water of fire fighting chemicals from coming in contact with the radiation source.

   c. Attempt to control runoff, preventing it from entering drainage systems until it has been monitored.

3. Injuries to personnel involving radiation

   a. Wash minor wounds immediately under running water while spreading the edges of the wound.

   b. Personnel with minor wounds will be monitored and decontaminated, if necessary, before leaving the radiation facility.

   c. Persons more seriously injured should not be moved until medical help arrives unless other emergencies exist (e.g. fire or possible explosion). Moving of the patient may become imperative.

XI. GENERAL SAFETY PROCEDURES

A. PROPER MARKING OF LABORATORIES, AREAS AND EQUIPMENT

1. A "Caution Radioactive Materials" sign must be conspicuously posted on the doors to laboratory areas where radioactive materials are being used or stored. The name and home phone number of the individual responsible for the posted area shall be shown in the designated place on the sign in order to facilitate contact in case of emergency. The supervisor shall be responsible for seeing that the posted information is current. The signs must not be removed from any room except by Radiation Safety personnel following an inspection survey.
2. Storage areas shall be conspicuously marked with a "Caution Radioactive Materials" sign. In addition, containers in which materials are transported or stored shall bear a durable, clearly visible label bearing the words "Caution Radioactive Materials." This label shall also state the quantities and kinds of radioactive materials in the containers and the date of measurement of the quantity.
3. Radiation areas in the laboratory, i.e., areas where radiation levels might expose individuals to 5 millirem in any one hour; or in any five consecutive days, a dose in excess of 100 mrem, shall be posted with the sign "Caution Radiation Area."
4. All equipment contaminated with radioactive material shall be marked with signs, decals, or other conspicuous means. Labelling shall not be required for laboratory containers such as beakers, flasks, and test tubes, used transiently in laboratory procedures during the presence of the user.

5. All signs referred to in this part are available from the Environmental Health and Safety Office.

B. SHIELDING OF SOURCES

1. Radioactive sources or stock solutions in the laboratory shall be shielded in such a manner that the radiation levels in any occupied area will not expose individuals in the area to more than 100 mrem in any five consecutive days.
2. Various shielding materials are available on loan from the Environmental Health and Safety Office.

C. AEROSOLS, DUSTS AND GASEOUS PRODUCTS

1. Procedures involving aerosols, dusts or gaseous products, or procedures which might produce airborne contamination shall be conducted in a hood, dry box, or other suitable closed system.
2. All releases from such systems shall not exceed the maximum permissible concentration in air for the nuclide in question. See Appendix B, Table II of 10 CRF 20 for appropriate values. However, where practical, traps should be incorporated in the experimental set-up to insure that environmental releases are as low as possible.
3. Radioactive gases or materials with radioactive gaseous daughters must be stored in gas-tight containers and must be kept in areas having approved ventillation.
4. Hoods to be used for radioisotope work should be tested by the Environmental Health and Safety Office, to insure that they meet minimum requirements for air velocity at the face of the hood, i.e., 100 lfm.

D. RADIOACTIVE MATERIALS IN GAS CHROMATOGRAPHY EQUIPMENT

1. Each cell containing a radioactive foil must have a label showing: The radiation caution symbol with the words "Caution Radioactive Material"; and The identity and activity of the radioactive material.

   The radioactive foil shall not be removed from its identifying cell except for cleaning and shall not be transferred to other cells.

2. The following notice shall appear in a conspicuous location on the outside of each gas chromatography unit: "This equipment contains a radioactive source registered with the Environmental Health and Safety Office as required by license from the Nuclear Regulatory Commission. Notify the Environmental Health and Safety Office before removing the source from this room or area or upon any change in custodial responsibility." These notification tags are available from the Environmental Health and Safety Office.

3. Individuals using radioactive components in gas chromatography equipment must vent the cell exhaust through plastic tubing into a hood, room exhaust, or Environmental Health and Safety approved trap, to avoid contamination of work areas from the release of radioactive tagged samples introduced into the system or from the accidental overheating of radioactive foils in the cells.

4. The Environmental Health and Safety Office will perform periodic leak tests, and maintain the necessary records on such tests.

E. WORK SURFACES

All work areas (bench tops, hood floors, etc.) as well as storage areas and areas adjacent to permanent set-ups and sinks should be covered at all times with stainless steel or plastic trays, uncracked glass plates,

or other impervious materials. For some purposes a plastic-backed absorbent paper will be satisfactory. However, if such paper is used, it should be discarded frequently to prevent active material from dusting off the surface.

F. REMOVAL OF EQUIPMENT FROM THE LABORATORY

Once used for radioactive substances, equipment shall not be used for other work, or sent from the area to central cleaning facilities, repair shops, surplus, or returned to the source of supply, until demonstrated to be free of contamination.

G. REPAIR AND MAINTENANCE OF EQUIPMENT IN THE LABORATORY

Equipment to be repaired by shop and maintenance personnel, or by commercial service contractors, shall be demonstrated to be free of contamination prior to servicing. If it becomes necessary to make emergency repairs on contaminated equipment, the work will be supervised by a member of the Environmental Health and Safety staff, who will assure that the necessary safeguards are taken. It is the responsibilityof the laboratory personnel to request this supervision from the Environmental Health and Safety Office.

H. HOUSE VACUUM LINES

House vacuum lines are vulnerable to contamination. If house vacuum lines are to be used, the withdrawn gas must be demonstrated to the Environmental Health and Safety Office to be free of radioactivity. It is advisable to use a separate vauum pump exhausting into a hood.

I. RADIOACTIVE CONTAMINATION OF AREAS

In general, no radioactive contamination can be tolerated. Exceptions to this will include certain hood trays, dry boxes, stainless steel trays, plastic-backed absorbant paper covered surfaces, or other equipment which

is used frequently for active work and which will be clearly marked with the standard radiation caution signs or stickers. Any contamination that is not confined to protected surfaces should be reported immediately to the Environmental Health and Safety Office. The Environmental Health and Safety staff will supervise the decontamination of such areas of equipment.

J. DECONTAMINATION OF AREAS CONTAMINATED WITH RADIOACTIVITY

Preparations for decontamination should be begun promptly. Determine the extent and hazard of contamination. The Environmental Health and Safety staff will assist in this evaluation. The individual responsible for the contamination will be expected to do most of the cleanup under the supervision of the Environmental Health and Safety staff (Refer to page 14.13) After decontamination, the area or equipment shall be considered contaminated until proved otherwise by the Environmental Health and Safety Office.

K. DECONTAMINATION OF PERSONNEL CONTAMINATED WITH RADIOACTIVITY

1. Notify supervisor immediately after contaminating accident.
2. Wash body area involved thoroughly for 2 or 3 minutes, repeatedly "soaping" and rinsing. Consideration should be given to the chemistry of the contaminant and an attempt made to find a suitable agent for dissolving it. Any cleansing agent may be used, but synthetic detergents are preferred to soaps. Avoid prolonged use of any one decontamination procedure. Irritation of the skin may impede the success of more suitable procedures. Avoid the use of organic solvents. They may make the skin more permeable to radioactive contaminants.
3. If this procedure is not immediately and completely effective, notify the Environmental Health and Safety Office.

XII. INSTRUCTION CONCERNING PRENATAL RADIATION EXPOSURE

The University, as a licensee of the Nuclear Regulatory Commission, is required to instruct all employees who work in a restricted area of the health protection problems associated with radiation exposure. In the case of a female employee, this instruction includes information on the possible risks to unborn babies.

Every attempt is being made, at the University, to keep exposures to radiation as low as is reasonably achievable. However, qualified scientists have recommended that the radiation dose to an embryo or fetus as a result of occupational exposure of the expectant mother should not exceed 0.5 rem because of possible increased risk of childhood leukemia and cancer. Since this 0.5 rem is lower than the dose generally permitted to adult workers, women may want to take special actions to avoid receiving higher exposures, just as they might stop smoking during pregnancy or might climb stairs more carefully to reduce possible risks to their unborn children.

You, as a female worker occupationally exposed to radiation, are encouraged to further discuss this matter with the Radiation Protection Officer if it is of concern to you.

XIII. HUMAN USES

The University's Nuclear Regulatory Commission licenses do not permit any human uses of licensed radioactive material.

APPENDIX

GLOSSARY

ABSORBED DOSE: The amount of energy imparted to matter by ionizing radiation per unit mass irradiated material. (See Rad)

ABSORPTION: The phenomenon by which radiation imparts some or all of its energy to any material through which it passes.

ACTIVITY: The number of nuclear disintegrations occuring in a given quantity of material per unit time (See Curie)

ALPHA PARTICLE: A strongly ionizing particle emitted from the nucleus during radioactive decay having a mass and charge equal in magnitude to a helium nucleus, consisting of 2 protons and 2 neutrons with a double positive charge.

ALPHA RAY: A stream of fast-moving helium nuclei (alpha particles), a strongly ionizing and weakly penetrating radiation.

ANNIHILATION: (Electron) An interaction between a positive and negative electron; their energy, including rest energy, being converted into electromagnetic radiation (annihilation radiation).

ATOM: Smallest particle of an element which is capable of entering into a chemical reaction.

AUTORADIOGRAPH: Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

BACKGROUND RADIATION: Ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

BETA PARTICLE: Charged particle emitted from the nucleus of an atom, having a mass and charge equal in magnitude to that of the electron.

BETA RAY: A stream of high speed electrons or positrons of nuclear origin more penetrating but less ionizing than alpha rays.

BREMSSTRAHLUNG: Electromagnetic (x-ray) radiation associated with the deceleration of charged particles passing through matter. Usually associated with energetic beta emitters, e.g. phosphorus-32.

CALIBRATION: Determination of variation from standard, or accuracy, of a measuring instrument to ascertain necessary correction factors.

CONTAMINATION, RADIOACTIVE: Deposition of radioactive material in any place where its presence may be harmful. The harm may be in vitiating the validity of an experiment or a procedure, or in actually being a source of excessive exposure to personnel.

CARRIER FREE: An adjective applied to one or more radioactive isotopes of an element in minute quantity, essentially undiluted with stable isotope carrier.

COUNT (Radiation Measurements): The external indication of a device designed to numerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term is often erroneously used to designate a disintegreation, ionizing event, or voltage pulse.

CRITICAL ORGAN: That organ or tissue, the irradiation of which will result in the greatest hazard to the health of the individual or his descendants.

CURIE: The quantity of any radioactive material in which the number of disintegrations is 3.700×10^{10} per second. Abbreviated Ci.

Millicurie: One-thousandth of a curie (3.7×10^{7} disintegrations per second). Abbreviated mCi.

Microcurie: One millionth of a curie (3.7×10^{4} disintegrations per second. Abbreviated uCi.

Picocurie: One millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute). Abbreviated pCi.

DECAY, RADIOACTIVE: Disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

DOSE: A general term denoting the quantity of radiation or energy absorbed in a specified mass. For special purposes it must be appropriately qualified, e.g. absorbed dose.

DOSE ABSORBED: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad, which is 100 ergs/gram.

DOSE EQUIVALENT: A quantity used in radiation protection expressing all radiation on a common scale for calculating the effective absorbed dose. The unit of dose equivalent is the rem, which is numerically equal to the absorbed dose in rads multiplied by certain modifying factors such as quality factor, distribution factor, etc.

EFFICIENCY (Counters): A measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably so it is well to make sure which factors (window, transmission, sensitive volume, energy dependence, etc). are included in a given case.

ELECTRON: Negatively charged elementary particle which is a constituent of every neutral atom. Its unit of negative electricity equals 4.8×10^{-10} electrostatic units or 1.6×10^{-19} coulombs. Its mass is 0.00549 atomic mass units.

ELECTRON CAPUTRE: A mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from the particular electron shell is designated as "K-electron capture," "L-electron capture," etc.

ELECTRON VOLT: A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbreviated eV. Larger multiple units of the electron volt frequently used are: KeV for thousand or kiloelectron volts, MeV for million electron volts and BeV for billion electron volts.

EXPOSURE: A measure of the ionization produced in air by x or gamma radiation. It is the sum of electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the roentgen.

FILM BADGE: A packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.

GAMMA RAY: Very penetrating electromagnetic radiation of nuclear origin. Except for origin, identical to x-ray.

GEIGER-MUELLER (G-M) COUNTER: Highly sensitive gas-filled detector and associated circuitry used for radiation detection and measurement.

GENETIC EFFECT OF RADIATION: Inheritable changes, chiefly mutations, produced by the absorption of ionizing radiations. On the basis of present knowledge these effects are purely additive, and there is no recovery.

HALF-LIFE, BIOLOGICAL: The time required for the body to eliminate one-half of an administered dose of any substance by the regular process of elimination. This time is approximately the same for both stable and radioactive isotopes of a particular element.

HALF-LIFE, EFFECTIVE: Time required for a radioactive nuclide in a system to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life} \times \text{Radioactive half-life}}{\text{Biological half-life} + \text{Radioactive half-life}}$$

HALF-LIFE, RADIOACTIVE: Time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

HALF VALUE LAYER (Half thickness): The thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

HEALTH PHYSICS: A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

INVERSE SQUARE LAW: The intensity of radiation at any distance from a point source varies inversely as the sqaure of that distance. For example: If the radiation exposure is 100R/hr at 1 inch from a source, the exposure will be 0.01 R/hr at 100 inches.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

IONIZATION: The process by which a neutral atom or molecule acquires either a positive or a negative charge.

IONIZATION CHAMBER: An instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

IONIZATION, SPECIFIC: The number of ion pairs per unit length of path of ionizing radiation in a medium; e.g. per centimeter of air or per micron of tissue.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

IOSOTOPES: Nuclides having the same number of protons in their nuclei, and hence having the same atomic number. Almost identical chemical properties exist between isotopes of a particular element.

LABELED COMPOUND: A compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition this compound or its fragments may be followed through physical, chemical or biological processes.

MAXIMUM PERMISSIBLE DOSE (MPD): Maximum dose of radiation which may be received by person working with ionizing radiation, which will produce no detectable damage over the normal life span.

MILLIROENTGEN (mR): A submultiple of the roentgen equal to one one-thousandth (1/1000th) of a roentgen. (See Roentgen)

MONITORING, RADIOLOGICAL: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region as a safety measure for purposes of health protection.

Area Monitoring: Routine monitoring of the level of radiation or of radioactive contamination of any particular area, building, room or equipment.

Personnel Monitoring: Monitoring any part of an individual, his breath, excretions, or any part of his clothing. (See Radiological Survey).

NEUTRON: Elementary particle with a mass approximately the same as that of a hydrogen atom and electrically neutral. It has a half-life in minutes and decays in a free state into a proton and an electron.

NUCLIDE: A species of atom characterized by its mass number, atomic number, and energy state of its nucleus, provided that the atom is capable of existing for a measurable time.

PROTECTIVE BARRIERS: Barriers of radiation absorbing material, such as lead, concrete, plaster, and plastic, that are used to reduce radiation exposure.

Protective Barriers, Primary: Barriers sufficient to attenuate the useful beam to the required degree.

Protective Barriers, Secondary: Barriers sufficient to attenuate stray or scattered radiation to the required degree.

RADIATION:

1. The emission and propagation of energy through space or through material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves.
2. The energy propagated through a material medium as waves; for example, energy in the form of electromagnetic waves or of elastic waves. The term "radiation" or "radiant energy," when unqualified, usually refers to electromagnetic radiation. Such radiation commonly is classified according to frequency as Hertzian, infrared, visible (light), ultraviolet, x-ray and gamma ray.

3. By extension, corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type, or as cosmic radiation.

RADIOLOGICAL SURVEY: Evaluation of the radiation hazards incident to the production, use or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of levels of radiation that may be involved, and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

RADIOTOXICITY: Term referring to the potential of an isotope to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE): For a particular living organism, the ratio of the absorbed dose of a reference radiation that produces a specified biological effect to the absorbed dose of the radiation of interest that produces the same biological effect.

REM: The special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors.

ROENTGEN (R): The quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 grams of dry air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. The roentgen is the special unit of exposure.

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SCINTILLATION COUNTER: A counter in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

SHIELDING MATERIAL: Any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water, and plastic are examples of commonly used shielding material.

SMEAR (Smear or Swipe Test): A procedure in which a swab, e.g. a circle of filter paper, is rubbed on a surface and its radioactivity measured to determine if the surface is contaminated with loose radioactive material.

SPECIFIC ACTIVITY: Total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.

TRACER, ISOTOPIC: The isotope or nonnatural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.

THERMOLUMINESCENT DOSIMETER: A dosimeter made of a certain crystalline material which is capable both of storing a fraction of absorbed ionizing radiation and releasing this energy in the form of visible photons when heated. The amount of light released can be used as a measure of radiation exposure to these crystals.

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RULES OF THUMB

BETA PARTICLES

A. Beta particles of at least 70 keV energy are required to penetrate nominal protective layer of the skin (7 mg/cm^2 or 0.07 mm).

B. The average energy of a beta-ray spectrum is approximately one-third the maximum energy.

C. The range of beta particles in air is $\sim$ 12 ft/MeV. (Maximum range of ^{32}P beta is 1.71 MeV X 12 ft/MeV $\cong$ 20 ft).

D. The dose rate in rads per hour in a solution by a beta emitter is 1.12 EC/ρ, where E is the average beta energy per disintegration in MeV, C is the concentration in microcuries per cubic centimeter, and ρ is the density of the medium in grams per cubic centimeter. The dose rate at the surface of the solution is one-half the value given by this relation. (For ^{32}P average energy of approximately 0.7 MeV, the dose rate from 1 uCi/cm^3 (in water) is 1.48 rads/hr).

E. The surface dose rate through the nominal protective layer of skin (7 mg/cm^2) from a uniform thin deposition of 1 uCi/cm^2 is about 9 rads/hour for energies above about 0.6 MeV. Note that in a thin layer, the beta dose rate exceeds the gamma dose rate, for equal energies released, by about a factor of 100.

F. For a point source of beta radiation (neglecting self and air absorption) of strength mCi millicuries, the dose rate at 1 cm is approximately equal to 200 X mCi rads/hour and varies only slowly with beta energy. Dose rate for 1 mCi ^{32}P at 1 cm is approximately 200 rads/hour.

GAMMA RAYS

A. For a point source gamma emitter with energies between 0.07 and 4 MeV, the exposure rate (mR/hr) within $\pm$ 20% at 1 foot is 6 X mCi X E X n,

where mCi is the number of millicuries; E, the energy in MeV; and n the number of gammas per disintegration.

B. The dose rate to tissue in rads per hour in an infinite medium uniformly contaminated by a gamma emitter is 2.12 EC/ρ where C is the number of microcuries per cubic centimeter, E is the average gamma energy per disintegration in MeV, and ρ is the density of the medium. At the surface of a large body, the dose rate is about half of this.

MISCELLANEOUS

A. The activity of any radionuclide is reduced to less than 1% after 7 half-lives (i.e., $2^{-7} = 0.8\%$).

B. For material with a half-life greater than six days, the change in activity in 24 hours will be less than 10%.

RADIOACTIVE MATERIALS DECONTAMINATION PROCEDURES
FOR LABORATORIES (1)

A. For non-porous surfaces:

1. Absorb all liquids containing radioactive material on surfaces to be decontaminated, using absorbent toweling.
2. Rub surface 1 minute with absorbent toweling moistened with detergent solution, then wipe dry with toweling.
3. Monitor surface with appropriate instrument.
4. Spray surface with complexing agent (2), keeping surface wet with agent for 10-30 minutes. Wipe surface with wet toweling and then dry toweling.
5. Monitor.
6. Repeat above until surface contaminated is reduced to background level.

B. For non-porous surfaces but with porous deposits (e.g., rusted metals, surfaces with calcareous growth):

1. Same as (1) in A above.
2. Leave acid solution (3) on weathered surfaces for 1 hour. If item is movable, use dip-bath procedure.
3. Flush surface with water and scrub with detergent solution.
4. Monitor with appropriate instruments.
5. Repeat until surface contamination is reduced to background level.

C. If unsuccessful contact Environmental Health and Safety Office at 5-2682 for assistance.

Key:

(1) Appropriate gloves and protective clothing should be worn during all decontamination procedures.

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"OFFICIAL RECORD COPY"

Key: (For Radioactive Materials Decontamination Procedures for Laboratories)

(2) Complexing agent - a solution should contain 3%, by weight, of the complexing agent, such as sodium hexametophosphate, sodium ethylene-diamine-tetroacetic acid (NaEDTA), oxalates, carbonates or citrates (may be used on overhead or vertical surfaces by adding foam - sodium carbonate or aluminum sulfate).

(3) A typical mixture consists of .1 gallon hydrochloric acid, .2 pounds sodium acatate and 1 gallon of water. Corrosive action may be moderated by the addition of corrosion inhibitors to the solution. Good ventilation is a must because of toxicity and explosive gases. Goggles should be worn.

APPLICATION FOR AUTHORIZATION TO USE RADIOISOTOPES

PART A

INSTRUCTIONS: Complete all pertinent items. If authorized user omit Part B. Forward to Chairman, Radioisotope Use Committee.

1. _____
Name of Applicant Dept. Lab Location Telephone

2. _____
Areas where radioactive materials will be used

3. _____
Previous authorization. (If this application is for an increase or for additional isotopes).

4. Radioisotopes for which authorization is requested. (Attach a supplementary sheet, if more space is needed.)

Element -symbol	Mass number	Total amount -mCi	Half Life	Chemical and/or Physical Form. If a sealed source, state name of manufacturer, model number and amount.

5. Certification: All information contained in this application is correct to the best of my knowledge. I have read and understood "Radioisotope Use Policy and Program" and NRC regulations 10CFR19 and 20.

Date _____ _____
(Typed name and signature of applicant)

6. APPROVAL of Radioisotope Use Committee - subject to any conditions cited on reverse, under Remarks.

Date _____ _____
(Typed name and signature, Chairman Radioisotope Use Committee)

7. Describe the purpose for which each radioactive material will be used, in sufficient detail to permit evaluation of potential hazard.

8. Describe laboratory facilities, remote handling equipment, storage containers, shielding, fume hoods, etc. (If already described in a previous authorization, omit details, but make a note to that effect.)

9. Describe radiation protection procedures, including control measures, waste disposal procedures, and emergency procedures. Use an extra sheet if more space is needed.

10. Remarks.

APPLICATION FOR AUTHORIZATION TO USE RADIOISOTOPES

PART B

Record your experience and training in detail, listing each training period separately. State where training was obtained, its duration, and whether it was formal, on-the-job; give inclusive dates. If Part B has been completed on a previous application, it may be omitted, unless pertinent new information is available.

1. TYPE OF TRAINING

   a. Principles and practices of protection:

   b. Radioactivity measurements and monitoring techniques; instrumentation:

   c. Mathematics and calculations, basic to the measurement of radioactivity:

   d. Biological effects of radiation:

   e. Pertinent other training, include college and university courses, degrees obtained, with dates and subjects:

2. TYPES OF EXPERIENCE

   List each type of experience separately. Append a second sheet if more room is needed. List radioactive materials separately or in logical groups, showing maximum amounts used, installation where experience was gained, duration of experience, and type of use:

Date_____

_____
Typed name and signature of applicant.

GENERAL PROCEDURE FOR OPENING PACKAGES (1)

1. Place package on open bench or in hood (depending on nature of material) on disposable plastic-backed absorbant paper.
2. Open (2) and inspect package upon receipt, i.e. verify receipt of material ordered, look for signs of leakage (exterior of package was already tested by Environmental Health and Safety before delivery).
3. If any interior leakage is observed, notify the Radiation Protection Officer immediately.
4. Open and inspect plastic storage liner and lead shield (if any), and inspect final isotope container.
5. If any leakage is observed, notify the Radiation Protection Officer immediately.
6. Swipe test final isotope container for removable contamination (3).
7. If the swipe test is negative, store isotope inside plastic liner in refrigerator or other appropriate storage area until ready for use.
8. Monitor all packing material for contamination. If packing material is free from contamination, obliterate all Radioactive Materials labels before discarding in regular trash. If contaminated, treat as radioactive waste.

Key:

(1) Environmental Health and Safety personnel will remain through this entire procedure to aid researcher if necessary.

(2) Gloves and lab coats must be worn through entire opening procedure.

(3) To be done when container is open or broken or when otherwise deemed necessary by RPO.

GUIDELINES FOR MAXIMUM POSSIBLE PERMISSIBLE DOSES FOR UNIVERSITY PERSONNEL

Organ	Dose in mrem			
	Year	Quarter	Month	Week
Whole Body (Including Gonads Lens of Eye, Red Bone Marrow)	5,000	1,250	400	100
Forearms, Hands, Feet and Ankles	75,000	18,750	6,250	1,500
Skin of Whole Body	30,000	7,500	2,500	650
Pregnant Women or Employees Under 18 Years of Age	500	125	40	10

For information on specific organs or tissues not listed, consult with the Environmental Health and Safety Office.

SELECTED PROPERTIES OF MOST FREQUENTLY ORDERED RADIONUCLIDES

Nuclide	Maximum Beta Energy (MeV)	Gamma Energy (MeV)	1 mR/hr/mCi at 1 m	MPBB (uCi)	Critical Organ	Half-life Radioactive	Half-life Biological (days)
^{3}H	0.0186			1000	Body Tissue	12.26y	12
^{14}C	0.156			300	Fat	5730y	12
^{24}Na	1.389	1.369 (100%) 2.754 (100%)	1.84	7	Total Body	14.96h	11
^{32}P	1.710			6	Bone	14.28d	1155
^{35}S	0.167			90	Testis	87.9d	
^{51}Cr		0.32(9%)	0.016	800	Total Body	27.8d	616
^{125}I		28 keV average (143%)	0.07	1.6	Thyroid	60.2d	138

Column (4), 1 Milliroentgens per hour at 1 meter from 1 millicurie.

Column (5), Maximum Permissible Body Burden (MPBB). The amount of the isotope maintained in the body which will deliver the maximum permissible dose equivalent rate to the limiting organ. The value given is for material that has been absorbed by the blood stream and deposited in the body. The lung or gastrointestinal tract may be more limiting for continued exposure to chemical forms that are not readily absorbed.

Column (6), Critical Organ. The organ that receives the highest dose equivalent relative to its maximum permissible dose equivalent from a sustained intake (See discussion of Column 5). The maximum permissible body burden may be identical for several organs. Then, the organ with the smallest maximum permissible dose equivalent or the organ affected by most other radioactive materials was chosen.

Column (7), Radioactive Half-life. Present best value, obtained from "Table of Isotopes-6th Edition" by C.M. Lederer, J.M. Hollander, and I. Perlman, John Wiley & Sons, New York, 1967. The abbreviations used here are: s, second; m, minute; h, hour; d, day; and y, year.

Column (8), Biological Half-life. The time required for one-half of the stable element to be removed from the critical organ by biological processes, as listed by the ICRP. The actual half-time of elimination depends also on the half-life of the isotope. The "effective half-life" in the critical organ (T_{eff}) is given by $T_{eff} = \frac{T_R T_B}{T_R + T_B}$

Where T_R is the radioactive half-life and T_B is the biological half-life.

Calcium – 45

165 Days

Days	Days									
	0	2	4	6	8	10	12	14	16	18
0	1.0000	.9916	.9833	.9751	.9670	.9589	.9508	.9429	.9350	.9272
20	.9194	.9117	.9041	.8965	.8890	.8816	.8742	.8669	.8596	.8525
40	.8453	.8383	.8312	.8243	.8174	.8105	.8038	.7970	.7904	.7838
60	.7772	.7707	.7643	.7579	.7515	.7452	.7390	.7328	.7267	.7206
80	.7146	.7086	.7027	.6968	.6910	.6852	.6794	.6738	.6681	.6625
100	.6570	.6515	.6460	.6406	.6353	.6300	.6247	.6195	.6143	.6091
120	.6040	.5990	.5940	.5890	.5841	.5792	.5743	.5695	.5648	.5601
140	.5554	.5507	.5461	.5415	.5370	.5325	.5281	.5236	.5193	.5149
160	.5106	.5063	.5021	.4979	.4937	.4896	.4855	.4814	.4774	.4734
180	.4695	.4655	.4616	.4578	.4540	.4502	.4464	.4427	.4389	.4353
200	.4316	.4280	.4244	.4209	.4174	.4139	.4104	.4070	.4036	.4002
220	.3969	.3935	.3902	.3870	.3837	.3805	.3773	.3742	.3711	.3679
240	.3649	.3618	.3588	.3558	.3528	.3499	.3469	.3440	.3412	.3383
260	.3355	.3327	.3299	.3271	.3244	.3217	.3190	.3163	.3137	.3110
280	.3084	.3059	.3033	.3008	.2982	.2957	.2933	.2908	.2884	.2860
300	.2836	.2812	.2789	.2765	.2742	.2719	.2696	.2674	.2651	.2629
320	.2607	.2585	.2564	.2542	.2521	.2500	.2479	.2458	.2438	.2417
340	.2397	.2377	.2357	.2337	.2318	.2299	.2279	.2260	.2241	.2223
360	.2204	.2186	.2167	.2149	.2131	.2113	.2096	.2078	.2061	.2043

Chromium – 51

27.8 Days

Days	Hours											
	0	2	4	6	8	10	12	14	16	18	20	22
0	1.0000	.9979	.9959	.9938	.9917	.9897	.9876	.9856	.9835	.9815	.9794	.9774
1	.9754	.9734	.9713	.9693	.9673	.9653	.9633	.9613	.9593	.9573	.9553	.9533
2	.9514	.9494	.9474	.9454	.9435	.9415	.9396	.9376	.9357	.9337	.9318	.9299
3	.9279	.9260	.9241	.9222	.9202	.9183	.9164	.9145	.9126	.9107	.9088	.9070
4	.9051	.9032	.9013	.8995	.8976	.8957	.8939	.8920	.8902	.8883	.8865	.8846
5	.8828	.8810	.8791	.8773	.8755	.8737	.8719	.8700	.8682	.8664	.8646	.8628
6	.8611	.8593	.8575	.8557	.8539	.8522	.8504	.8486	.8469	.8451	.8433	.8416
7	.8398	.8381	.8364	.8346	.8329	.8312	.8294	.8277	.8260	.8243	.8226	.8209
8	.8192	.8175	.8158	.8141	.8124	.8107	.8090	.8073	.8057	.8040	.8023	.8007
9	.7990	.7973	.7957	.7940	.7924	.7907	.7891	.7875	.7858	.7842	.7826	.7809
10	.7793	.7777	.7761	.7745	.7729	.7713	.7697	.7681	.7665	.7649	.7633	.7617
11	.7601	.7586	.7570	.7554	.7538	.7523	.7507	.7492	.7476	.7460	.7445	.7430
12	.7414	.7399	.7383	.7368	.7353	.7337	.7322	.7307	.7292	.7277	.7262	.7247
13	.7232	.7217	.7202	.7187	.7172	.7157	.7142	.7127	.7112	.7098	.7083	.7068
14	.7053	.7039	.7024	.7010	.6995	.6981	.6966	.6952	.6937	.6923	.6908	.6894
15	.6880	.6865	.6851	.6837	.6823	.6809	.6795	.6780	.6766	.6752	.6738	.6724
16	.6710	.6696	.6683	.6669	.6655	.6641	.6627	.6613	.6600	.6586	.6572	.6559
17	.6545	.6532	.6518	.6504	.6491	.6477	.6464	.6451	.6437	.6424	.6411	.6397
18	.6384	.6371	.6357	.6344	.6331	.6318	.6305	.6292	.6279	.6266	.6253	.6240
19	.6227	.6214	.6201	.6188	.6175	.6162	.6150	.6137	.6124	.6111	.6099	.6086
20	.6073	.6061	.6048	.6036	.6023	.6011	.5998	.5986	.5973	.5961	.5949	.5936
21	.5924	.5912	.5899	.5887	.5875	.5863	.5850	.5838	.5826	.5814	.5802	.5790
22	.5778	.5766	.5754	.5742	.5730	.5718	.5706	.5695	.5683	.5671	.5659	.5647
23	.5636	.5624	.5612	.5601	.5589	.5577	.5566	.5554	.5543	.5531	.5520	.5508
24	.5497	.5485	.5474	.5463	.5451	.5440	.5429	.5418	.5406	.5395	.5384	.5373
25	.5362	.5350	.5339	.5328	.5317	.5306	.5295	.5284	.5273	.5262	.5251	.5240
26	.5230	.5219	.5208	.5197	.5186	.5175	.5165	.5154	.5143	.5133	.5122	.5111
27	.5101	.5090	.5080	.5069	.5059	.5048	.5038	.5027	.5017	.5006	.4996	.4985
28	.4975	.4965	.4954	.4944	.4934	.4924	.4913	.4903	.4893	.4883	.4873	.4863
29	.4853	.4843	.4832	.4822	.4812	.4802	.4792	.4783	.4773	.4763	.4753	.4743

Hydrogen – 3

12.26 Years

Years	Months											
	0	1	2	3	4	5	6	7	8	9	10	11
0	1.0000	.9953	.9906	.9860	.9813	.9767	.9721	.9676	.9630	.9585	.9540	.9495
1	.9450	.9406	.9362	.9318	.9274	.9230	.9187	.9144	.9101	.9058	.9015	.8973
2	.8931	.8889	.8847	.8805	.8764	.8723	.8682	.8641	.8600	.8560	.8520	.8480
3	.8440	.8400	.8361	.8321	.8282	.8243	.8205	.8166	.8128	.8090	.8052	.8014
4	.7976	.7939	.7901	.7864	.7827	.7790	.7754	.7717	.7681	.7645	.7609	.7573
5	.7538	.7502	.7467	.7432	.7397	.7362	.7327	.7293	.7259	.7225	.7191	.7157
6	.7123	.7090	.7056	.7023	.6990	.6957	.6925	.6892	.6860	.6827	.6795	.6763
7	.6732	.6700	.6669	.6637	.6606	.6575	.6544	.6513	.6483	.6452	.6422	.6392
8	.6362	.6332	.6302	.6272	.6243	.6214	.6184	.6155	.6126	.6098	.6069	.6040
9	.6012	.5984	.5956	.5928	.5900	.5872	.5844	.5817	.5790	.5762	.5735	.5708

Iodine – 125

60.2 Days

Days	Days									
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.0000	.9943	.9886	.9829	.9772	.9716	.9660	.9605	.9550	.9495
5	.9441	.9386	.9332	.9279	.9226	.9173	.9120	.9068	.9016	.8964
10	.8912	.8861	.8810	.8760	.8710	.8660	.8610	.8560	.8511	.8462
15	.8414	.8366	.8317	.8270	.8222	.8175	.8128	.8081	.8035	.7989
20	.7943	.7898	.7852	.7807	.7762	.7718	.7673	.7629	.7586	.7542
25	.7499	.7456	.7413	.7370	.7328	.7286	.7244	.7203	.7161	.7120
1 Month	.7079	.7039	.6998	.6958	.6918	.6878	.6839	.6800	.6761	.6722
5	.6683	.6645	.6607	.6569	.6531	.6494	.6456	.6419	.6382	.6346
10	.6309	.6273	.6237	.6201	.6166	.6130	.6095	.6060	.6025	.5991
15	.5956	.5922	.5888	.5854	.5821	.5787	.5754	.5721	.5688	.5656
20	.5623	.5591	.5559	.5527	.5495	.5464	.5432	.5401	.5370	.5339
25	.5309	.5278	.5248	.5218	.5188	.5158	.5128	.5099	.5070	.5040
2 Months	.5012	.4983	.4954	.4926	.4897	.4869	.4841	.4814	.4786	.4758
5	.4731	.4704	.4677	.4650	.4623	.4597	.4571	.4544	.4518	.4492
10	.4466	.4441	.4415	.4390	.4365	.4340	.4315	.4290	.4265	.4241
15	.4217	.4192	.4168	.4144	.4121	.4097	.4073	.4050	.4027	.4004
20	.3981	.3958	.3935	.3913	.3890	.3868	.3846	.3823	.3802	.3780
25	.3758	.3736	.3715	.3694	.3672	.3651	3630	.3610	.3589	.3568
3 Months	.3548	.3527	.3507	.3487	.3467	.3447	.3427	.3408	.3388	.3369
5	.3349	.3330	.3311	.3292	.3273	.3254	.3236	.3217	.3199	.3180
10	.3162	.3144	.3126	.3108	.3090	.3072	.3055	.3037	.3020	.3002
15	.2985	.2968	.2951	.2934	.2917	.2900	.2884	.2867	.2851	.2834
20	.2818	.2802	.2786	.2770	.2754	.2738	.2722	.2707	.2691	.2676
25	.2660	.2645	.2630	.2615	.2600	.2585	.2570	.2555	.2541	.2526
4 Months	.2512	.2497	.2483	.2469	.2454	.2440	.2426	.2412	.2398	.2385

Days	Hours											
	0	6	12	18	24	30	36	42	48	54	60	66
0	1.0000	.9962	.9924	.9887	.9849	.9812	.9775	.9737	.9701	.9664	.9627	.9591
3	.9554	.9518	.9482	.9446	.9410	.9374	.9339	.9303	.9268	.9233	.9198	.9163
6	.9128	.9094	.9059	.9025	.8891	.8957	.8923	.8889	.8855	.8821	.8788	.8755
9	.8721	.8688	.8655	.8623	.8590	.8557	.8525	.8492	.8460	.8428	.8396	.8364
12	.8333	.8301	.8270	.8238	.8207	.8176	.8145	.8114	.8083	.8052	.8022	.7991
15	.7961	.7931	.7901	.7871	.7841	.7811	.7782	.7752	.7723	.7693	.7664	.7635
18	.7606	.7577	.7549	.7520	.7492	.7463	.7435	.7407	.7379	.7351	.7323	.7295
21	.7267	.7240	.7212	.7185	.7158	.7130	.7103	.7076	.7050	.7023	.6996	.6970
24	.6943	.6917	.6891	.6865	.6839	.6813	.6787	.6761	.6735	.6710	.6684	.6659
27	.6634	.6609	.6584	.6559	.6534	.6509	.6484	.6460	.6435	.6411	.6386	.6362
1 Month	.6338	.6314	.6290	.6266	.6242	.6219	.6195	.6172	.6148	.6125	.6102	.6079
3	.6055	.6033	.6010	.5987	.5964	.5942	.5919	.5897	.5874	.5852	.5830	.5808
6	.5786	.5764	.5742	.5720	.5698	.5677	.5655	.5634	.5612	.5591	.5570	.5549
9	.5528	.5507	.5486	.5465	.5444	.5424	.5403	.5383	.5362	.5342	.5322	.5301
12	.5281	.5261	.5241	.5221	.5202	.5182	.5162	.5143	.5123	.5104	.5084	.5065
15	.5046	.5027	.5008	.4989	.4970	.4951	.4932	.4913	.4895	.4876	.4858	.4839
18	.4821	.4803	.4784	.4766	.4748	.4730	.4712	.4694	.4677	.4659	.4641	.4624
21	.4606	.4589	.4571	.4554	.4536	.4519	.4502	.4485	.4468	.4451	.4434	.4417
24	.4401	.4384	.4367	.4351	.4334	.4318	.4301	.4285	.4269	.4253	.4237	.4220
27	.4204	.4189	.4173	.4157	.4141	.4125	.4110	.4094	.4079	.4063	.4048	.4032
2 Months	.4017	.4002	.3987	.3972	.3956	.3941	.3926	.3912	.3897	.3882	.3867	.3853
3	.3838	.3823	.3809	.3794	.3780	.3766	.3751	.3737	.3723	.3709	.3695	.3681
6	.3667	.3653	.3639	.3625	.3612	.3598	.3584	.3571	.3557	.3544	.3530	.3517
9	.3503	.3490	.3477	.3464	.3451	.3437	.3424	.3411	.3399	.3386	.3373	.3360
12	.3347	.3335	.3322	.3309	.3297	.3284	.3272	.3259	.3247	.3235	.3222	.3210
15	.3198	.3186	.3174	.3162	.3150	.3138	.3126	.3114	.3102	.3091	.3079	.3067
18	.3055	.3044	.3032	.3021	.3009	.2998	.2987	.2975	.2964	.2953	.2942	.2930
21	.2919	.2908	.2897	.2886	.2875	.2864	.2853	.2843	.2832	.2821	.2810	.2800
24	.2789	.2779	.2768	.2758	.2747	.2737	.2726	.2716	.2706	.2695	.2685	.2675
27	.2665	.2655	.2645	.2635	.2625	.2615	.2605	.2595	.2585	.2575	.2565	.2556

Phosphorus – 32

14.28 Days

Days	Hours											
	0	2	4	6	8	10	12	14	16	18	20	22
0	1.0000	.9960	.9919	.9879	.9840	.9800	.9760	.9721	.9682	.9642	.9604	.9565
1	.9526	.9488	.9449	.9411	.9373	.9335	.9298	.9260	.9223	.9186	.9149	.9112
2	.9075	.9038	.9002	.8965	.8929	.8893	.8857	.8821	.8786	.8750	.8715	.8680
3	.8645	.8610	.8575	.8541	.8506	.8472	.8438	.8404	.8370	.8336	.8302	.8269
4	.8235	.8202	.8169	.8136	.8103	.8070	.8038	.8005	.7973	.7941	.7909	.7877
5	.7845	.7813	.7782	.7750	.7719	.7688	.7657	.7626	.7595	.7565	.7534	.7504
6	.7473	.7443	.7413	.7383	.7353	.7324	.7294	.7265	.7235	.7206	.7177	.7148
7	.7119	.7091	.7062	.7033	.7005	.6977	.6949	.6921	.6893	.6865	.6837	.6809
8	.6782	.6755	.6727	.6700	.6673	.6646	.6619	.6593	.6566	.6540	.6513	.6437
9	.6461	.6435	.6409	.6383	.6357	.6331	.6306	.6280	.6255	.6230	.6205	.6179
10	.6155	.6130	.6105	.6080	.6056	.6031	.6007	.5983	.5959	.5935	.5911	.5887
11	.5863	.5839	.5816	.5792	.5769	.5746	.5722	.5699	.5676	.5653	.5631	.5608
12	.5585	.5563	.5540	.5518	.5495	.5473	.5451	.5429	.5407	.5385	.5364	.5342
13	.5321	.5299	.5278	.5256	.5235	.5214	.5193	.5172	.5151	.5130	.5110	.5089
14	.5068	.5048	.5028	.5007	.4987	.4967	.4947	.4927	.4907	.4887	.4867	.4848
15	.4828	.4809	.4789	.4770	.4751	.4732	.4713	.4693	.4675	.4656	.4637	.4618
16	.4600	.4581	.4562	.4544	.4526	.4507	.4489	.4471	.4453	.4435	.4417	.4399
17	.4382	.4364	.4346	.4329	.4311	.4294	.4277	.4259	.4242	.4225	.4208	.4191
18	.4174	.4157	.4140	.4124	.4107	.4090	.4074	.4057	.4041	.4025	.4009	.3992
19	.3976	.3960	.3944	.3928	.3912	.3897	.3881	.3865	.3850	.3834	.3819	.3803
20	.3788	.3773	.3757	.3742	.3727	.3712	.3697	.3682	.3667	.3652	.3638	.3623
21	.3608	.3594	.3579	.3565	.3550	.3536	.3522	.3508	.3493	.3479	.3465	.3451
22	.3437	.3424	.3410	.3396	.3382	.3369	.3355	.3341	.3328	.3314	.3301	.3288
23	.3275	.3261	.3248	.3235	.3222	.3209	.3196	.3183	.3170	.3157	.3145	.3132
24	.3119	.3107	.3094	.3082	.3069	.3057	.3045	.3032	.3020	.3008	.2996	.2984
25	.2972	.2960	.2948	.2936	.2924	.2912	.2900	.2889	.2877	.2865	.2854	.2842
26	.2831	.2819	.2808	.2797	.2785	.2774	.2763	.2752	.2741	.2730	.2719	.2708
27	.2697	.2686	.2675	.2664	.2653	.2643	.2632	.2621	.2611	.2600	.2590	.2579
28	.2569	.2559	.2548	.2538	.2528	.2517	.2507	.2497	.2487	.2477	.2467	.2457
29	.2447	.2437	.2427	.2418	.2408	.2398	.2388	.2379	.2369	.2360	.2350	.2341

Sodium – 24

14.96 Hours

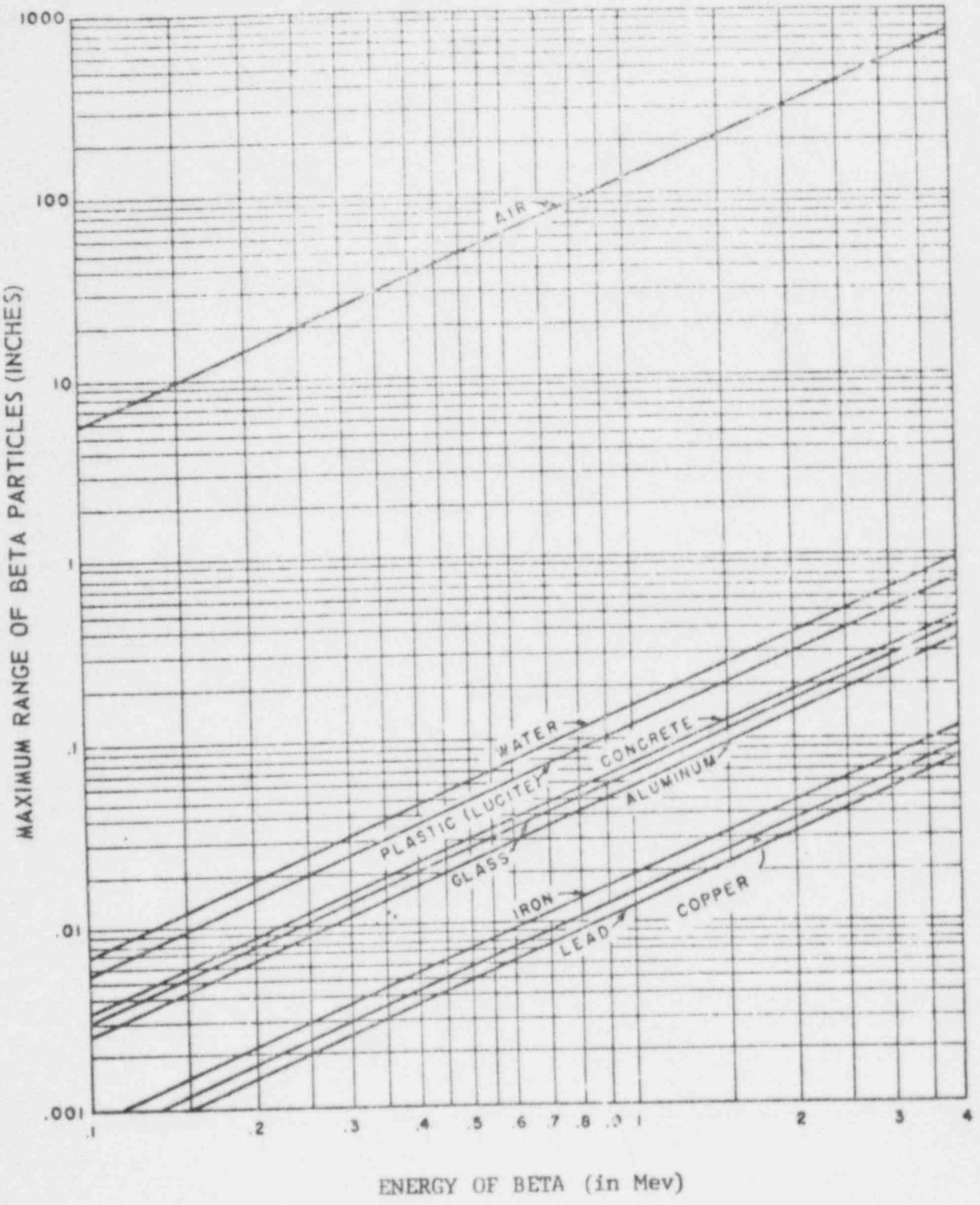
Hours	Minutes											
	0	10	20	30	40	50	60	70	80	90	100	110
0	1.0000	.9923	.9847	.9771	.9696	.9621	.9547	.9474	.9401	.9329	.9257	.9186
2	.9115	.9045	.8975	.8906	.8838	.8770	.8702	.8635	.8569	.8503	.8438	.8373
4	.8308	.8244	.8181	.8118	.8056	.7994	.7932	.7871	.7811	.7750	.7691	.7632
6	.7573	.7515	.7457	.7400	.7343	.7286	.7230	.7174	.7119	.7065	.7010	.6956
8	.6903	.6850	.6797	.6745	.6693	.6641	.6590	.6540	.6489	.6439	.6390	.6341
10	.6292	.6243	.6195	.6148	.6100	.6054	.6007	.5961	.5915	.5869	.5824	.5779
12	.5735	.5691	.5647	.5604	.5561	.5518	.5475	.5433	.5391	.5350	.5309	.5268
14	.5227	.5187	.5147	.5108	.5068	.5029	.4991	.4952	.4914	.4876	.4839	.4802
16	.4765	.4728	.4692	.4656	.4620	.4584	.4549	.4514	.4479	.4445	.4411	.4377
18	.4343	.4310	.4277	.4244	.4211	.4179	.4146	.4115	.4083	.4051	.4020	.3989
20	.3959	.3928	.3898	.3868	.3838	.3809	.3779	.3750	.3722	.3693	.3665	.3636
22	.3608	.3581	.3553	.3526	.3499	.3472	.3445	.3418	.3392	.3366	.3340	.3314
1 Day	.3289	.3264	.3239	.3214	.3189	.3164	.3140	.3116	.3092	.3068	.3045	.3021
2	.2998	.2975	.2952	.2929	.2907	.2884	.2862	.2840	.2818	.2797	.2775	.2754
4	.2733	.2712	.2691	.2670	.2649	.2629	.2609	.2589	.2569	.2549	.2530	.2510
6	.2491	.2472	.2453	.2434	.2415	.2396	.2378	.2360	.2342	.2324	.2306	.2288
8	.2270	.2253	.2236	.2218	.2201	.2184	.2168	.2151	.2134	.2118	.2102	.2085
10	.2069	.2053	.2038	.2022	.2006	.1991	.1976	.1960	.1945	.1930	.1916	.1901
12	.1886	.1872	.1857	.1843	.1829	.1815	.1801	.1787	.1773	.1760	.1746	.1733
14	.1719	.1706	.1693	.1680	.1667	.1654	.1641	.1629	.1616	.1604	.1592	.1579
16	.1567	.1555	.1543	.1531	.1519	.1508	.1496	.1485	.1473	.1462	.1451	.1440
18	.1428	.1417	.1407	.1396	.1385	.1374	.1364	.1353	.1343	.1333	.1322	.1312
20	.1302	.1292	.1282	.1272	.1262	.1253	.1243	.1234	.1224	.1215	.1205	.1196
22	.1187	.1178	.1169	.1160	.1151	.1142	.1133	.1124	.1116	.1107	.1099	.1090
2 Days	.1082	.1073	.1065	.1057	.1049	.1041	.1033	.1025	.1017	.1009	.1001	.0994

Sulfur – 35

87.9 Days

Days	Days									
	0.	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.0000	.9961	.9921	.9882	.9844	.9805	.9766	.9728	.9689	.9651
5	.9613	.9576	.9538	.9500	.9463	.9426	.9389	.9352	.9315	.9278
10	.9242	.9205	.9169	.9133	.9097	.9061	.9026	.8990	.8955	.8920
15	.8884	.8849	.8815	.8780	.8745	.8711	.8677	.8643	.8609	.8575
20	.8541	.8507	.8474	.8441	.8407	.8374	.8341	.8308	.8276	.8243
25	.8211	.8178	.8146	.8114	.8082	.8050	.8019	.7987	.7956	.7924
1 Month	.7893	.7862	.7831	.7800	.7770	.7739	.7709	.7678	.7648	.7618
5	.7588	.7558	.7529	.7499	.7469	.7440	.7411	.7382	.7353	.7324
10	.7295	.7266	.7237	.7209	.7181	.7152	.7124	.7096	.7068	.7040
15	.7013	.6985	.6958	.6930	.6903	.6876	.6849	.6822	.6795	.6768
20	.6742	.6715	.6689	.6662	.6636	.6610	.6584	.6558	.6532	.6507
25	.6481	.6455	.6430	.6405	.6380	.6354	.6329	.6305	.6280	.6255
2 Months	.6230	.6206	.6182	.6157	.6133	.6109	.6085	.6061	.6037	.6013
5	.5990	.5956	.5943	.5919	.5896	.5873	.5850	.5827	.5804	.5781
10	.5758	.5735	.5713	.5690	.5668	.5646	.5623	.5601	.5579	.5557
15	.5535	.5514	.5492	.5470	.5449	.5427	.5406	.5385	.5364	.5342
20	.5321	.5300	.5280	.5259	.5238	.5218	.5197	.5177	.5156	.5136
25	.5116	.5096	.5075	.5056	.5036	.5016	.4996	.4976	.4957	.4937
3 Months	.4918	.4899	.4879	.4860	.4841	.4822	.4803	.4784	.4765	.4746
5	.4728	.4709	.4691	.4672	.4654	.4635	.4617	.4599	.4581	.4563
10	.4545	.4527	.4509	.4492	.4474	.4456	.4439	.4421	.4404	.4387
15	.4369	.4352	.4335	.4318	.4301	.4284	.4267	.4250	.4234	.4217
20	.4200	.4184	.4167	.4151	.4135	.4118	.4102	.4086	.4070	.4054
25	.4038	.4022	.4006	.3990	.3975	.3959	.3944	.3928	.3913	.3897
4 Months	.3882	.3867	.3851	.3836	.3821	.3806	.3791	.3776	.3761	.3747

PENETRATION ABILITY OF BETA RADIATION



CLASSIFICATION OF ISOTOPES ACCORDING TO RELATIVE RADIOTOXICITY[1] PER UNIT ACTIVITY

Group 1 (very high toxicity)

Pb-210	Po-210	Ra-223	Ra-226*	Ra-228	Ac-227	Th-227	Th-228	Th-230
Pa-231	U-230	U-232	U-233	U-234	Np-237	Pu-238*	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Am-243	Cm-242	Cm-234	Cm-244	Cm-245	Cm-246
Cf-249	Cf-250	Cf-252*						

Group 2 (high toxicity)

Na-22*	Cl-36*	Ca-45*	Sc-46	Mn-54	Co-56	Co-60*	Sr-89	Sr-90*
Y-91	Zr-95	Ru-105	Ag-110m	Cd-115m	In-114m	Sb-124	Sb-125	Te-127m
Tc-129m	I-124	I-125*	I-126	I-131*	I-133	Cs-134	Cs-137*	Ba-140
Ce-144	Eu-152(13 y)		Eu-154	Tb-160	Tm-170	Hf-181	Ta-182	Ir-192
Tl-204	Bi-207	Bi-210	At-211	Pb-212	Ra-224	Ac-228	Pa-230	Th-234
U-236	Bk-249							

Group 3 (moderate toxicity)

Be-7	C-14*	F-18	Na-24	Cl-38	Si-31	P-32*	S-35*	A-41
K-42	K-43	Ca-47	Sc-47	Sc-48	V-48	Cr-51*	Mn-52	Mn-56
Fc-52	Fc-55	Fc-59	Co-57	Co-58	Ni-63*	Ni-65	Cu-64	Zn-65
Zn-69m	Ga-72	As-73	As-74	As-76	As-77	Sc-75	Br-82	Kr-85m
Kr-87	Rb-86	Sr-85	Sr-91	Y-90*	Y-92	Y-93	Zr-97	Nb-93m
Nb-95	Mo-99	Tc-96	Tc-97m	Tc-97	Tc-99	Ru-97	Ru-103	Ru-105
Rh-105	Pd-103	Pd-109	Ag-105	Ag-111	Cd-109	Cd-115	In-115m	Sn-113
Sn-125	Sb-122	Te-125m	Te-127	Te-129	Te-131m	Te-132	I-130	I-132
I-134	I-135	Xe-135	Cs-131	Cs-136	Ba-131	La-140	Ce-141	Ce-143
Pr-142	Pr-143	Nd-147	Nd-149	Pm-147	Pm-149	Sm-151	Sm-153	Eu-152
Eu-155	Gd-153	Gd-159	Dy-165	Dy-166	Ho-166	Er-169	Er-171	(9.2 hr)
Tm-171	Yb-175	La-177	W-181	W-185	W-187	Re-183	Re-186	Re-188
Os-185	Os-191	Os-193	Ir-190	Ir-194	Pt-191	Pu-193	Pt-197	Au-196
Au-198	Au-199	Hg-197	Hg-197m	Hg-203	Tl-200	Tl-201	Tl-202	Pb-203
Bi-206	Bi-212	Rn-220	Rn-222	Th-231	Pa-233	Np-239		

Group 4 (slight toxicity)

H-3*	O-15	A-37	Co-58m	Ni-59	Zn-69	Gc-71	Kr-85	Sr-85m
Rb-87	Y-91m	Zr-93	Nb-97	Tc-96m	Tc-99m	Rh-103m	In-113	I-129*
Xe-131m	Xe-133	Cs-134m	Cs-135	Sm-147	Re-187	Os-191m	Pt-193m	Pt-197m
Th-232	Th-Nat	U-235	U-238*	U-Nat				

[1] Radiotoxicity - see definition in Glossary

* Indicates commonly used at the University

BIOASSAY

A. General: Bioassays will be required of all researchers using H^3 and/or I^{125} according to the following:

1. Occasional use of 10 mci or more of H^3 labelled compounds or 100 mci or more of other uncontained forms of H^3 labelled material will require a bioassay within 48 hours after completion of the work. Continuous use requires weekly bioassays.
2. Occasional use of carrier-free I^{125} for iodination requires thyroid counting at 48 hours after completion of the work. Continuous use requires weekly thyroid checks.
3. Bioassays for uptakes of other radioisotopes will be done for cause.

B. Tritium Bioassay Procedure: Urine samples will be requested and collected by EH&S personnel, and the following procedures will be used:

1. Calibrate Liquid Scintillation Counter.
2. 1 ml of tap water, in 10 ml Aquasol, will be used for the background count.
3. 1ml of urine into 10 ml Aquasol and count 10 minutes in LSC. Record counts.
4. Add 100λ of toluene (H^3), 2 X 10^4 dpm/100λ calibration solution to a second vial containing 1 ml urine and 10 ml Aquasol and count 10 minutes in LSC. This permits accurate computation of counting efficiency even in the presence of quenching.

Calculations: $\text{eff} = \frac{\text{cpm of spiked sample}}{2 \times 10^4 \text{ dpm of spiked sample}}$

$$\frac{\text{non-spiked sample count - background count}}{\text{efficiency}} = \text{dpm of urine sample}$$

$$\frac{\text{dpm of urine sample}}{2.22 \times 10^3 \text{ dpm/nCi}} = \text{activity (nCi)/ml}$$

activity X 43,000 ml/std man body fluid - Body Burden (nCi)

C. I^{125} Thyroid Counting Procedure: Researchers will be requested to to come to the EH&S Office at N407 Morrill Science Building at the appropriate time. Two minute thyroid counts will be performed using an external scintillation probe/single channel analyzer system.

A. General:

1. User must schedule use of facility with EH&S at least three days in advance. This must include written experimental procedure for EH&S review.
2. EH&S will issue a key to user for period of use. Room is to remain locked at all times.
3. EH&S will place duct air sampling filter in the attic air sampler (at the beginning) and remove for analysis at the end of each use period (minimum sampling period will be daily).
4. No iodinations will be allowed after normal working hours or during weekends or holidays.

B. Experimental Procedure:

1. Turn hood exhaust system on.
2. Turn glove box recirculating filter on.
3. Place all materials needed into the secondary chamber, including waste container.
4. Seal secondary chamber door.
5. Place all materials into primary chamber.
6. Seal primary chamber door.
7. Put disposable plastic gloves over glove box gloves.
8. Complete iodination procedure.
9. Place all contaminated materials into RAD waste container. The waste container should contain saturated sodium thiosulfate solution sufficient to allow all waste to be submerged in it.

(Large columns may protrude after being filled and their external surfaces being rinsed with sodium thiosulfate solution. Parofilm should be used to seal both ends.) All dry waste (e.g. disposable gloves, Kimwipes, etc.) should be drenched with thiosulfate solution after being placed into the waste container.

10. Extreme care should be exercised to avoid contaminating the outside of any containers to be removed from the glove box to other labs. All containers or materials whose outside surface is suspected of contamination must be swiped and counted on the portable scintillation counter before being removed from the primary chamber. Any decontamination found necessary (200 dpm/100 cm^2 above background) must be done in the primary chamber.

11. All containers must be tightly covered before being removed from the primary chamber (Parofilm may be used).

12. All waste containers will be removed from the glove box for disposal by EH&S.

13. All vessels containing iodinated materials must be placed into a secondary transport container* for safety during transition from 41 Goessmann to researcher's lab.