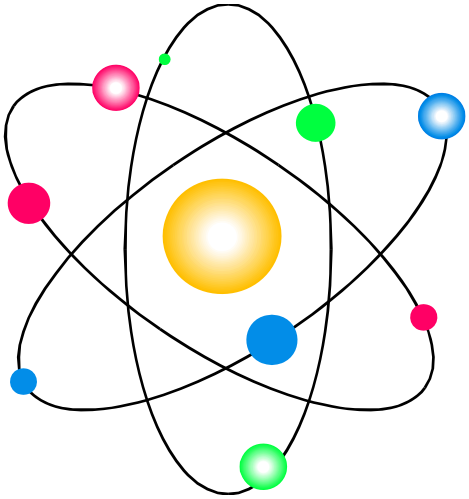
UNIVERSITY OF ROCHESTER

Radiation Safety Unit



Radiation Safety Training Manual and Resource Book

http://extranet.urmc.rochester.edu/radiationSafety/

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1. INTRODUCTION

The purpose of this course is not to turn students into radiation professionals; the training process for that takes several years. Instead, there are several reasons for this course. They are listed below:

1) To provide basic information of radiation and radioactivity.
2) To describe the biological effects of exposure to radiation at all dose ranges at both the cellular and whole body levels.
3) To define basic health physics terms and concepts.
4) To allow students to realistically determine, for themselves, the risks associated with radiation, radioactivity, and radiation exposure

Health physics is the science that deals with radiation and its interaction with matter. People who work in this field are commonly referred to as Health Physicists. Understanding health physics requires knowledge in a variety of fields. These include atomic structure, the properties of the sub-atomic particles, the various mechanisms and properties by which radioactive atoms decay, and the manner in which ionizing radiation interacts with matter. Knowledge in the effects of ionizing radiation on life, the penetrating ability of various kinds of radiation and the shielding that is required to reduce the absorbed dose from these radiations, as well as the many instruments that can be used to detect radiation and the principles under which they operate, dose monitoring, actions to be taken in the event of a radioactive accident, dose calculation and assessment, and several other technical areas is also necessary. Radiation protection professionals must also be aware of the federal and state regulations governing the use of radiation, the storage and transport of radioactive materials, the criteria to be used for decontamination of contaminated areas, and the levels at which the presence of radiation becomes not only a regulatory concern, but a genuine health concern, as well.

Radiation protection also has several branches that require additional, specialized knowledge. For example, when working with reactor plant safety, a thorough knowledge of reactor plant design, construction, and operation is required. Similarly, when working with contaminated sites, it is helpful to have some knowledge of the chemical compounds that may share the site with the radioactive material, the solubility of the various radioactive compounds, and the site's hydrogeological characteristics.

It is possible, however, to observe good radiation protection practices without this knowledge. Proper contamination control can be used and, if necessary, proper decontamination techniques can be performed without the above knowledge. In fact, in many cases, radiological decontamination is easier than chemical or biological decontamination for the reason that radioactivity can be measured quickly, easily, and accurately in the field with relatively inexpensive equipment.

Although the entire field of radiation protection is too large to cover thoroughly in just one class, an overview of the purpose of it is possible as is the introduction of enough information to allow you to determine for yourselves what risks you will find acceptable.

2. RADIATION PROTECTION TERMINOLOGY

Most of the definitions given in this section are from the glossary of the Health Physics Handbook. The remaining definitions are taken from the definitions in the Code of Federal Regulations, title 10, section 20 (10 CFR 20), which regulates exposure to ionizing radiation and radioactive materials.

ACTIVITY: the number of nuclear transformations occurring in a given amount of material per unit time

$A=(\lambda) * m * N(a) / W$

Where:

A = activity level in disintegrations/sec
λ = decay constant (units = sec^{-1}) = $\ln(2)/t_{1/2}$
m = mass of material present (units = grams)
N(a) = Avogadro's number = $6.023x10^{23}$
W = atomic weight (units = atomic mass units)

BECQUEREL: a measure of activity defined as the amount of material which gives a disintegration rate of 1 disintegration per second. The Becquerel (Bq) is the SI unit for activity level.

BREMSSTRAHLUNG: secondary x-ray energy radiation emitted when a beta particle passes near a heavy atom, such as lead. Reduction of bremsstrahlung radiation is the primary reason for using plastic to shield beta-emitting nuclides.

CONTAMINATION: the deposition of radioactive material in any place where it is not desired (units = dpm/100 cm^2)

CURIE: a measure of activity defined as the amount of material which gives a disintegration rate of $3.7x10^{10}$ disintegrations per second. The Curie (Ci) is the American unit for activity level

1 Ci = $3.7x10^{10}$ Bq

DECAY CHAIN (SERIES): a series of isotopes resulting from the decay of a parent nuclide and its subsequent radioactive daughters ultimately to a stable form

DECAY CONSTANT: the fraction of the number of atoms that will decay in a unit period of time

$\lambda = \ln(2)/t_{1/2}$

Where
ln (2) = natural logarithm of 2 ~ 0.693...
$t_{1/2}$ = isotope half-life

DOSE (absorbed): the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest

D = dr * t

Where:
dr = dose rate in mR/hr
t = time in hrs

Units of Dose:

1 RAD = 100 ergs/gram in any material
1 GRAY = 100 RAD = 10,000 ergs/gram in any material
1 ROENTGEN = 2.58 * 10^{-4} Coulomb/kg of air

The RAD is the American unit of dose.
The Gray is the SI unit of dose.
The Roentgen is an obsolete unit of exposure in air, still mentioned in regulations.

DOSE EQUIVALENT: the biological damage caused by the absorbed dose

DE = D x QF

Where:
D = dose
QF = quality factor

Units of Absorbed Dose:

1 REM = 100 ergs/gram biological equivalent damage
1 SIEVERT = 100 REM = 10,000 ergs/gram

The REM is the American unit of absorbed dose.
The Sievert is the SI unit of absorbed dose.

Quality factor (QF):

beta and gamma radiation = 1
thermal neutron radiation = 3
fast neutron radiation = 10
alpha radiation = 20

Quality Factors listed are from 10CFR20, section 20.4

DOSE METER: an instrument designed to measure the dose rate of ionizing radiation - usually displayed in mR/hr

DOSE RATE: absorbed dose delivered per unit time (mr/hr)

DOSIMETER: an instrument used to detect and measure accumulated radiation exposure (film badge, audible dosimeter)

ELEMENT: a category of atoms having the same number of protons and the same chemical properties

HALF-LIFE (biological): the amount of time that is required for 1/2 of an ingested, inhaled, or administered substance to be eliminated from the body

HALF-LIFE (effective): the amount of time required for radioactive material in the body to have its activity reduced by 50% by a combination of radioactive decay and elimination.

$$t_{1/2}(\text{eff}) = \frac{t_{1/2}(\text{bio}) \times t_{1/2}(\text{rad})}{t_{1/2}(\text{bio}) + t_{1/2}(\text{rad})}$$

HALF-LIFE (radiological): the amount of time that is required for a radioactive substance to lose 1/2 of its activity

HALF-VALUE LAYER (HVL): the amount of a material that is required to reduce the dose rate from a radiation source by a factor of 2

HIGH RADIATION AREA: any accessible area where a major portion of the whole body could receive a radiation dose in excess of 100 milli-rads in one hour at a distance of 30 cm from the source.

- must be posted "Caution (or Danger) - High Radiation Area"
- must have a physical barrier
- must have dosimetry to enter

ISOTOPE: atom of the same atomic number (containing the same number of protons) but with a different number of neutrons in the nucleus (different atomic mass) - can be stable or radioactive

NARM: Naturally Occurring or Accelerator-produced Radioactive Material - material that is either naturally radioactive or has been made radioactive by bombardment with high-energy particles or ions in an accelerator

NORM: Naturally Occurring Radioactive Material - material that is naturally radioactive due to containing naturally-occurring radioactive isotopes

NUCLIDE: an atom characterized by the number of protons in its nucleus AND its energy level (ex: Tc-99m is a different nuclide than Tc-99, exhibiting a different half-life and different decay energies due to its existing in a different nuclear excitation (metastable) state

NUCLIDE (daughter): the nuclide resulting from the radioactive decay of a parent nuclide (current terminology has replaced the term “daughter” with “progeny”)

NUCLIDE (parent): the nuclide that exists prior to radioactive decay, decaying to form the daughter nuclide

ex: Xe-138 will β-decay to form Cs-138. Therefore, Xe-138 is the parent nuclide and Cs-138, the daughter nuclide

RADIATION: the emission and propagation of energy through space and/or through a material medium in the form of waves or, by extension, corpuscular emissions such as α or β particles

RADIATION AREA: any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the whole body could receive a dose in any one hour in excess of 5 mR at a distance of 30cm from the source

- must be posted "Caution - Radiation Area"

RADIOACTIVITY: the property of certain nuclides of spontaneously emitting particles or gamma radiation following orbital electron capture, electron emission, isomeric transition, nuclear rearrangement, or spontaneous fission. The process of undergoing spontaneous transformation of the nucleus of an unstable isotope, generally with the emission of alpha or beta particles, often accompanied by gamma rays.

SURVEY: a systematic check of radiation and/or contamination levels using radiation or contamination detectors

URANIUM (natural): uranium containing the relative abundance of isotopes that is found in nature (U-238, 99.275%; U-235, 0.720%; U-234, 0.005%)

URANIUM (depleted): uranium containing less than 0.720% U-235

URANIUM (enriched): uranium containing more than 0.720% U-235

16 NYCRR: The section of the New York Code of Rules and Regulations pertaining to radiation safety

3. A BRIEF HISTORY OF RADIATION PROTECTION

The study of radiation is a relatively new field, having begun with the discovery of X-rays in 1895. The initial experimenters did not realize the potential adverse effects of radiation due to a lack of experience with it. They noted that X-rays could penetrate matter and expose photographic plates, even while being invisible, and wondered if they presented a unique way to treat diseases from within the body. In the absence of any immediate physical effects (with the exception of reddening of the skin) it was assumed that there would be no adverse biological effects from this treatment.

It took less than one year to discover that X-rays could, in large enough doses, indeed, cause bodily harm. They began to use shielding. The radiation protection field, however, was still in its infancy and researchers simply had not had the time to amass sufficient information to make any determination as to the extent of the effects of exposure to X-rays. In the absence of any negative information, doctors and the public went under the assumption that exposure to X-rays was more beneficial than harmful.

In a classic experiment in that same year, a physicist decided to determine for himself whether or not X-rays could cause burns. In this experiment, Elihu Thompson exposed his little finger to X-rays for a short time each day until the skin started to redden and his finger became painful. In this manner he determined that low doses of X-rays can cause cumulative harm that may not appear for some time. Discovery of even longer-term effects, delayed cancers, was years in the future, leading to the general perception that, so long as there was no short-term effect, there was no risk. A common method of calibrating x-ray machines was to place one's hand in the path of the beam until the skin began to redden. This corresponds to an absorbed dose of approximately 200 REM to the hand, compared to today's legal dose limit of 50 REM per year for the extremities.

The next several years saw increasing use of X-rays and, after its discovery in 1896, radiation, for a variety of "treatments". X-rays were used for treatment of tuberculosis, chronic aches and pains, criminal behavior, and to remove women's unwanted facial hair. This last use alone kept many plastic surgeons in business for a number of years. Even legitimate uses of X-rays, such as diagnostic imaging, led to great overexposure from poorly-shielded machines, inefficient film emulsions, and a lack of concern for dose reduction.

Adding to the exposure problem was the lack of personnel dosimetry, standard units for measuring of radiation dose, quantitative measurements relating radiation dose with biological damage, and exposure limits. Without any method of measuring the exposure received and without even a standard unit of measurement, no radiation protection was even possible at this time. This overexposure was more of a concern for the technician who worked with the equipment daily than for the patient, but both were overexposed routinely.

By 1904 radium had been discovered and was hailed, as X-rays had been, as a new medical miracle. Radium-bearing medicines were a common treatment for a variety of problems that would expand over the next 30 years to include over 160 ailments, including, ironically, lethargy, impotence, and baldness. Some radium-laced products that were sold during this time frame were toothpastes, hair tonics, skin creams, and water treatment units that infused radium or thorium into drinking water as a “preventative medicine”. Another popular use

for radium was in the painting of luminous watch dials. Studies done in the mid 1920's revealed many cases of death from radium poisoning in both the radium watch dial painters, mostly young women, and in the regular users of radium-bearing nostrums. These investigations generally had little effect on the official perception of the dangers of radium until the death of a famous industrialist, Eben Byers, in 1934 from radium poisoning. Byers had been drinking a “medicine" named Radiothor in an effort to improve his virility, consuming an average of 8 μCi daily for several years. This resulted in an untimely and horrible death and led to the banning of radium in any consumer products in 1936. The estimated body burden of the radium watch dial painters ranged up to 36 μCi, as compared with today's legal body burden limit of 0.1 μCi. This provided the first definite link between radioactive materials and cancer.

In the mid and late 1920's came the adoption of a standard unit of measurement (the Roentgen), radiation detection equipment, and the first recommended dose limits of 200 mr/day. This dose limit was based on receiving one tenth of the dose that was needed to produce skin erythema (reddening of the skin). This dose limit recommendation was repeated in 1931 by the National Bureau of Standards. In 1932, recognizing the varying tolerances of different parts of the body to radiation, it was suggested that the daily dose limit be 100 mr to the whole body or 500 mr to the hands. In 1949, this was reduced even further by the National Council on Radiation Protection (NCRP) to 300 mr/wk and, in 1956, the limits of 5 REM/yr to the whole body for occupationally-exposed individuals and 0.5 REM/yr for non-occupationally exposed individuals was adopted. The yearly limit for the general public has since dropped to 0.1 rem (100 mrem).

The field of Health Physics was officially born in 1942 when a physicist for the Manhattan Project, Ernest Wollen, was assigned the task of determining the effects of radiation on Project workers, recommending proper techniques to control their exposure, and to develop reliable methods of measuring this exposure. The result was, in the space of just a few years, amassing enough information to found a new profession and to lay the groundwork for years of studies.

Following the dropping of the atomic bombs on Japan, Manhattan Project scientists were dispatched to Hiroshima and Nagasaki to study the effects of radiation on humans over both short-term and long-term time frames. Other health physicists covered the atomic and hydrogen bomb tests in Nevada and in the Pacific, studying the effects of the explosions, the immediate radiation, and the fallout on plant and animal life, including their effects on humans. From these studies, as well as from accidental releases of fission products and from more laboratory work, our present limits for exposure to radiation and radioactive isotopes were derived. Most of today's exposure and concentration limits are a direct result of the work done by the Manhattan Project health physicists.

There is still ongoing research with respect to the recommended radiation limits. The meltdown of Chernobyl yielded a large amount of data on the effects of radiation doses on humans, and reassessments of the radiation release from the atomic bombs is still going on, as well. There has been more research done on the effects of ionizing radiation than on any toxic substance and there is more known about radiation's effects on humans than about any other harmful agent.

It is also interesting to note that, despite radiation's being undetectable to the senses, it is more easily detected in any quantities than virtually any other substance known. Radiation detectors can reliably detect, depending on the isotope, as little as 10^{-23} grams of radioactive material. This means that we can detect radiation at levels several orders of magnitude below the lowest levels shown to be harmful.

The standards that we follow and the radiation limits to which we adhere are based upon nearly a century of trial and error. Most of the practices of the past seem ridiculous, antiquated, naive, or just plain stupid with our current knowledge of the effects of radiation and radioactivity. However, without this stupidity and naiveté we might still be blissfully unaware of the potential hazards of radiation. Eben Byers and the radium watch dial painters died prematurely and horribly but their deaths led to studies that emphasized the importance of minimizing body burdens of radium and, by extension, of all radioisotopes. Early radiographers suffered burns which taught them the lessons of time, distance and shielding, the three basic tenets of safety from external sources.

Finally, the beneficial uses of radiation must be noted. Radiation is widely used to diagnose and treat many diseases, including cancer. Radiolabeled compounds are indispensable in research, and radioactive sources are used to measure tank levels, paper and steel thickness, and other industrial quality control parameters. Other uses of radiation or radioactivity include sterilization of surgical equipment, verifying pipe and weld integrity, food irradiation to prolong shelf-life, security at airports and buildings, power production (with less CO_2 emission than fossil fuel plants), and so on.

4. ADMINISTRATIVE AND REGULATORY ISSUES

4.1 Federal Regulations

The regulations that govern the use of radioactive materials and radiation generating devices are developed by several different federal agencies. There is no unifying group of regulations or guidance, so the rules can sometimes seem complex. Most radiation protection requirements are developed by the Nuclear Regulatory Commission, but others are developed by the Environmental Protection Agency and the Department of Transportation. The Food and Drug Administration regulates many of the radiation producing devices.

4.2 State Regulations

Many states choose to regulate the use of radioactive material. They sign an agreement with the Nuclear Regulatory Commission that transfers regulatory authority to a state agency. In New York State, the Department of Health (DOH) is the regulatory agency that governs most use of radioactive material. Radiation generating devices are also regulated by the DOH. The Department of Environmental Conservation regulates all discharges into the water and air in New York State, as does DOH.

State Regulations require that all radioactive workers and permit holders receive training prior to starting work with any radioactive materials. Training **must** be refreshed annually.

4.3 Radioactive Materials License

The University also is required to maintain special licenses for using radioactive materials. These licenses allow the University to purchase radioactive materials from vendors and provide additional radiation safety requirements. The licenses are maintained by the Radiation Safety Unit, and may be reviewed at the Radiation Safety Office. Contrary to popular belief, this is considered to be a public document by the DOH and is available for review at the Radiation Safety Office.

The license allows the University to possess limited amounts of radioactive material from tritium through uranium. Other radionuclides are added to the license by special amendment. In turn, Radiation Safety has the responsibility to sub-license each specific use of radioactive material at the University. To receive a radioactive materials permit, a researcher must complete a three-part application and submit it to Radiation Safety. The application is reviewed by both the Radiation Safety Officer and the Radiation Safety Committee. After approval, a permit is issued by Radiation Safety.

The DOH will periodically inspect activities involving radioactive materials and may visit your lab. Your cooperation in following these procedures and keeping abreast in our training program will ensure the renewal of the University license, and assist lowering exposure to ionizing radiation.

4.4 Radiation Safety Fees

The Radiation Safety Unit is not considered part of general University of Rochester overhead. Our activities are entirely funded through fees collected for various activities we perform. These fees are debated and approved by the Radiation Safety Advisory Committee, a committee composed of representatives from a wide variety of University of Rochester departments and radioactive

materials users. A copy of our fee schedule is available through our web page. A brief description of the types of fees we charge is included below.

Laboratory Permit Fees are assessed based on the number of long-lived and short-lived isotopes purchased and any violations accrued during inspections. These fees cover the administrative and technical services provided to support research laboratories. These services include all of the administrative work that goes into maintaining our radioactive materials license, the laboratory inspections, radiological emergency response, a portion of staff salaries, and the equipment used for our activities in support of research laboratories. The costs associated with ordering, receiving, surveying, and delivering radioactive materials, as well as the costs associated with radioactive waste collection, processing, and disposal are also covered by these permit fees. Calibration of survey meters and leak testing of radioactive sealed sources are included in the permit fees and performed for no additional cost.

Radiation Dosimetry Badge Fees are billed to recover the costs associated with monitoring radiation exposure to workers. These fees include the monthly badge charge, the administrative processing of dosimetry reports, and shipping costs. Additional fees are charged for late or lost badges.

Other Services are billed on a per-item basis. Some of these services include removal and disposal of radioactive sources from Liquid Scintillation Counters, instrument repair, lab decommissioning, shielding evaluations, and monitoring of x-ray producing machines.

4.5 Lab Permits

Lab permits are issued by Radiation Safety for any and all use of radioactive material. The permit lists the authorized user, the types of materials that may be used, rooms authorized for radioactive materials, and the total quantity of material that may be possessed at any one time. Labs may only use the radionuclides listed on the permit, and use is restricted to posted rooms authorized for radioactivity. New radionuclides or additional rooms may be added to a permit by submitting an amendment form to Radiation Safety.

Researchers apply for radioactive materials permits by completing and submitting an application form. Attached to the form should be a copy of the researcher's CV and a map of the proposed laboratory space. This application package is reviewed by the Radiation Safety Officer (RSO) and members of the Radiation Safety Committee. Following approval, the researcher will be asked to meet with the RSO to discuss any conditions associated with their permit and their responsibilities as permit holders.

Lab permits are issued only by Radiation Safety and must be maintained in each lab's Radioisotope Log Book. If a researcher wishes to change the isotopes authorized for use, the isotope possession limits, or the rooms authorized for radioactive use, an amendment form must be submitted for review and approval by the RSO beforehand. This includes cases where the researcher moves from one location to another. In the event the researcher wishes to terminate their permit or leave the university, an amendment form must be filled out and a termination survey must be performed before leaving the university. A researcher may also inactivate their permit which will allow them to reactivate it at any time with out reapplying. All radioactive materials must be surrendered, a survey must be performed, and an amendment form filled out. An inactive fee will be charged to the PI semiannually.

4.6 Ordering and Receiving Radioactive Materials

Radioactive materials may only be ordered through the Radiation Safety Office using an internal requisition form. An example of a properly-filled out requisition form is shown in Appendix F of this training booklet. Orders must be submitted to Radiation Safety by 2 PM on the day they are to be ordered. Requisitions placed after 2 PM will be ordered the next business day.

Radioactive materials can be ordered by anyone, but all orders must be approved by a permit holder for use under their radioactive materials permit. In addition, radioactive materials may only be used by qualified radiation workers inside of posted laboratories assigned to the Permit Holder signing for the order.

All of our radioactive materials vendors have been instructed that radioactive materials may only be ordered by Radiation Safety staff. Phoned or faxed orders from elsewhere in the University of Rochester will not be accepted. In addition, our vendors have been told to ship radioactive materials only to the Radiation Safety Office. The primary reason for this is so that Radiation Safety staff may perform the regulatorily-mandated radiological surveys and inspections and so we can enter the package into our inventory system.

After the package surveys are completed, Radiation Safety staff will deliver the packages to the individual labs who have ordered radioactive materials. If, instead, you would like to pick the package up at our office, please indicate this on the order form and it will be held for your pickup.

If there is a problem with the isotope Radiation Safety must be notified, even if a solution is worked out with the vendor. This ensures prompt delivery of any replacement isotopes. Otherwise, we will not be expecting an order and will not know which lab should receive the isotope.

4.7 Maintaining a Radioactive Material Inventory

Each package of radioactive materials is accompanied by an inventory sheet (Isotope Use Record) when delivered. These sheets indicate the total amount of radioactivity contained in the package as of a given date (assay date). All radioactive decay calculations should be based on this activity and date in order to be correct.

As aliquots are withdrawn from the stock vial the inventory sheet must be updated to reflect the total amount of activity used and the amount remaining in the stock vial. In addition, activity decay calculations should be performed at least once per half-life on remaining activity to account for radioactive decay. The activity shown on the inventory sheet must accurately reflect the total amount of radioactivity present in the stock vial. An example of an isotope use record is included in Appendix F.

As experiments are completed, solid and liquid waste will be generated. You should maintain a Radioactive Waste Container log for each waste container as waste is generated. It should include the nuclide, the activity level, the Source number (found on the Isotope Use Record) and the disposal date for each waste disposal into that container. In addition, the contents of each waste container should be corrected for radioactive decay in the same way stock vials are. An example of a completed waste sheet is included in Appendix F.

While maintaining this degree of information in the waste inventory sheets may seem excessive, state and federal regulations require that each shipment or disposal of radioactive materials be

properly documented. This cannot be accurately done without the information noted above. Maintaining an accurate and up-to-date radioactive materials inventory and waste sheets will help to ensure that each researcher is properly credited with radioactive material use, decay, and waste disposal, allowing researchers to order new isotopes without worrying about exceeding their permit limits and having an order refused.

Liquid scintillation vials containing less than 0.05 μCi/ml of H-3 or C-14 are not considered radioactive waste. Similarly, animal carcasses containing less than 0.05 μCi/gm of H-3 or C-14 are not considered radioactive waste. These wastes, however, will still need to be processed by Radiation Safety. Therefore, they must have **2 copies** of the waste sheet attached indicating the PI name, isotope(s), source number(s) and activity present. The remaining copy should be kept by the lab in the log book. Please note that these exemptions are only valid for H-3 and C-14 present in scintillation vials and animal carcasses. Other isotopes or any isotopes in any other waste form must be disposed of as radioactive waste. The Radiation Safety Unit, not the individual lab, will determine whether the waste fits the 0.05 μCi/g or ml threshold.

4.8 Disposing of Radioactive Waste

There are two primary concerns regarding radioactive waste, safety and cost containment. Improperly-packaged radioactive waste can pose a health and safety threat to both laboratory personnel and to Radiation Safety staff. In addition, taking the time to segregate waste can help to keep costs down while, at the same time, making sure we don't violate any regulations.

4.8.1 Health and Safety Concerns

Most of the solid radioactive waste is sorted by hand at some point. For this reason, it is important to make sure that there are no sharp objects in the waste container unless the container is designed specifically for holding "sharps." Any containers that are found to contain hypodermic needles, broken glass, Pasteur pipettes, or any other sharp objects will be returned to the research lab for removal of the sharps unless they are in a sharps container.

Every effort should be made to segregate organic waste from aqueous waste. All liquid radioactive waste must be processed by Radiation Safety. Call x5-3781 to schedule a liquid pick-up. Since a great deal of pouring and container-handling is involved, we ask that you not fill containers any higher than 4 inches (10 cm) from the top of the bottle (the beginning of the neck of the bottle). This is to minimize the chance of splashing liquid onto staff members while handling or processing the liquid waste. All containers must have **2 copies** of the Waste Sheet attached indicating the PI name, isotope(s), source number(s), original activity, and current activity present. A copy should also be kept by the lab in the log book. All containers must be stored within a secondary container. Any containers that are over-full or do not have a completed waste sheet attached will not be picked up by Radiation Safety until the situation is corrected.

In addition, please list **ALL chemicals** present in a liquid waste container by their specific chemical names. This will alert us to the presence of possible reactivity problems before mixing liquids and will also help us to identify any possible mixed wastes (waste that is both radioactive and listed as hazardous by the US EPA). Mixed wastes are much more expensive to dispose of than normal radioactive waste and their disposal costs will be billed back to the laboratory. Our waste treatment vendors sample waste containers received and, if they receive unlabeled radioactive mixed waste,

they will return the container to us and may refuse further shipments from the University of Rochester.

4.8.2 Cost Containment

Radioactive waste disposal is very expensive, costing over $300 per cubic foot for land burial and up to $1000 per gallon for disposal of liquid wastes. Certain types of waste can be treated prior to disposal to reduce our costs dramatically, but these require some degree of waste segregation on the part of research staff at the time the waste is generated. These are described below.

Liquid wastes should be segregated into aqueous and organic containers. If the chemicals present are listed as hazardous by the EPA, these materials should be stored in a separate container for disposal as mixed waste. If you are not sure about the hazard classification of your chemicals, you should contact Radiation Safety and we will find out for you. Even one liter of mixed waste in a 20 liter container is enough to make the entire container into mixed waste.

Solid waste should be segregated first into long-lived and short-lived isotopes. Short-lived isotopes are those with a radioactive half-life of 90 days or less. Examples of short-lived isotopes are P-32, S-35, and I-125. These isotopes can be stored for radioactive decay at the University of Rochester and their disposal is relatively inexpensive. Long-lived isotopes, having a half-life of more than 90 days, include H-3 (tritium), C-14, and Ca-45. They must be shipped off-site for treatment or disposal. Short-lived solid wastes should be further segregated into containers for isotopes with half-lives less than 30 days, half-lives of 30-50 days, and half lives greater than 50 days. Some of the most common isotopes that can be mixed in solid waste include mixing P-32, I-131, and Cr-51; mixing S-35 and I-125; and mixing H-3, C-14 and Ca-45. If you are not sure what isotopes can be mixed together please contact Radiation Safety and we will be happy to help you. All solid waste containers must have **2 copies** of the waste sheet attached indicating PI name, isotope(s), source number(s), original activity, and current activity. The remaining copy should be filed in the log book.

Long-lived solid waste should be segregated into incinerable and non-incinerable containers. Incinerable solid waste includes paper and soft plastics (such as latex gloves) and it is much less expensive to dispose of than non-incinerable materials. Metal, glass, hard plastics, and other non-incinerable materials must not be placed into containers to be sent for incineration or the University of Rochester runs the risk of losing access to this waste treatment option.

A final note: Please don't put any lead into radioactive waste containers. The disposal of lead into radioactive waste is prohibited by Federal laws. If you have lead pigs from radioactive stock vial shipments, you may return them to Radiation Safety for decontamination and disposal after removing the stock vials, removing all radiation labels, and surveying for contamination.

4.9 Radiation Producing Devices Registration

The University has several state registrations for radiation producing devices. This allows a fairly broad use of these machines. Each device at the University must be registered with the Radiation Safety Office. Periodic inspections will be performed by Radiation Safety Technicians to ensure that operators and patients are not being unnecessarily exposed to radiation. In addition, periodic Quality Assurance testing ensures that the machines meet all State and Federal requirements.

4.10 Radiation Safety Manual

Because the regulations governing radiation protection are complex, the University publishes a Radiation Safety Manual. The Manual's intent is to summarize all pertinent requirements for users of radioactive material, rather than having the users wade through all the regulations and University Radioactive Material License.

Each lab is required to maintain a copy of the Radiation Safety Manual in an accessible location, preferably in the isotope log book.

4.11 Radiation Safety Office

The Radiation Safety Office is a service unit of the University located in Room G-8842 of the Medical Center. The mission of Radiation Safety is to assist those working with radioactive materials and to ensure the safety of staff and visitors. Please call or visit the office at any time for assistance with technical problems. There are experienced health physicists and technicians who can answer questions and provide guidance.

The University's Radiation Safety Officer (RSO), Thomas Morgan, manages the activities of the office. The RSO is listed on the University's radioactive materials license as the person responsible for ensuring implementation of the radiation protection program, and the day-to-day conduct of the program.

4.12 Radiation Safety Committee

The Radiation Safety Committee (RSC) is a committee chartered by the President of the University to oversee Radiation Safety Unit (RSU) activities. The committee ensures that the RSU effectively administers the University's Radiation Safety Program to ensure that all use of radioactive materials and the operation of radiation-producing machines is accomplished safely and in accordance with all federal and state regulations and the conditions of the radioactive material license. This committee is chaired by Walter Shmayda of the Laboratory for Laser Energetics, and its membership is a cross section of the University community.

4.13 Laboratory Inspection Program, Regulatory and Policy Violations

The Radiation Safety Office periodically inspects all facilities either semi-annually (every six months) or quarterly (every three months) based on the lab's violation history and issues inspection reports. These inspection results should be used by permit holders to improve operations and safety in their labs. Inspections include a confirmatory radioactive contamination survey, an audit of records, and an inspection of radiological work practices.

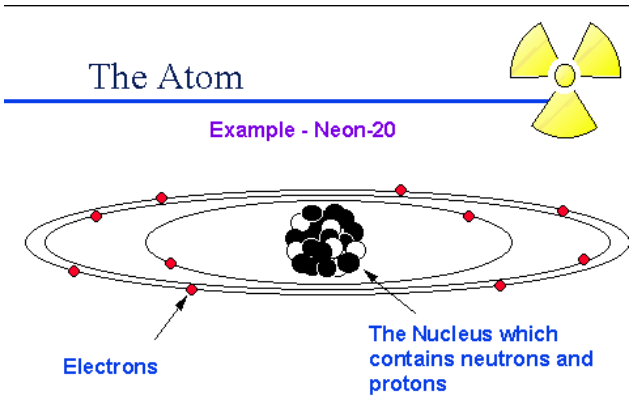
During laboratory inspections or other visits, Radiation Safety staff may notice practices or administrative records that do not comply with regulatory requirements or with University of Rochester policies. These violations, if minor in nature, may be corrected on the spot and reported to the permit holder. Major violations will result in a letter being sent to the permit holder requesting a response detailing corrective actions to be taken. Repeated violations may result in corrective or disciplinary actions being taken against the responsible person or the laboratory, including possible temporary suspension of the privilege to use radioactive materials.

4.14 Responsibilities

Individual users, working under the direction of a PI, are ultimately responsible for all work with radioactive materials and radiation producing devices. In order for the University to maintain its licenses and registrations, each user must ensure that all regulations and guidance are understood and implemented. Failure to adhere to these important regulations could result in the loss of the license, and therefore the loss of the ability to perform certain research, medical treatments and diagnoses. Further, criminal and civil penalties could be levied against individuals and the University.

5. RADIATION PROTECTION FUNDAMENTALS

5.1 Review of Atomic Structure and the Basic Types of Radiation

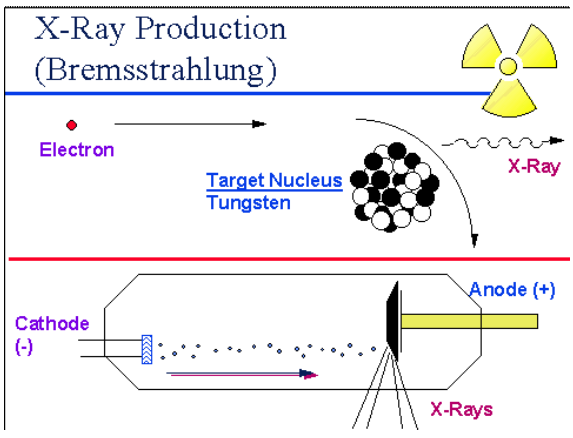


Atoms are the fundamental units of nature. They bond together by electrostatic interactions to form chemical compounds. The sizes of atoms range from one tenth of an angstrom to nearly two angstroms (10^8 A = 1 cm).

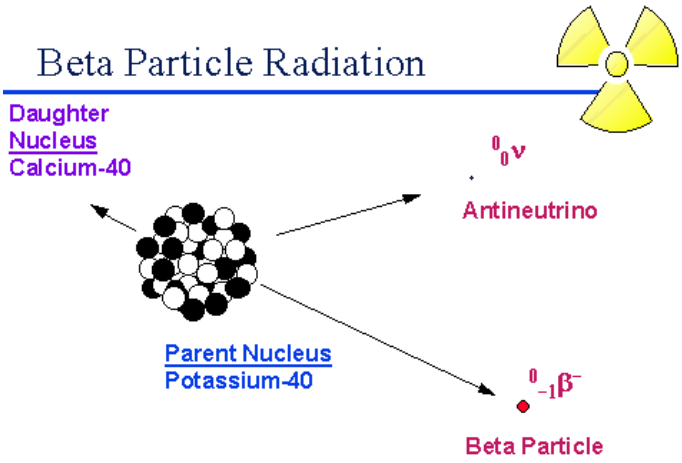
Atoms are composed of a variety of subatomic particles. All but three of these particles are irrelevant to the field of health physics and can be safely disregarded. The three that are of interest to health physicists are the electron, the proton, and the neutron. In addition, the nucleus of the helium atom and photons (not really particles at all) are also of interest.

Radiation Safety considers two major properties of these particles, their mass, and their charge as these both have a bearing on their interactions with matter and their ability to cause damage. The higher the charge and the more mass that a particle contains, the more damage that it can do.

Electrons are the lightest of the particles. They carry a charge of -1 and have a mass of one thirty-thousandth that of the proton or neutron. They can interact with matter either by direct ionization, or by bremsstrahlung. High-energy electrons emitted from the nucleus of unstable atoms are referred to as beta radiation.



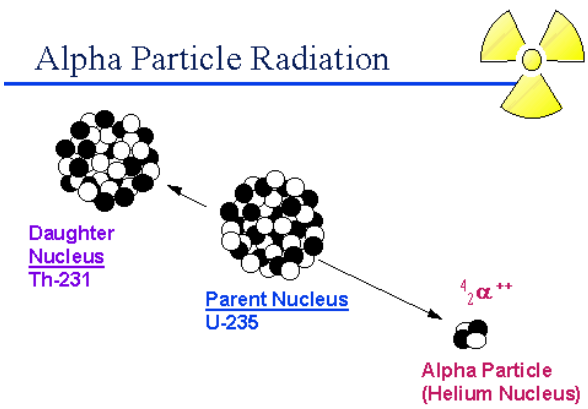
Direct ionization consists of an electron striking an atom and knocking loose one of that atom's electrons. This creates an ion pair (a positively charged atom and a negatively charged electron) that can go on to cause more ionizations within the cell. Bremsstrahlung is German for "braking radiation" and is caused by an electron passing near to a heavy atom. The atom and electron interact electrostatically, the atom deflecting the electron, which gives off radiation (usually in the x-ray region) as it changes course. A thin lead shield that is placed around a beta source will shield all of the beta radiation but will emit X-rays due to bremsstrahlung. Beta radiation is weakly penetrating and usually constitutes a skin dose only, although the lens of the eye is also susceptible. Due to its low mass, and charge of -1, beta radiation can sometimes be shielded by clothing.



The number of ionizations caused by beta radiation is proportional to the energy (velocity) of the beta radiation and to the mass of the atoms that it is passing through. So, in general, higher-energy beta particles will cause more ionizations and those that are passing by heavier atoms will cause more bremsstrahlung X-rays.

The next particulate form of radiation (also referred to as “corpuscular") is the neutron. Neutrons are neutrally-charged and relatively massive, weighing in at one atomic mass unit (amu). Being electrically neutral, the neutron only interacts by direct collision but, being massive, the neutron can collide numerous times, creating many ion pairs, while slowing down. Neutrons may be moving either very quickly (fast neutrons) or relatively slowly. Slow-moving neutrons are referred to as "thermal" neutrons if their speed is similar to that of the gas atoms in the air at that temperature. This speed is on the order of hundreds of meters to kilometers per second. Neutrons interact best with hydrogen-containing (hydrogenous) material such as water, plastic, or body tissue. The best shield, therefore, for neutron radiation is hydrogenous material. Some materials, such as boron, also have a propensity for absorbing neutrons, making them good shielding material, as well. Thermal neutrons are more likely to be absorbed by the boron and, having less energy to start with, cause less damage than do fast neutrons.

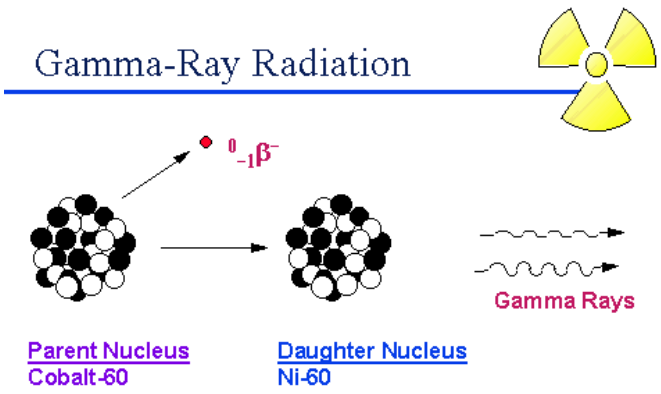
Protons are large particles, also found in the nucleus of the atom. They do not, however, play a major role in health physics as they are a source of radiation primarily at synchrotrons and cyclotrons. They are as massive as neutrons and have a charge of +1. In order to keep an atom electrically neutral there must be the same number of protons as there are electrons in the atom. An atom with an imbalance is referred to as an ion or a charged particle.



The last type of particulate radiation is the alpha particle. Alpha particles are actually helium atoms that have had their electrons removed, giving them a charge of +2. They are also very massive with a mass of 4 amu. This means that they are capable of causing more damage than any other form of radiation, but they are also far less penetrating. A piece of paper is an adequate alpha shield, and they generally cannot penetrate the dead layer of skin that we all have. This strong interaction with matter makes alpha particles a concern for internal dose only.

Another type radiation is the gamma ray, a high-energy photon that is given off by atomic nuclei that have been excited by beta emission, neutron capture, electron capture, or some other means. Most radioactive decays will produce gamma radiation. An atomic nucleus contains protons and neutrons in discrete energy states, much like the electrons surrounding it. During radioactive decay, the decay particles carry off energy. Unless this energy is the exact amount needed for transition to the next lower energy level,

the nucleus is still in an excited state. The nucleus will de-excite by emission of a gamma containing the energy difference between the energy state that the nucleus is in and the next lower energy level. There are a few nuclides, such as tritium (H-3) that emit a particle containing the exact amount of radiation that is required for this transition to a stable configuration; the rest of the nuclides will emit gamma radiation when they decay.

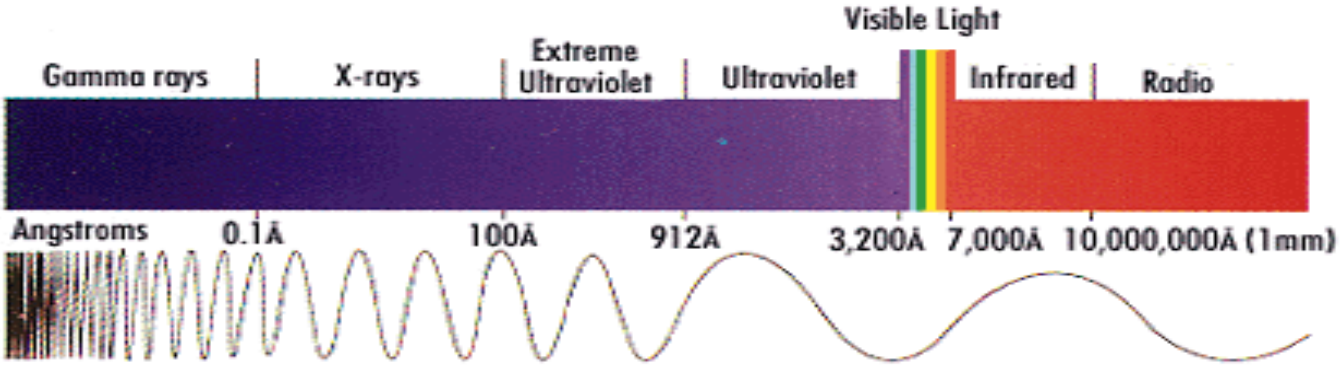


Gammas (photons) have no mass and no charge. They interact either by direct collision with electrons, knocking them out of their orbits, (the photo-electric effect); by production of an electron-positron pair if it passes near a heavy nucleus (pair production); or by absorption and re-emission by an atom, usually in a different direction and at a different energy (Compton scattering). Photons interact very weakly with matter and are best shielded by dense materials such as lead. Photons, along with neutrons, are considered a whole-body dose as they will penetrate through the entire body.

5.2 Radioactive Decay

The reason for an atom to be unstable is either an excess or a deficit of neutrons in the nucleus. The neutrons provide the nuclear force that keeps the positively charged protons from repelling each other and ripping the atoms apart. An atom with an insufficient number of neutrons is more likely to decay radioactively, as is an atom with an excessive number of neutrons than an atom with the correct number of neutrons. In addition, when atoms reach a certain size, the distance across the atom becomes great with respect to the range of the force that is trying to hold them together. This makes these elements more likely to give off protons or neutrons. The two major mechanisms for this are alpha emission (giving off two protons and two neutrons) and spontaneous fission (breaking into two or more parts of similar size). The best way to give an element an excess of neutrons is to bombard it with neutrons from a neutron generator or in the interior of a nuclear reactor.

The major decay mode for lighter atoms is either beta emission or electron capture. In beta emission, the unstable atom will emit an electron or a positron (β- or β+) from a neutron or a proton, giving the neutron a net positive charge and turning it into a proton or turning a proton into a neutron. Either of these will change the atom from one element to another since the chemical properties of an element are due to the number of protons that the nucleus contains.



Another method of releasing energy from atoms is in the form of high-energy photons, known as gamma radiation. Any change in the nuclear structure of an atom should result in the emission of a gamma as the nucleus reverts to a less-excited energy state. The energy of the gamma depends upon the excitation state of the nucleus and on whether the nucleus de-excites by emitting one gamma or several. On occasion, too, the emission of a gamma from the nucleus will knock an orbital electron out, turning the atom into an ion pair. These electrons are known as Auger (pronounced o-zhay) electrons.

The final common means for radioactive decay is called electron capture. This occurs when a nucleus "captures" an orbital electron, merging it with a proton to form a neutron. This, too, will change the atomic number and usually results in the emission of a gamma.

A table summarizing the properties of the various types of radiation is below.

TYPE	MASS	CHARGE	PENETRATING ABILITY	QF	SHIELDING
alpha	4	+2	very low	20	skin, paper
beta	~0.0003	± 1	low	1	clothing, plastic
gamma	0	0	high	1	lead, water
neutron	1	0	high	3-10	water, plastic

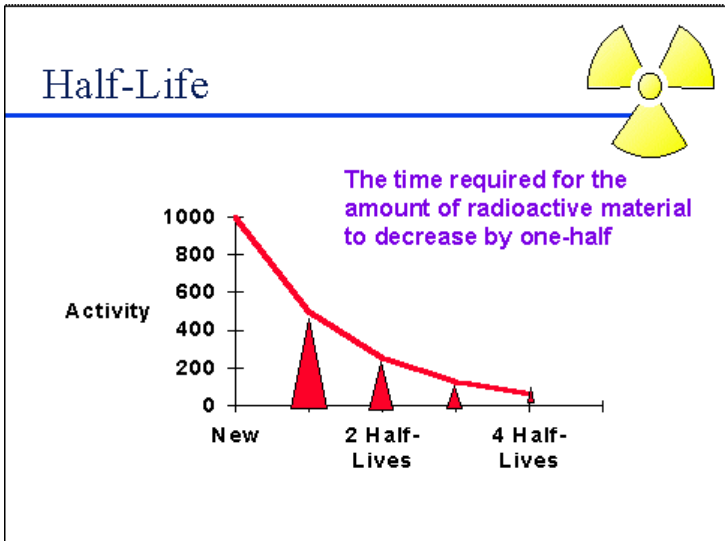
QF refers to what is known as the quality factor that is analogous to the amount of damage that the radiation can cause in the body. Different sources will give different values for the quality factors associated with neutron and alpha radiation. The ones shown here are typical values.

5.3 Half-life

All radioactive isotopes undergo radioactive decay at a characteristic rate. The rate at which one half of the original radioactive atoms decay is called the half-life. The half-life is unique for all radioactive elements and, if precisely determined, is sufficient to identify a radionuclide.

Calculating the amount of radioactivity remaining in a sample is relatively simple if the half-life is known. The equation is similar to the equation to determine compound interest, $A_t = A_o\, e^{-\lambda t}$

In this equation, A_0 and A_t are the amounts of radioactivity present originally and at any subsequent time, t respectively. The decay constant, λ, is the fraction of atoms that will decay in any given time period and is calculated by dividing the natural logarithm of 2 (equal to about 0.693) by the half life of the isotope ($\lambda = \ln(2)/t_{1/2}$). The decay constant is also used to relate the radioactive decay rate to the number of radioactive atoms present by the relationship $A=\lambda N$ where A is the activity in disintegrations per unit time and N is the total number of radioactive atoms present in a sample. The accompanying figure shows graphically how radioactivity decreases over time.



5.4 Methods of Exposure Control

There are three basic methods for reducing the radiation dose that is received: time, distance, and shielding.

Time is largely self-explanatory. The less time that is spent in the vicinity of a radiation source, the less exposure will be received. Methods of reducing the amount of time that is spent in a radiation field include rapid transit through the areas of highest radiation levels, preplanning of any activities that are to take place in the radiation field, practicing on mockups of a work area prior to the work to be done in order to improve familiarity with the procedure, and thorough training prior to performing any work.

Distance is another factor that can be used in reducing radiation dose. The intensity of a radiation source, for the most part, falls off as the square of the distance from that source. Therefore, if you double your distance you will reduce your exposure by a factor of four.

Shielding is the final major method used to reduce the dose received. Any material will provide some amount of shielding. The more material that is between you and the source of the radiation, the lower the dose that you receive will be. Denser material provides better shielding than lighter material does for gamma radiation. Neutrons are best shielded by hydrogenous material, and alpha radiation can be shielded by virtually anything. Methods of utilizing shielding include the use of plastic shields in work areas, around stock vials, or around waste containers if P-32 is in use, use of leaded glass shields around I-125 work areas, or placing lead bricks or lead foil around I-125 waste containers. Low-energy beta emitters such as H-3, C-14, and S-35 do not necessarily require shielding.

Other methods to reduce your radiation exposure include wearing appropriate protective clothing (at a minimum, gloves, lab coats, closed-toe shoes, and long pants should be worn), working in a fume hood when necessary, and keeping food and drink out of the lab. In particular, it should be noted that it is against the law in New York to eat, drink, or store food in any lab posted with the radiation symbol.

ALARA is an acronym used by the NRC in 10 CFR 20. It stands for keeping your radiation dose As Low As Reasonably Achievable. Utilization of time, distance, and shielding is a major part of ALARA. The other major part is ensuring that each trip into a radiation area is really necessary. ALARA applies to institutions, as well as people. Institutions are required to maintain their cumulative radiation exposure as low as reasonably achievable. Therefore, it is in the best interests of everyone to do what they can to assist in this goal.

6. THE BIOLOGICAL EFFECTS OF IONIZING RADIATION

6.1 Cellular effects of Exposure to Ionizing Radiation

The first impact of radiation is on individual cells. Radiation can damage the cells by causing or creating:

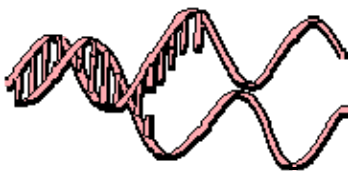
- Ionizations of atoms within the cell
- Free radical formation within the cell
- Hydrogen peroxide poisoning of the cell
- Breakage of DNA strands (both single-strand and double-strand breaks)

Ionizing radiation will cause ionizations within the cell due to the primary and secondary effects of the radiation. Ionization of water can lead to the formation of H^+ and OH^- free radicals within the cell that will attack proteins within the cell and that can recombine to form hydrogen peroxide (H_2O_2) that poisons the cell. Finally, the free radicals or the direct radiation can interact with the DNA strands in the nucleus of the cell to cause damage to the information stored there. Under normal circumstances this damage can be repaired properly but, on occasion, it is either improperly repaired or not repaired at all, leading to errors when the cell reproduces itself.

If this damage occurs slowly then it can be repaired as it happens. However, in the case of a large acute dose the damage may be extensive enough and in a short enough time frame to be irreversible, resulting in the death of the cell.

Genetic Effects:

- Damage to ova in ovaries
- Damage to sperm-forming cells
- Damage to ova or sperm
- Mutations of genetic material in ova or sperm



The genetic effects of radiation are well documented in humans and in animals. Under a high enough radiation dose mutations can occur as the radiation causes changes in the DNA (usually in the ova, as the sperm are relatively short-lived). Studies done on the survivors of Hiroshima and Nagasaki and their children, as well as those on mice, indicate that the increased mutation rate due to most radiation doses is statistically insignificant. Most mutations that occur, whether due to the normal mutation rate or radiation-induced, are either stillborn or are spontaneously aborted (miscarried).

6.2 Effects on the Organism

Gross effects:

- Increased cancer risk of about 2 cancers per 10,000 person-REM of exposure (*)
- Increased cancer death rate of about 4 fatality per 10,000 person-REM of exposure (*)
- Cataracts from cumulative exposures of several hundred REM over years
- Life expectancy changes:~2 1/2 days per REM (low) ~10 days per REM (high dose) radiation burns (skin erythma) from acute doses of a few hundred REM

(*) Assuming that the linear, no-threshold model is accurate, otherwise risk is lower

The USEPA conversion factors for converting millirem of exposure to excess lifetime fatal cancer risk are 3.9 * 10^{-7}/mREM for beta-gamma radiation and 3.2 * 10^{-6}/mREM for alpha radiation. This comes out to about 4 fatal cancers per 10,000 person-REM for exposure to beta-gamma radiation and 32 fatal cancers per 10,000 person-REM for exposure to alpha radiation.

The gross effects of radiation generally do not appear immediately. The increased cancer risk and the life expectancy changes are far lower than the expected cancer and mortality risks that are encountered daily by smokers, residents of urban areas, drivers, construction workers, and numerous others.

6.3 Radiation Sickness

A large acute dose of radiation can result in radiation sickness. The different organs in the body respond differently to radiation and to radiation doses with the blood-forming organs and the digestive system being the most sensitive, and the extremities and the brain being the least sensitive. Radiation sickness, in general, consists of vomiting, fatigue, and nausea in varying degrees with hair loss and skin burns in severe cases.

0 - 50 REM no obvious effects, blood chemistry changes

100 REM minor radiation sickness in about 10% of the population exposed

150 REM minor radiation sickness in about 25% of the population exposed

200 REM radiation sickness in about 50% of the population exposed

300 REM radiation sickness in all exposed, about 20% death rate within one month

450 REM about 50% death rate without medical treatment

500 REM radiation sickness within 4 hrs, over 50% death rate

1000 REM radiation sickness within 1 - 2 hours, 100% death rate

The yearly legal dose limit is 5 REM for occupational workers and 0.1 REM for non-occupationally exposed personnel.

The dose to an embryo/fetus, due to occupational exposure of a declared pregnant woman, shall not exceed 500 millirem during the entire pregnancy and 50 millirem in any month after the pregnancy is declared. This is much lower than any dose shown above. When a woman

voluntarily declares pregnancy, in writing, Radiation Safety shall review past exposure history and provide exposure counseling. When necessary, the pregnant worker's supervisor may have to adjust working conditions to comply with the limits listed above. Declaration of pregnancy is a voluntary act. If a declaration is not made, then the limits do not apply.

It should also be noted that there is a difference between exposure to high levels of radiation in a short period of time (acute exposure) and long-term exposure to low levels of radiation (chronic exposure). Generally, chronic exposure is less damaging than acute exposure because the body has a chance to repair damage as it occurs rather than being overwhelmed. It is akin to throwing small pebbles at someone over a long period of time as opposed to dropping a boulder on them.

6.3.1 Risks Associated with Exposure to Ionizing Radiation

It is estimated that there are 4 additional cancer deaths for each 10,000 person-REM of radiation exposure. The cancer death rate in the population in general is 2,000 per 10,000, so the impact of a total dose of 10,000 person-REM will be to raise the expected cancer death rate to 2,004 per 10,000.

There are two major models that are used for estimating the effects of exposure to low levels of ionizing radiation. The more conservative model, linear regression, assumes that any exposure will do damage. This model linearly extrapolates from high dose and high dose rate exposures (Chernobyl, Hiroshima) which have known effects to determine the effects of exposure to low levels of radiation. The other model assumes that there is a threshold level of exposure below which there are no measurable effects from radiation exposure. We currently have no indication that use of the linear-regression model is justified at low doses. This model is currently in use since it is the more conservative model.

Both of these models attempt to estimate the effects of low levels of radiation based upon the known effects on people from acute, high doses and both models, therefore, contain inherent inaccuracies. Please note that there have been no verified adverse health effects from chronic exposure to low levels (within the limits set by 10CFR20) of ionizing radiation. Also note that all models used assume that chronic exposure consists of continual exposure - 24 hours per day over a period of decades.

Given the large doses required for radiation sickness to occur and the larger doses required for death from radiation sickness it is obvious that radiation exposure at even the federal limit cannot be considered an immediate health risk. Both of the exposure models used, the USEPA risk conversion factor, and the NCRP risk factor indicate that exposure to the these radiation doses does not constitute a significant risk in terms of fatal cancer risk. In fact, using the most conservative risk model, exposure to 100 mrem per year (a typical exposure at the University of Rochester) for 50 years will give almost exactly the same risk as any other job-related risk, about one in 10,000. Estimated exposures for large groups from other sources are summarized below for comparison.

One REM is defined as the amount of ionizing radiation that will cause the biological damage equivalent to depositing 100 ergs of energy per gram of body tissue. If we assume a 100 kg person (220 pounds) whose body contains 10^{12} cells, then an absorbed dose of one REM will result in absorbing 1 Joule of energy in the form of energy. This is the same as 1/4 calorie, about 1/1000 BTU, 3/4 of a foot pound, or $6x10^{18}$ eV. As the average chemical bond strength for

covalent bonding is in the neighborhood of 300 kJ/mole then approximately 2000 bonds are broken per cell from this dose.

PERSON-REM PER YEAR	SOURCE
4000	Naval nuclear power - ~200 reactors and 10,000 personnel
12,000	Air travel
100,000	Denver residents (above natural background)
650,000	Cooking with natural gas - US population (radon)
17,000,000	Medical and dental X-rays - US population
20,000,000	Natural background - US population

6.4 Hazards Related to Inhalation or Ingestion of Radioactive Materials

There are special hazards associated with the inhalation or ingestion (uptake) of radioactive materials. First, introducing radioactive materials into the body increases the radiation dose internal organs such as the stomach, lungs, or intestines are exposed to. In addition, once in the body, radioactive materials may enter the bloodstream and be taken to other internal organs, concentrating there. For example, if radium is ingested, it will concentrate in the bones, exposing the bone surface and marrow to long-term radiation dose. Alpha radiation cannot normally penetrate the skin to deliver radiation dose but, once taken internally, is extremely damaging. For these reasons it is important to minimize the amount of radioactive materials ingested or inhaled to the maximum amount possible.

6.4.1 Sample Radiation Doses From "Normal" Activities

DOSE (mR/yr)	SOURCE
0.3 - 1	watching TV for 4 hours daily at 12 feet *X-ray emission from screen*
4	reading glossy magazines for 1 hr/day *uranium and potassium in clay paper coating*
5	eating 1 banana per day *potassium (K-40) in banana*
8	carrying radium dial pocket watch 12 hrs/day *gamma emission from radium paint*
10	living in a brick house instead of a wood one *potassium, uranium and thorium in clay in the bricks*
25 - 4000	wearing enameled jewelry (with/without metal backing) 10 hrs/week *uranium compounds in glazing*
70	living in Denver instead of at sea level *increased background radiation due to elevation and igneous rocks*
100	flying ~5000 miles per month *reduced atmospheric radiation shielding*
100 - 200	radon gas inhalation (national average)
100 - 200	foods and fertilizers *naturally-occurring potassium (K-40) and uranium in super-phosphated fertilizers*
150	medical technicians (yearly average) *combination x-ray and nuclear medicine*
170	flight crews *reduced atmospheric radiation shielding*
2000-5000	dose to lungs - smoking 1 pack of cigarettes/daily *polonium (Po-210) and lead (Pb-210) from U decay series*

7. GOOD RADIOLOGICAL WORK PRACTICES

For the most part, good laboratory work practices are similar whether working with radioactive materials or other hazardous substances. Most important is to take all reasonable actions to prevent direct contact with the skin, avoid inhalation or ingestion of radioactive materials, and to minimize the potential for contamination of the work areas. In addition, the properties of radiation call for some added protective measures. The following sections contain a summary of several good radiological work practices.

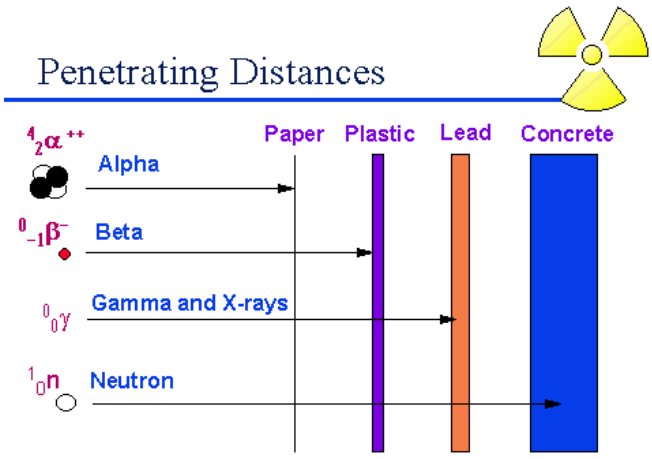
7.1 Time

Radiation dose is proportional to the amount of time spent in a radiation field. Taking steps to reduce the amount of time you are working in the vicinity of radioactive materials will reduce your radiation dose. Some examples of these steps are:

Plan your work in advance so the amount of time you spend using radioactive materials is minimized. If possible, leave radioactive materials in their shielded stock vials until you actually need to withdraw an aliquot, capping and shielding the stock vial as soon as possible when it is no longer needed. Conduct your work with radioactively labeled substances as quickly as possible without creating errors. When possible, conduct dry runs for new protocols using water or other non-radioactive substances.

7.2 Distance

Radiation dose rate falls off as the inverse square of the distance. Therefore, a stock vial held at arms' length will give only one fourth the dose rate as one held at half the distance. Similarly, radiation dose from waste containers will be reduced by placing the containers as distant as possible from frequently used work areas.



7.3 Shielding

Interposing shielding between yourself and a source of radiation will reduce radiation exposure according to the properties of the emitted radiation and the thickness of shielding. For beta-emitting radionuclides, about 1 cm of plastic will provide excellent shielding. Because of bremsstrahlung radiation (x-ray radiation emitted when charged beta particles pass near the nucleus of heavy atoms) lead should never be used to shield beta-emitting nuclides such as H-3, C-14, P-32, or S-35. However, lead is appropriate shielding for gamma-emitting nuclides such as I-125. Wearing lead aprons may be required for some medical uses of radiation but is not normally called for in a research laboratory. If you feel you may need lead apron shielding to work safely in your laboratory call Radiation Safety for an independent assessment.

7.4 Personal Protective Equipment (PPE)

All work with radioactive materials requires the use of proper PPE. At a minimum, you must wear a buttoned lab coat and gloves at all times when handling radioactive materials. In addition, you may not wear skirts, shorts, open-toed shoes (unless you are wearing socks also) or any other clothing that exposes bare skin below the shoulders. Dressing appropriately will reduce the potential for skin contamination which can lead to very high skin radiation dose and uptake of radioactive materials with subsequent internal exposure. BEFORE starting to work with radioactive materials you must ensure your gloves are intact and they should be checked frequently while working for holes, rips, or cuts. If working with volatile radionuclides or chemical forms (such as iodine isotopes or methionine) you should work in a properly operating fume hood. You will not normally need to wear a respirator.

7.5 Food and Drink in Posted Rooms

New York State law and University of Rochester policies strictly prohibit eating, drinking, smoking, applying cosmetics or food storage at any time in any room or hallway marked with the radiation symbol. This is to avoid the potential for accidental ingestion of radioactivity. In addition, any evidence of eating, drinking, or food storage in any posted room is considered the equivalent of eating or drinking in that room and is similarly prohibited. All food wrappers, drink containers, coffee-stained cups, and other evidence of eating or drinking is considered a violation of this legal requirement.

7.6 Radiation Dosimetry

Workers having the potential to exceed a quarterly radiation dose of 125 mrem are required to wear radiation dosimetry. Workers who only work with low-energy beta-emitting nuclides (such as H-3, C-14, and S-35) are not required to wear dosimetry because the radiation is too low in energy to register on dosimeter materials. Workers who have been assigned dosimeters must wear them when working with radioactive materials. They should be worn on the trunk of the body (between the waist and shoulders unless otherwise noted) and should be worn on the side of the body closest to the primary source of radiation. When not in use, dosimeters must be kept in a common location as far from radioactive materials as possible. Dosimeters should not be taken out of the work area. You should never wear any dosimeter except your own. For most non-medical workers dosimeters are exchanged every second month.

7.7 Contamination Surveys

New York State and Federal laws require documented weekly contamination surveys be performed in ALL areas where radioactive materials are used. If radioactive materials were not used in your laboratory in a particular week then no survey is required. However, a blank survey map with the words NO RAM USED and the applicable dates must be included in your log book in place of a survey. Chapter 11 contains more information about performing contamination surveys.

7.8 Radioactive Waste Handling and Disposal

Radioactive waste should be strictly segregated into liquid and solid waste. All sharps (needles, Pasteur pipettes, broken glass, etc.) must be stored in an approved sharps shelter. Liquid wastes

must be further segregated into aqueous and organic liquids. Be careful not to mix chemicals together that may produce reactivity problems. **Laboratories are NOT permitted to pour radioactive liquid wastes into laboratory sinks.** Call Radiation Safety for a liquid waste pickup.

A summary of waste packaging guidelines is presented below. Further information on radioactive waste disposal is found in Chapter 4.8 of this booklet and in the Guide to Radioactive Waste Management.

Medical Center and River Campus Radioactive Waste Packaging Requirements

Concerns have arisen regarding the packaging of radioactive waste for pickup and subsequent disposal by Radiation Safety Unit (RSU) personnel. Specifically, containers have been picked up that are over-full, liquid containers have been noted to have solid material in them, and some containers have not been fully characterized with respect to their contents. In addition, changes in waste disposal policies in other states require more complete labeling of waste containers. To assist the Radiation Safety staff in addressing scheduling, regulatory, and health & safety concerns, please observe the following requirements prior to pickup of any packages of radioactive waste.

1. River Campus / offsite pick-ups are every other Tuesday. Requests for all River Campus / offsite pick-ups must be called into Radiation Safety at x53781 by 12:00 PM on Monday for the Tuesday run. Otherwise, waste will be picked up on the next regularly scheduled run.
    - When requesting a pick-up of a waste container, the following information is needed: Container type (solid or liquid), Container size, Radionuclide and Activity in container.
2. Medical Center, MRB and MRBX solid waste and vials should be dropped off in room B-5730. Liquid waste will be picked up. Call x53781 to schedule a pick-up.
3. Prior to collection, all containers must have a wipe survey performed on the outside surfaces of the container(s). All smear wipes must read less than 100 DPM. Nuclides for which DPM is not calculated must be less than twice the background of the LSC counter. This must be documented and a copy attached to the container. **Waste at offsite facilities will not be picked up if documentation of survey is not present.**
4. 2 copies of the Waste Sheet must be attached to each container. The remaining copy should be filed in the log book. Waste sheets must be filled out with:
    - Laboratory room number
    - PI name
    - Contact person and phone number
    - Radionuclide(s)
    - Source number(s) from which the nuclide(s) originated
    - Original activity
    - Current activity
    - Dates in which waste was entered into the container
    - Date the container was sealed
    - Chemical contents. NOTE: Chemical contents must be specific (e.g. scintillation cocktail, ethanol, etc. Do NOT simply note “organic” or “aqueous”.)

5. Liquid containers must not be filled over 4 inches from the top of the container and must be stored within a secondary container. Organic waste must be separated from aqueous waste.
6. Decay In Storage Boxes must have the inner bag sealed and top flaps taped closed.
7. Sharps **must not** be in any container other than an approved sharps container.
8. Boxes containing incinerable waste may not contain glass, metal, or any other non-incinerable materials.
9. Lead in any form may not be included in any radioactive waste container. Please contact Radiation Safety at x53781 for disposal of all lead. Please indicate if lead is believed to be contaminated.
10. Mixed wastes will be accepted, but disposal is exceptionally expensive and will be charged back to the lab. Please contact RSU if you have any questions about mixed waste disposal.

RSU will not pick up your radioactive waste unless the above criteria are met. If your radioactive waste is not accepted, a note will be left explaining why the waste was refused.

Radioactive Waste Pickup Refusal Explanation

Date:_____ Time:_____ Lab_____

The University of Rochester Radiation Safety Unit attempted to pick up your radioactive waste today, but was unable because of the reason(s) indicated below. Please contact our office once this has been corrected to schedule a waste pickup or with any questions you may have.

- □ Sharps not properly packaged or found in dry waste
- □ Waste not properly labeled with respect to nuclide, activity, and/or chemical constituents
- □ Lead included in waste container
- □ Liquid waste container overly full (less than four inches of free space at top)
- □ Solid material included in liquid waste container
- □ Pre-pickup container survey not performed
- □ Container not properly sealed
- □ Waste container information provided to RSU incomplete or incorrect
- □ No laboratory personnel present at time pickup was attempted

7.9 Isotope-specific information

Each individual isotope has unique characteristics, depending on the decay mode, decay energy, and chemical element. These characteristics and associated isotope-specific handling practices are found in Appendix E.

8. RADIOACTIVE CONTAMINATION AND DECONTAMINATION

Radiological contamination is much like chemical contamination in that the methods for prevention, control, and decontamination are virtually identical. The advantage of radioactive contamination is that it is much easier and faster to detect and to quantify than chemical contamination. You can virtually instantly detect radiation and can, therefore, monitor the decontamination efforts; while, with chemicals that may not always be the case. Also, radiation is detectable at far lower levels than are harmful to humans, unlike many chemicals.

Contamination has already been defined as the unwanted presence of radioactive material. The effect of contamination is to make something that is not radioactive appear to be radioactive. For example, a stainless steel counter-top is not inherently radioactive. If, however, one were to spill water containing Co-60 (a radioactive isotope of cobalt) onto the counter, a radiation meter would indicate the presence of radiation. This illustrates the difference between radiation and contamination - radiation is a natural property of an element and contamination is not.

There are two basic kinds of contamination: fixed contamination and loose contamination. Loose contamination can be removed, either accidentally or on purpose. The deliberate removal of loose surface contamination is known as decontamination. Fixed contamination is embedded in the material and cannot be removed other than by abrading or grinding it off. Of the two, loose contamination poses the greatest hazard as it can become airborne, creating an ingestion or inhalation hazard. It can also rub off onto clothing, shoes, hands, or anything else that comes in contact with it, allowing it to be spread to areas that are normally controlled. Fixed contamination, unless present in large quantities, is not a significant risk. If, however, it is present in levels sufficient to raise area radiation levels, then it does constitute a risk and must be dealt with appropriately.

8.1 Contamination Control

The best way to control the spread of contamination is not to allow any to occur. This is impossible, though, in virtually any environment. That being the case, the next best solution is to delineate and enforce boundaries beyond which contamination will not be permitted. Access should be limited to as few points as possible to minimize the possibility of undetected contamination being carried out of the area unwittingly. These boundaries should enclose the smallest area possible and should be monitored to ensure that no contamination can escape. Monitoring should include, but not be limited to, surveys of all personnel and equipment entering and leaving the contaminated areas, the entry and exit areas, and any boundaries that are not solid (i.e. any rope boundaries, turnstiles, open doorways, etc.).

It is also helpful to have at the entrance points a buffer zone with a step-off pad that will allow personnel entering and exiting the contaminated area a place to don or to remove anti-contamination clothing and to frisk themselves for contamination before their entrance or exit. This buffer zone should be surveyed frequently to ensure that it is maintained contamination-free. If this area is the only egress from the contaminated area and it is clean then the likelihood that contamination will spread beyond that point is remote.

The boundaries of and entry points to any contaminated area should be clearly marked and posted with the requirements for entry. This may include anti-contamination clothing, respirators, or only protective gloves. There should also be a supply of the proper clothing available at the entrance to the area and waste cans in which to dispose of the clothing upon exiting. Finally, there should be a person present in the vicinity of the entrance/exit point to ensure that proper frisking is performed and to deal with any problems that may arise.

Much of radiological contamination control is similar to chemical contamination control, which should not be much of a surprise. The best way to prevent personal contamination is to avoid coming in contact with any source of contamination. If this is not possible then one should carefully dress in anti-contamination clothing that is appropriate for the nature and amount of contamination that is present. Upon exiting an area, one should remove any of the potentially-contaminated clothing and perform a personal survey to ensure that there was no leakage of contamination past the protective clothing. Anything that comes in contact with a piece of contaminated material such as a floor, pipe, wall, and so on should be treated as contaminated and either left in the contaminated area, placed in a bag to prevent the spread of contamination from that object to other areas, or decontaminated and removed from the area.

8.2 Decontamination

Decontamination can range from easy to virtually impossible and decontamination techniques can vary from very simple to very complex. The simplest decontamination can consist of merely washing an object with de-ionized water and wiping it off. At the worst, it can call for constructing an enclosure with filtered air for the removal of the offending material by grinding. Before embarking on decontamination one must determine whether the end result will be worth the effort. One can expend many hours and generate a large amount of radioactive waste in trying to decontaminate an object of minor cost and importance.

The most basic decontamination technique consists of washing the object with water or with soap and water. If it is a person who is contaminated then the water should be lukewarm. This is to avoid injuring the person. If the water is too hot the person may be injured by scalding, if the water is too cold the pores may close in the contamination.

The next more aggressive form of decontamination is wiping down the contaminated area with alcohol or with another solvent. Detergent may also be used. Care must be used in personal decontamination to avoid abrading or chapping the skin. This should take care of the majority of the remaining cases of contamination.

If neither of these techniques is successful, in the case of skin contamination, another possibility is encasing the contaminated area with plastic; for example, taping a hand inside of a plastic bag. This will cause the contamination to be sweated out over time. Usually a few hours to a few days are sufficient for this method of decontamination.

If, by this point, the object is still contaminated, the situation must be assessed more fully. Any further decontamination techniques that are to be used will generate an increasing amount of radioactive waste and will consume a large amount of time. In the case of personal contamination many factors must be weighed. The half-life of the isotope, the mode and energy of decay, the degree of contamination, the solubility of the element or compound, and the specific area that is contaminated are all important. It may be best, in the case of very short-lived isotopes, to just

allow it to decay away. On the other hand, a large amount of something energetic and relatively long-lived will warrant more extensive measures. Any cases such as this must be dealt with on a case-by-case basis.

The same is true with equipment or with areas that have not been successively decontaminated by this point. The equipment simply may not be worth the cost in terms of time and disposal of the generated low-level radioactive waste required to decontaminate it. Further techniques are discussed in The Health Physics and Radiological Health Handbook.

9. RESPONDING TO RADIOLOGICAL INCIDENTS

A radiological incident is any incident involving radioactive contamination, ingestion or inhalation of radioactive materials, high radiation levels, or the loss of radioactive materials. All radiological incidents must be reported immediately to Radiation Safety (x 5-3781) during working hours and to Security (x 13) after hours and on weekends or holidays. The actions to take for some of these incidents are provided in the following sections.

9.1 Spill of Radioactive Material

A radioactive material spill is defined as the inadvertent release of radioactive materials to an area in which their presence is not desired. Radioactive spills are rarely a physical hazard in the research environment, but they have the potential to cause great trouble and expense in the future because they can result in contamination of university facilities, requiring future decontamination. Spills of radioactive materials may jeopardize ongoing and future research activities. **All spills of radioactive materials shall be reported to the Radiation Safety Unit (x 5-3781) or Security (x 13) immediately or as soon as spill is contained.** Research personnel involved in the spill shall take the immediate actions noted below and shall proceed with spill cleanup until Radiation Safety personnel arrive on the scene. At that time, Radiation Safety personnel may assume responsibility for continuing cleanup of the spill, may render assistance to laboratory personnel in completing spill cleanup, or may act in an advisory capacity. The immediate actions to be taken in the event of a radioactive materials spill are outlined below. The acronym used to remember these actions is “SWIMS”.

Stop *the spill by capping any open container(s) and placing absorbent materials on top of spilled liquids.* The purpose of this step is to take actions to prevent the spill from worsening. Taking these actions help contain the potential spread of radioactive contamination.

Warn *others of the spill by announcing it to co-workers, posting a notice on the door to the laboratory (if appropriate) and contacting Radiation Safety or Security.* These actions let others know of the spill so they can take appropriate actions such as rendering assistance, donning protective clothing, evacuating the area, or avoiding walking through the spill area, as appropriate for the specific instance.

Isolate *the area by erecting boundaries, posting warning signs, or other actions as appropriate.* This prevents the inadvertent contamination of personnel and limits the spread of contamination away from the spill area.

Minimize *personnel exposure by carefully considering the extent of the spill, determining appropriate personal protective equipment, and conducting radiological surveys to delineate the spill area*. This helps to maintain personal exposures as low as reasonably achievable.

Stop *ventilation if possible and appropriate by turning off room or area ventilation, shutting ventilation dampers, or other appropriate measures.* This reduces volatilization of liquid compounds and distribution of powdery solids.

Cleanup of the spill shall commence immediately upon completion of the above actions. In general, cleanup should proceed from areas of slight contamination towards areas of high contamination in order to reduce the spread of contamination. Following decontamination, surveys shall be performed using appropriate equipment to verify cleanup to appropriate levels has been accomplished. Copies of these surveys will be maintained by Radiation Safety and by the laboratory involved in the spill. These surveys shall note the exact location and extent of spilled radioactive materials prior to commencing decontamination efforts, the contamination levels noted at the time of the spill, and post-cleanup contamination levels (both fixed and removable). In general, use the following rules of thumb when cleaning up a radioactive spill:

1. Clean from top to bottom on vertical surfaces or when contamination is at several different levels.
2. Clean from the outside to the inside of a spill.
3. Clean from areas of low contamination towards areas of high contamination.

9.2 Skin Contamination

Skin contamination refers to the presence of radioactive materials in direct contact with a person's skin. Skin contamination is a concern because of the potential for very high localized radiation dose and because of the potential for uptake of radioactive materials attached to compounds that are absorbed through the skin and into the body. Skin contamination is almost entirely preventable through the proper use of protective clothing (gloves, lab coats, closed-toe shoes, wearing pants instead of shorts, and so forth). In the event that skin contamination does occur, the following procedure should be followed:

1. Notify Radiation Safety (x 5-3781) or Security (x 13) immediately.
2. Estimate the amount of radioactive material on the skin. This may be done using an appropriate meter and recording the count rate, type of detector, and isotope.
3. Commence decontamination efforts, beginning with mild soap and cool or warm water. In general, do not take measures that cause pain or that may degrade the skin's natural ability to act as a barrier. Decontamination efforts should continue until Radiation Safety personnel arrive, the decontamination is successful, or it is determined that continued efforts are inadvisable.

In the event of contamination with radioactive isotopes of iodine, a thyroid bioassay will be required between 24 and 72 hours after the contamination occurred. In the event of contamination with a beta-emitting nuclide (H-3, C-14, S-35, P-32, for example) a urine bioassay will be required between 24 and 48 hours after the contamination occurred. The purpose of these bioassay measurements is to determine if uptake of radioactive materials occurred. Personnel who are exposed to skin contamination shall remain in or near their laboratory area until released by Radiation Safety personnel.

9.3 Ingestion or Inhalation of Radioactive Materials

Potentially, the most serious form of exposure to radioactive materials is via inhalation or ingestion as these exposure pathways bring radioactive materials into direct contact with living tissues and give these materials a way to directly affect internal organs. Virtually all cases of ingestion or inhalation of radioactive materials may be avoided through the use of proper laboratory safety equipment including the use of fume hoods, face shields (when appropriate), and the elimination of eating and drinking in the laboratory environment. Personnel who may have ingested or inhaled radioactive materials shall remain in or near their laboratory area until released by Radiation Safety personnel. In the event there is a suspected uptake of radioactive materials through inhalation or ingestion, the following actions shall be taken immediately:

- Stop the source of uptake if possible (for example; leave the room, move into fresh air, spit contaminated liquids out of the mouth, blow your nose, etc.)
- Notify Radiation Safety (x 5-3781) or Security (x 13) immediately
- Estimate the amount of uptake to the best of your ability (save empty or partially empty stock vials, laboratory glassware, etc. that may help in this estimate).
- Urine samples for bioassay will be collected between 24 and 48 hours following any uptake of radioactive materials. Personnel working with radioactive isotopes of iodine shall have thyroid bioassay measurements performed between 24 and 72 hours following exposure.

9.4 Exposure to High Levels of x-Ray, Beta or Gamma Radiation

High levels of x-ray, beta, or gamma radiation are those levels that exceed 5 mrad/hr at 30 cm (approximately one foot) from the source or that result in off-scale readings on the highest setting of any survey instrument. Radiation levels of 5 mrad/hr pose no risk to personnel, but are indicative of problems that must be investigated. Levels of 5 mrad/he at 30 cm is also the level at which an area must be posted as a Radiation Area. In the event high radiation levels are encountered, personnel shall note the readings on their radiation survey instruments and immediately contact Radiation Safety (or Security after normal working hours). If radiation levels exceed 50 mrad/hr, personnel shall leave the area and assemble in a common area until released by Radiation Safety personnel. Depending on the perceived severity of the incident, Radiation Safety may collect or exchange radiation dosimetry at this time to ensure no personnel were exposed to excessive levels of radiation.

9.5 Loss of Radioactive Materials

Radioactive materials are considered lost if they cannot be located within four hours. Loss of radioactive materials is a potentially serious concern that may have to be reported to the State of New York. If you think you have lost radioactive materials, inform Radiation Safety immediately. Be prepared to provide the following information:

1. The isotope(s) involved and the approximate activity of each isotope
2. The radioactive materials stock vial number (also called the “RS number”)
3. The last time that particular stock vial was used
4. The normal storage location
5. What actions have you taken to locate the missing stock vial

Upon arrival at the scene, the Radiation Safety Unit will assist with attempting to locate the missing radioactive materials. If the materials can not be located, all involved parties will be required to write a report detailing the circumstances surrounding the loss of radioactive materials and describing all actions taken. In addition, the Radiation Safety Unit will determine the risk posed by the loss of radioactive materials (if any) and will report the loss to the New York Department of Health if necessary.

10. RADIATION DETECTION AND MONITORING EQUIPMENT

10.1 Detection Equipment

Most instruments used for radiation detection utilize either Geiger-Muller (G-M) tubes or air ionization chambers. Both methods take advantage of the ionizations caused by ionizing radiation.

10.1.1 G-M Tubes

G-M tubes are sealed, gas-filled tubes containing an anode and a cathode with a large voltage applied across them. The interaction of ionizing radiation with this gas causes secondary ionizations to occur, creating a current spike as the positive ions are attracted to the anode and the negative ions to the cathode. This current is amplified and registers as a count on the meter. The ionized gas will quickly recombine, allowing detection of the next ionizing event. There is a small amount of “dead time” while this recombination is taking place, usually in the neighborhood of 1-2 μsec, during which no counting can take place. This imposes an upper limit on the count rate for which the instrument can theoretically be used, in this case, 200,000 cpm. The disadvantage of a G-M tube is that there is, however briefly, a period during which no counts can be registered. This also allows for the tube to become "saturated" and not register accurately if the count rate is too great. The chief advantages of the G-M tube are its extreme simplicity, leading to great reliability, and its high sensitivity.

Geiger-Muller tubes are primarily used for the detection of gamma and beta contamination and measure in cpm (counts per minute). There may be a mr/hr scale, but it should not be used since the meter was not calibrated for mr/hr.

10.1.2 Air Ionization Chambers

The ion pairs created in the detector are collected and measured before they can recombine. This gives an output current that is proportional to the strength of the radiation field.

The advantages of the air ionization chamber are that the output current (the meter reading) is largely independent of the operating voltage and that they are, for the most part, easy to use and very portable.

The disadvantages of this instrument are that the generated current is very small, leading to a low sensitivity, and it is very sensitive to changes in humidity and barometric pressure.

Ion chambers can measure alpha, beta, or gamma radiation but require a special window in order to measure alpha radiation and to measure in REM per hour.

10.1.3 Scintillation Counters

Another common means of measuring radioactivity is the scintillation counter. The passage of radiation through a scintillating medium will cause the emission of light photons in the scintillant. These photons leave the scintillation medium and interact with one or more photo-multiplier tubes

(P-M tubes) to register as counts. There are two types of scintillation counters, solid (NaI) and liquid.

The advantages of the NaI detector is it is portable and has high efficiency for detection of gamma rays (at least 10 fold higher than a GM meter). Disadvantages include dead time, and the hygroscopic nature of crystal requires crystals to be hermetically sealed, usually in an aluminum cylinder. This prevents contact with humid air and protects the crystal, but also prevents alpha or beta particles from reaching the crystal.

The advantages of the liquid scintillation counter include being very sensitive to low energy alpha, beta, and gamma radiation with beta radiation having 100% efficiency for most isotopes. In the case of H-3 it is practically the only type of detector with the necessary sensitivity. Disadvantages include not being portable and due to dead time, it is not useful for high concentrations of activity.

A disadvantage to both types is that the scintillating medium and photo multiplier tubes must be kept dark at all times. Even a tiny pinhole can admit enough light to ruin not only the reading but the detector.

Since liquid scintillation counters contain a radioactive source, Radiation Safety must be notified for disposal when the LSC is no longer needed.

10.1.4 Compensated Ion Chamber

The most commonly-used method for detecting neutron radiation is by use of the compensated ion chamber (CIC). This detector consists of two concentric "cans" filled with a gas. The outer can is coated with a boron compound while the inner can is uncoated. A voltage is applied across the can and an anode in the center of the inner can. Either gammas or neutrons will cause interactions with the gas in the outer can but the neutrons will be absorbed by the boron in the coating, only causing ionizations in the outer can. The measurement circuitry uses the signal from the inner can (gammas only) to correct the signal from the outer can (gammas and neutrons), giving a final value for the neutron dose rate. These detectors are usually covered with several inches of polystyrene to approximate the shielding effect of body tissue. This allows most neutrons to give readings in mREM/hr instead of the more typical mRAD/hr.

The advantage of the CIC is that it is the only detector available for neutron measurement.

Its major disadvantage is that its response time is very dependent upon the strength of the neutron flux and the energy of the neutrons that it is detecting. In a low flux of low-energy neutrons it can take up to a few minutes to obtain a neutron level reading.

10.2 Personal Dosimetry

There are several types of personnel dosimetry. The three major types, Luxel badges, the Thermo Luminescent Dosimeter (TLD), and the film badge, are used for legal records of individual exposure. Radiation dosimetry should be worn on the trunk of the body unless otherwise specified and must be worn at all times when working with or around radiation or radioactive materials. You should only wear the badge(s) you have been issued – never wear anyone else's dosimetry. In addition, your dosimetry should not be taken home with you. Instead, there should be a central location in your lab to store dosimeters when not in use.

Dosimetry is issued to radiation workers who handle or work around large (milliCurie level) amounts of radioactive materials or who may receive more than 125 mrem in any calendar quarter. Dosimeters are issued to people by the Radiation Safety Unit.

10.2.1 TLD's

TLD's consist of small crystals, usually calcium fluoride, containing small amounts of impurities. Incident radiation excites atoms in the crystal which are "trapped" by these impurities. Upon heating (thermo-), the "trapped" excited electrons fall back to the ground state, giving up a photon (-luminescent) in the process. The number of photons released is proportional to the total radiation dose received. This photon signal is amplified by a photo-multiplier tube and the output sent to the dosimeter reader to register the dose.

TLD's, which are used at the U of R by those who have quarterly badges, have several advantages. They are extremely rugged and are not adversely affected by extremes in temperature. They are accurate over a very large exposure range - from mR to thousands of R. They are relatively quick and easy to read, allowing for speedy monitoring in emergency situations. They can be reused many times each, saving the expense of replacing them continually. And, finally, they are sensitive to beta, gamma, and x-ray radiation.

The disadvantages of TLD's over other methods of dosimetry are their higher initial cost and the fact that, once heated, the dose information is erased, unlike film badges, which can be reread if any questions arise at a later date.

10.2.2 Film Badges

Film badges, the badges used at the University of Rochester by everyone else, make use of the fact that radiation, like light, will interact with silver halide crystals in film emulsion, causing them to darken. Also like light, the amount of the darkening is related to the total exposure. The film is placed in a holder that can also contain two or three shields of varying thicknesses, allowing measurement of skin dose as well as whole body (deep) dose. The film, once developed, is read by a densitometer to determine the overall dose that the wearer received.

The advantages of the film badge are its permanence, its cost, and the ability to allow simultaneous recording of exposure to different types or energies of radiation.

The disadvantages of film badges are the amount of time that it takes to develop and process the film, the sensitivity of the film to environmental factors such as temperature and humidity, and the fading that can occur if the film is not read promptly.

Film badges can be used to measure beta, gamma, and x-ray dose.

11. RADIATION AND CONTAMINATION SURVEYS

State law requires that all laboratories in which radioactive materials are used be surveyed and documented on survey map weekly when radioactivity is in use. In addition, University of Rochester policies require performing a radiological survey of your work area after ***every*** use of radioactive materials. If no isotopes are used in a particular week, no survey needs to be performed. However, a blank survey map should be placed into the lab's Radiation Safety binder with the words "No isotope use" written on the map with the appropriate dates indicated. Otherwise, a survey must be performed and documented on a weekly basis.

Smear wipes for removable contamination are all that is required for those laboratories that only use low energy beta emitters (e.g. H-3, C-14, S-35, Ni-63, etc)

Both smear wipes for removable contamination and radiation surveys with appropriate instruments for fixed contamination are required for all other isotopes (e.g. P-32, P-33, Cl-36, Tc-99m, I-131, I-125, Cs-137, etc)

Radiation field measurements, in mr/hr, must also be completed and documented for those laboratories using gamma emitting radionuclides (e.g. Cr-51, Tc-99m, I-131, Cs-137 etc)

The Radiation Safety Office has developed a procedure for performing radiological surveys. For your convenience, this procedure is included in the following pages.

University of Rochester/Strong Memorial Hospital		Radiation Safety Unit
Title: Routine Laboratory Radiation and Contamination Surveys	Number: SOP 2.10	Revision: 2
Initiator/Date: T. Morgan 12/4/07	Reviewer/Date: T. Rich 12/6/07	Approved/Date: T. Morgan 12/12/07

1.0 Purpose

The purpose of this procedure is to define how to conduct radioactive contamination surveys. The performance of periodic surveys and the way in which they are performed are required under sections of the New York Code of Rules and Regulations. This procedure is based on the model radiological survey procedure developed by the State of New York.

2.0 Scope

This procedure applies to all research laboratories at the University of Rochester and Strong Medical Center.

3.0 References

3.1 NYS DOH, Bureau of Environmental Protection Radiation, Guide for the Preparation of Applications for Medical Programs, Guide 10.1, rev. 2, Appendix I (April 1991)

3.2 NYS DOH, Bureau of Environmental Protection Radiation, Guide for the Preparation of Applications for Academic Programs of Limited Scope, Guide 10.2 rev. 1, Appendix I

3.3 New York State Sanitary Code Chapter I, Part 16

4.0 Safety

Radiation safety practices are governed by the University of Rochester Radiation Safety Manual. Personnel are required to read, understand, and follow these procedures when handling radioactive materials or radiation-generating devices.

5.0 Definitions

DPM – disintegrations per minute
CPM – counts per minute

6.0 Equipment / Supplies

6.1. One inch (2.5 cm) diameter filter paper smear wipes (or equivalent)

6.2. Appropriate gloves and lab coat

6.3. Appropriate radiation detection instrument (liquid scintillation counter and/or hand-held meter)

7.0 Flowchart

N/A

8.0 Procedure

8.1. Research laboratories where unsealed sources of radioactive material are used shall be surveyed and documented weekly.

8.2. **Smear wipes for removable contamination**.

8.2.1. Smear wipes shall be conducted regardless of the isotope used in the laboratory.

8.2.2. Wipe tests are performed by wiping a piece of dry filter paper or equivalent over an area of 100 square centimeters.

8.2.3. Protective gloves should be worn when smear wiping potentially-contaminated surfaces.

8.2.4. Wipes should be separated to avoid cross-contamination.

8.2.5. Do not use a single smear wipe to survey multiple 100 cm^2 locations or to survey areas significantly larger than 100 cm^2 (for example, one smear wipe may not be used to survey an entire laboratory bench top or to survey several 100 cm^2 locations on a work bench).

8.2.6. Pay special attention to posted work areas, hoods, waste disposal areas, storage areas, and floor surfaces. Also check non-use areas in labs such as desks, trash containers, phones and areas where possible cross contamination may occur.

8.2.7. Count smear wipes for removable contamination in an appropriate counting device (i.e. liquid scintillation counter or beta counting system)

8.2.8. Record results as described below (see Section 8.3.6)

8.2.9. Any areas containing removable contamination in excess of 200 dpm per 100 cm^2 shall be decontaminated to less than these levels.

STOP: Notify the RSO immediately if removable contamination levels exceed 500 dpm/100 cm^2 after reasonable cleanup attempts.

Fixed contamination surveys

8.2.10. Surveys shall be conducted for fixed contamination using instruments appropriate to the isotope(s) used in the laboratory (e.g. GM detector for P-32 or NaI(Tl) for I-125). See Section 8.2.6 above for areas to survey.

8.2.11. Most survey instruments are not sensitive to isotopes emitting beta particles with energies less than 300 keV (e,g, H-3, C-14, Ni-63). Smear wipes shall be sufficient for these radionuclides (see Section 8.2 above).

8.2.12. Prior to using a radiation meter survey, the following checks shall be performed:

- Verify the meter to be used is in calibration. All radiation detection instruments must be calibrated annually.
- Verify proper battery operation by taking the main switch to the "Battery Test" position (or equivalent) and observing the needle deflection to the "Battery Test" (or equivalent) position.
- Verify the physical condition of the instrument is satisfactory.
- Verify the instrument cable is intact, in good physical condition, and does not have any cuts or tears in the insulation.
- Set the audible response switch to the "On" position and set the response switch to the "F" (fast response) position.
- Verify the meter has been checked for proper response against a source of known strength on the day of use.
- Make note of the background count with meter on lowest scale.
- Start performing the survey on lowest scale and go up in scale as contamination is found.

8.2.13. Hold the radiation detector between 0.5 and 1 cm from the surface to be surveyed and move at a rate of 3-5 cm per second. **NOTE**: Holding the probe at an excessive distance or moving the probe too rapidly may result in not detecting radioactive contamination. Holding the probe too close to the surface being surveyed may result in contamination of the probe.

8.2.14. Record the highest net count rate reading noted on the survey map as noted.

8.2.15. To determine the net count rate, subtract background count rate from the instrument reading. For example, if you have 50 cpm from background radiation (measured outside the laboratory) and the instrument reads 300 cpm, your net count rate is 250 cpm.

8.2.16. *Convert this count rate to a disintegration rate using the meter efficiency for the isotope in use.* For example, if a net count rate of 250 counts per minute is noted for P-32 and the meter efficiency for P-32 is 50%, the disintegration rate is 500 disintegrations per minute (dpm).

STOP: Notify the RSO immediately if contamination levels exceed 500 dpm/100 cm^2 after reasonable cleanup attempts.

8.3. **Gamma radiation field surveys**

8.3.1. Laboratories using gamma-emitting isotopes (e.g., Cr-51, Tc-99m, I-131, Cs-137, etc) shall conduct and document surveys weekly. An ion chamber-type instrument (Ludlum Model 9 or equivalent) shall be used. DO NOT USE GM or NaI(Tl) survey meters as these instruments are not calibrated for detection of gamma rays.

8.3.2. Ion chamber survey instruments are not sensitive to radionuclides emitting low energy gamma rays (e.g. I-125). Conduct fixed contamination surveys as described in Section 8.3 above for these isotopes.

8.3.3. All areas where an individual could receive a dose of 5 mrem or more in any one hour must be labeled "CAUTION RADIATION AREA"

8.4. *Permanent records will be kept of **all** survey results, including negative results*. These records shall be maintained in the radiation safety record binder maintained by each radiation permit holder for 3 years.

8.5. *The record will include location, date, serial numbers of instruments used, results of the daily instrument response check (see 8.10.6 above), and the name of the person conducting survey*. Record background count rate in units of counts per minute if a direct radiation meter survey was used instead of smear wipes.

8.5.1. The survey record will include drawings of areas surveyed, identifying relevant fixtures such as active storage areas, waste, and work areas.

8.5.2. *Results shall be noted in units of disintegrations per minute per 100 cm^2*. To convert instrument count rates to disintegration rates, divide the count rate by the instrument efficiency for the specific nuclide detected as noted on meter calibration tag.

8.5.3. In the event no radioactive materials were used during the month this will be noted on blank survey map.

9. **Appendix**

N/A

10. **Document Revision History**

Revision No.	Date	Description of Revision
0	12/17/98	Original
1	5/16/04	Reformatted
2	12/4/07	Changed survey frequency to weekly; rewrote fixed contamination survey section; added section on gamma radiation field surveys

12. RADIATION AND RADIOACTIVITY IN THE ENVIRONMENT

12.1 Natural Sources of Radiation

The surface of the Earth and all organisms on it are continually exposed to background radiation from a variety of sources. These sources are both natural and artificial. The predominant source of background radiation is due to inhalation of radon and its radioactive progeny, contributing over 50% of typical background radiation dose. Other natural sources of radiation dose are natural radionuclides in rocks, soil, and building materials; radiation from solar and cosmic sources; and cosmogenic radionuclides (formed by the cosmic ray bombardment of stable isotopes). External natural radiation sources account for approximately 71% of annual background radiation exposure.

Artificial sources of background radioactivity are mostly from consumer products, such as smoke detectors, medical x-rays, and nuclear medicine. Additional radiation dose results from the deposition of fallout from atmospheric nuclear weapons testing (which can be detected globally) and from the accident at Chernobyl (which is detectable throughout the Northern Hemisphere). All told, artificial radionuclides account for approximately 18% of annual background radiation exposure.

The balance of background radiation exposure is due to internal emitters, virtually all of which is due to ^{40}K which is an essential part of cellular biochemistry. Other internal emitters include U and Ra, which are ingested and can enter the mineral portion of the bone. Like the ^{40}K, U and Ra are naturally-occurring radionuclides. Exposure to internal emitters accounts for approximately 11% of annual background radiation exposure.

12.1.1 Naturally-Occurring Radionuclides

Naturally-occurring radionuclides have already been mentioned several times in this booklet. They are those radionuclides that exist in nature without having been created by humans. Many natural radionuclides also exist as artificial radionuclides, such as tritium (^{3}H and ^{14}C, for example) while others, such as ^{40}K and the uranium or thorium decay series, do not. Most natural radionuclides are not a significant source of radiation dose and are of use only to isotope geologists. This is because of their very long half-lives and relative scarcity at the surface of the earth. The following table identifies many of the known naturally-occurring radionuclides and summarizes their properties, including their method of formation and radioactive half-lives.

Nuclide	half-life	formation	decay mode	comments
^{3}H	12.27 yrs	cosmogenic	β, no γ	"tritium spike" from atmospheric nuclear weapons tests used to date groundwater movement
^{14}C	5715 yrs	cosmogenic	β, no γ	basis for carbon-14 dating method, spike from nuclear weapons tests used to date glacial ice layers globally
^{129}I	1.57×10^{7} yrs	primordial	β, γ	^{129}I in meteorites used to help determine time of solar system formation
^{26}Al	7.2×10^{5} yrs	cosmogenic	β, γ	used with ^{10}Be in geologic dating
^{210}Pb	22.3 yrs	U decay series	α	a major source of radiation dose from smoking tobacco products
^{50}V	$> 5.9 \times 10^{17}$ yrs	primordial	β, γ	note exceptionally long half-life
^{87}Rb	4.8×10^{10} yrs	primordial	β, no γ	used in geologic dating (Rb-Sr method)
^{147}Sm	1.06×10^{11} yrs	primordial	α	used in geologic dating (Nd-Sm method)
^{36}Cl	3.01×10^{5} yrs	cosmogenic	β, no γ	used to date ice cores, groundwater, and to determine past solar activity levels
^{10}Be	1.6×10^{6} yrs	cosmogenic	β, no γ	used with ^{26}Al in geologic dating

12.2 Exposure Pathways

Exposure pathways are the different ways that radiation released into the environment can reach humans. Exposure pathways depend on many factors and are identified by naming the steps involved from the time of release until the time of exposure to humans. For example, a plume of radioactive gas that is inhaled would give the inhalation pathway. By comparison, a plume of radioactive iodine that settled out in a field, was ingested by a cow, passed into the milk, and was drunk by a person would result in a grass-cow-milk ingestion pathway.

Exposure pathways depend on many factors that include the method of radioactive material release (into the air, groundwater, surface water, onto the ground, etc.), land use (farming, residential with home gardens, industrial, etc.), and lifestyle of area residents (farmers, nomadic herders, professional, fishermen, etc.). The following short example indicates some of the exposure pathways from a relatively simple scenario.

Example:

A small amount of radioactive liquid is spilled from a 5-gallon bottle onto a parking lot. The liquid contains radioactive iodine, a volatile liquid. Local land use is agricultural and residential. The parking lot drains into a small creek. Summarize potential exposure pathways from this release.

Pathways:
Evaporation→inhalation
Runoff→stream→river→fish→fishermen
Evaporation→deposition on vegetables→ingestion
Direct gamma exposure to personnel on parking lot
Evaporation→gamma exposure to personnel in radioactive plume
Runoff→soil→groundwater→well water→ingestion
Evaporation→fallout on grass→ingestion by cows→muscle tissue→ingestion
Evaporation→fallout on grass→ingestion by cows→milk→ingestion

More exposure pathways from this release exist. Note, too, that the chemical and radiological properties of the released nuclide are important. For example, iodine is volatile and easily utilized by organisms, but ^{131}I has a half-life of only 8 days. Any lengthy pathways are unlikely to be important because most of the iodine will have decayed before exposure can occur. Similarly, the release of ^{60}Co, with a half-life of 5.27 years, may not result in much exposure either because of cobalt's relative immobility in the environment.

12.3 Environmental Monitoring

Environmental monitoring consists of the methods used to measure the presence and effect of contaminants in the environment from an operating facility, a contaminated site or an accident involving contamination release. Environmental monitoring must initially include all potential media and pathways until it is determined that some may be of minor importance. For this reason, it may be necessary to collect and analyze samples of air, soil, surface and ground water, sediments, plants, produce, dairy products, meats, and/or wild animals on a regular basis. In developing an environmental monitoring plan it is important to understand that some pathways are of little significance even though we can determine a dose resulting from them. If expected radionuclide concentration along one pathway is very small then it will not be possible to accurately quantify either the amount of radionuclide present or the expected dose to the population from that pathway. In this case it may not be economically defensible to monitor such a pathway once it is confirmed to be minor. This section will discuss accepted forms of monitoring and sampling various environmental media.

12.3.1 Air Monitoring

Monitoring for airborne radioactivity is typically done using large volume air samplers that draw air through filters which are removed periodically and analyzed for radioactive content. The simplest filters measure particulates such as dust with adsorbed radionuclides. Other physical forms, such as noble gases or iodine may not be monitored by a simple filter. It is possible, by careful selection of sampling media, to monitor for a number of physical forms of radionuclides and for a variety of chemical contaminants although this is more expensive. Fixed filter

systems are removed at intervals (at the end of a shift, daily, monthly, etc.) while continuous monitors, which filter the air sample through a moving tape of filter paper that, in turn moves, past a radiation detector to determine airborne radioactivity levels in "real-time". Filter media vary, but most commonly consist of glass fiber or cellulose. Cellulose filters are easily dissolved in acid for further analysis but are not as strong as glass fiber filters.

Another form of air monitoring is "stack monitoring" which is common at nuclear power plants and at many facilities that use radioactive materials. Stack monitors are usually read continuously and indicate airborne radioactivity levels in "real time". Other real-time monitors include some radon detectors.

Air monitors may be high-volume, low-volume, or personal. High-volume air samplers have high flow rates and are very sensitive to low levels of radioactivity. They are often used at the perimeter of outside work areas such as remediation sites. They are also frequently used for environmental monitoring outside of nuclear facilities to monitor for airborne releases of radioactivity to the environment. High-volume air samplers require an outside source of electricity such as special power lines and can filter approximately 60 cubic feet per minute. These air samplers are large and bulky and are usually installed permanently or semi-permanently at fixed locations. If used as fixed monitors it is important to be aware of local wind patterns so that any radiological releases are actually monitored. Their filters are usually glass fiber and measure 8"x10". They are relatively expensive, costing over $1000 each.

Low-volume air samplers have lower flow rates and are most frequently used to determine airborne or dust-borne radioactivity levels in the vicinity of a work area to determine if workers require respiratory protection. They may use batteries or run from an extension cord and can filter about 60 liters per minute. They are small and light and can easily be hand-carried to a sampling location. Their filters are usually glass fiber or cellulose and measure about 2" in diameter. They are moderately-priced at $300-$500 each.

Personal air samplers are small devices that are usually clipped to the user's belt with the filter clipped to the lapel (giving them their alternate name, lapel air samplers). They have very low flow rates and are used to determine internal dose to workers working in the vicinity of radioactive materials who may inhale radioactive dust. Lapel samplers run on batteries and usually filter 10-20 liters per minute. Filters are usually glass fiber or cellulose and measure about ½" in diameter. They are comparable in price to low-volume air samplers.

12.3.2 Radiation Monitoring

Environmental radiation fields are often monitored to determine off-site dose (dose to personnel who do not work at a facility) from normal operations, dose due to radiological emergencies or releases, or background radiation dose from environmental media. Many nuclear facilities, including nuclear power plants, low level radioactive waste (LLRW) disposal facilities, sealed source manufacturers, and so forth, are required to maintain active environmental monitoring programs to document radiation exposure to the public or the environment.

Environmental radiation fields may be monitored over long periods of time, using TLDs, or may be monitored at specified times using an instrument called a Pressurized Ion Chamber (PIC) which contains a very sensitive ion chamber pressurized to 25 atmospheres with argon. The

high pressure provides more atoms for the ionizing radiation to interact with, greatly enhancing detector sensitivity.

Environmental monitoring TLDs are normally placed at regular intervals around the perimeter of a site. In addition, some TLDs may be placed several miles from the site to monitor background radiation levels while others may be placed adjacent to the nearest roads, workplaces, or dwellings. The TLDs are collected periodically, often monthly, quarterly, or semi-annually. Longer exposure times result in greater accuracy and lower detection limits but do not provide results as frequently. TLDs must be kept in the same location for their entire exposure if the results are to be meaningful and should be kept in the same locations for several years to allow meaningful comparison of long-term data trends. TLDs are small, rugged, inexpensive, easily read, relatively accurate, and may be re-used many times.

Environmental monitoring PICs are used for short-term real-time monitoring of an area. They may be used to check environmental TLD results, during a radiological emergency or release, to verify contamination levels at a contaminated site, or to verify successful site remediation. They are typically large, but can be moved and set up by a single person and are battery-operated (usually a car or truck battery). PICs are rugged, highly accurate, and exceptionally sensitive due to their high gas pressure, and give reliable and consistent results that are largely independent of gamma energy. They are also very expensive, costing from $10,000 to $20,000 each.

12.3.3 Water Monitoring

Water-borne radioactivity may occur in groundwater, surface water, or both. Depending on local hydrogeology, water may flow from the surface water bodies (rivers, lakes, streams) into the groundwater system or may discharge from groundwater to surface water. These flow patterns may change during the year or from year to year, based on precipitation, land use, or water use. Water is also an excellent solvent. Because of these occurrences, and because of the importance of water for so many human activities, water monitoring may be very important.

Surface water monitoring usually consists of obtaining water samples from rivers, lakes, springs, or streams using a bucket, automatic sampler, or sample jar. The water sample may be preserved or treated with acid to keep metals in solution and is transported to a laboratory for analysis. Care must be taken when developing a surface water sampling plan to ensure that samples are taken at locations downstream of potential contaminant sources as well as from areas known to be uncontaminated. Blanks are usually taken, too, for quality control purposes, and consist of tap water or distilled water that is known to contain no contamination. Surface water sampling may involve a great deal of hiking to arrive at a sampling location or may be performed from bridges passing over the water body of interest. When sampling any water body near an influent point (whether an outfall point or a tributary) care must be taken to sample sufficiently far from the influent point to allow the waters to mix. Surface water sampling, although sometimes laborious and time-consuming, is usually relatively inexpensive. The accuracy of the results depends primarily on the accuracy of the laboratory performing the analyses, provided the samples are properly obtained and preserved.

Groundwater samples must be obtained from the sub-surface. In some locations it may be possible to utilize existing wells (industrial wells, city water supplies, or household wells), but this is not often the case. In most locations it is necessary to drill into the aquifer to obtain

groundwater samples, requiring a drill rig and the personnel to operate it. Because of this, groundwater sampling is often expensive and time-consuming. In addition, groundwater flow is sometimes difficult to predict, and a well can only sample one point. This sometimes results in obtaining samples that are not representative of actual groundwater conditions.

Groundwater monitoring can take the form of obtaining samples for laboratory analysis or monitoring the properties of the groundwater itself. Obtaining samples is performed similarly to obtaining surface water samples except that it is also necessary to purge water from the well prior to obtaining the sample to ensure the water sample is representative of the actual groundwater. Other testing that can be done includes installing piezometers to measure water level and flow direction, measuring chemical parameters such as Eh, pH, or conductivity in-situ, or testing aquifer properties to help design aquifer treatment systems.

12.4 Monitoring Other Environmental Media

Other environmental media which are often monitored include soils, sediments, and biota (plants, animals, and foods). These samples are typically obtained in the field (or sometimes at the supermarket) and are sent to the laboratory for analysis.

Sediments refers to sediments at the bottom of water bodies. They may be difficult to obtain, depending on the depth of the water body or, in the case of rivers and streams, the current. Because of the ion exchange properties of the clay minerals sediments often provide a sensitive record of environmental releases for many years. In addition, particulates will often settle out at the same locations that collect silt or mud, providing information regarding the release of small (micron-sized or smaller) particle releases that may not be easily filterable. Soils are similar to sediments except for their location above water.

Biota sampling may include obtaining specimens of local plants or animals downwind or downstream of a facility. Most biota sampling includes fish, insects, and plants, although in some areas rodents or deer are also killed for analysis. Biota sampling typically avoids sampling rare or endangered species or dangerous species (for example, there are few, if any, studies performed on bears, probably due to a lack of volunteers wiling to obtain samples). Biota sampling can also include obtaining samples of an animal's hair/fur or excrement for analysis as these often reflect dietary contaminants. Biota sampling is often laborious and may be time-consuming, but is usually less expensive than obtaining groundwater samples. Samples are usually refrigerated and sent to the laboratory for analysis. Live samples must be killed prior to analysis.

Another form of biota sampling consists of sampling crops or other foodstuffs (such as meat or milk) that may be contaminated. This is often performed in the fields with subsidiary sampling at supermarkets, butcher shops, or other food outlets to ensure completeness. While less laborious than obtaining many other samples, sampling food is arguably of primary importance because most foods are destined for human consumption. As with other samples, food samples are usually refrigerated and sent to a laboratory for analysis.

13. RISK

Webster's dictionary defines risk as "the chance of injury, damage, or loss; a dangerous chance; a hazard". The chance of incurring risk can often be quantified and is usually shown as a probability of death resulting from an action or activity. The field of risk management seeks to minimize risk to personnel who are often engaged in complex activities with several sources of risk.

13.1 Sources of Risk

Virtually all activities have some risk associated with them. The most common activities, such as driving, showering, taking the stairs, and going to work all carry with them the risk of injury or death. Any activity can result in a quantifiable risk because any activity can result in injury or death.

Most risks that are studied are those resulting from toxins, from carcinogens or those from workplace activities. Toxins include pesticides, chemicals, and often radioactivity. Workplace activities include falls, slips, electrocution, being crushed, and so forth. It is interesting to note that many toxin and workplace hazards also exist at home.

13.2 Quantifying Risk

The following table summarizes the risk from a variety of activities, including exposure to radiation. Please note that two ways to quantify risk are shown: the probability of death from an activity and loss of life expectancy. A risk of 10^{-4} means that one person in 10,000 will die from exposure to that activity. A risk that results in a Loss of Life Expectancy (LLE) of 20 days means that over an average lifespan an average person will die 20 days sooner from exposure to that risk than if they had never encountered it. If we assume a lifespan of 70 years, a risk of 10^{-4} will result in an LLE of 2.56 days.

13.3 Risk Reduction and Mitigation

Some risks can be reduced. Risk reduction may be accomplished by education, engineering controls, administrative controls, and a variety of other methods. However, when trying to reduce risk, it is very important to look at total risk to the population, not just at the risk to a small segment of the population. For example, we can virtually eliminate the risk of dying from heart attack by removing everyone's heart at age 18. This does not, however, reduce overall risk to society. Similarly, eliminating a small risk to a neighborhood by remediating a mildly contaminated site by excavation and disposal in another state may slightly reduce risk in that neighborhood from the site, but at the expense of increasing overall risk because of the risks of excavation, construction, and transportation.

Also important is the cost of risk reduction. Published reports indicate that there is a range of over 10 orders of magnitude (10^{10}) in the cost per year of life saved due to a variety of risk-reduction measures. Choosing to mitigate one risk at great expense may take money from other, more cost-effective risk reduction measures that could be more beneficial to society.

Activity	**Loss of Life Expectancy (days)**	**Risk Factor (x 10^{-5})**
Peanut butter ingestion (1 tbsp/day)	1	0.091
Milk ingestion (1 pint/day)	0.9	0.082
Chlorinated water use	0.5	0.045
Broiled meat ingestion (2 lb/wk)	3 hrs	0.011
Alcohol abuse (risk to drinker)	10.8-15.5 yrs	358-514
Alcohol abuse (risk to society members)	0.3-1.0 yrs	9.95-33.2
Snowmobiling	2	0.18
Hang gliding	25	2.27
Skydiving	25	2.27
Tornadoes	0.88	.080
Weather-related traffic accidents	2.03	0.18
Lightning	0.6	.055
Continuous exposure to 100 mrem/yr	9.9	0.90
Single exposure to 1 rem	1.5	0.14
Continuous exposure to 1 rem/yr	51	4.64
Work (averaged over all occupations)	60	5.45
Agriculture	320	29.1
Government	60	5.45
Transportation, utility	160	14.5
Manufacturing	40	3.64
Motor vehicle accidents	366	33.3
Electrocution	4.5	0.41
Animal injury	0.6	0.045
Falls	28	2.55
Firearms	6.5	0.59
Falling objects	6.5	0.59
Cancer (all types)	1247	113
Diabetes	82	7.45
Nutrition deficiency	3.5	0.32
Liver diseases	81	7.36
Homicide	93	8.45
Heart Disease	1607	146
Nephritis	41	3.73

All risk statistics are taken from "Catalog of risks extended and updated" by Bernard L. Cohen, published in Health Physics vol. 61, No. 3, pp. 317-335 (1991) and included references.

13.4 Information on Risk from Various Sources

Risk statistics are available for a wide variety of activities or exposure to many dangerous agents. Some of these statistics are summarized in the preceding table. Others have been compiled by governmental agencies such as OSHA or the EPA. Actuarial information is maintained by insurance agencies for their work, although a great deal of this information is proprietary. There are also a number of journals devoted to risk assessment and risk reduction; these journals carry information about risks and the costs of mitigating them.

14. CONCLUSIONS

There is some risk associated with radiation and contamination. The magnitude of this risk, so long as exposure is kept within that required by law, is very small. It has been proven that high doses of radiation can increase the incidence of cancer. It has also been proven that cigarettes can cause cancer, and at a much higher incidence rate than exposure to low levels of radiation. At various times potato chips, beer, and chlorinated drinking water have also been linked with cancer, as have birth-control pills, exposure to gasoline fumes or used motor oil, bacon, hot dogs, and the air of Los Angeles. The latter are all deemed to be acceptable risks for a variety of reasons; we like the taste of hot dogs, we like the nightlife in LA, we have to drive, or we choose to smoke.

You will undoubtedly run into situations that are not familiar. Unfortunately, common sense only works when it has a large amount of background knowledge to draw upon (Is it common sense for a five-year-old child to check the car's blind spots before changing lanes? It is for any experienced driver who wishes to avoid an accident.) When this happens, do not be afraid to call someone for assistance. With something that is potentially hazardous, worrying about asking questions should not be a concern. The primary concern should be minimizing the risk to yourself. Better to ask for help than to risk causing a spill or skin contamination incident,

When these questions do arise there are several sources that you can use. The most knowledgeable source is likely to be the Radiation Safety staff. Another source of information is the New York Department of Health, Bureau of Environmental Radiation Protection.

There is a risk from radiation, but the amount of risk posed by exposure to low levels of radiation on a daily basis is not known. There could be a slight risk, no risk, or even some beneficial effects. As long as you treat radiation with the proper respect it deserves, which consists of ensuring that you follow good health physics practices, ask for help when you are out of your depth, and adhere to the federal dose limits, the risk is low compared with other risks that we encounter daily.

APPENDIX A: ADDITIONAL READING

PLEASE NOTE: This is not meant to be a comprehensive or definitive list. This is a list of books that were used in the preparation of this guide or that have proven themselves helpful or informative over the years. There are many others. In addition, there is an exceptionally complete World Wide Web site, the Radiation Protection Home Page, maintained by the University of Michigan. The URL of this and other valuable sites are:

U of M Radiation Safety Home Page http://www.umich.edu/~radinfo/
The Oklo natural nuclear reactor http://www.physics.isu.edu/radinf/natural.htm
http://www.ocrwm.doe.gov/factsheets/doeymp0010.shtml
National Council on Radiation Protection http://www.ncrp.com/
Effects of low-dose radiation exposure http://www.angelfire.com/mo/radioadaptive/
Radiation Effects Research Foundation http://www.rerf.or.jp
(joint US-Japanese foundation studying atomic bombing survivors and their health)
Chart of the Nuclides http://www.nndc.bnl.gov/chart/
Nuclear Regulatory Commission Home Page http://www.nrc.gov/
Radioactive decay calculator http://www.radprocalculator.com/Decay.aspx
Bq to Curie calculator:
http://www.translatorscafe.com/cafe/units-converter/radiation-activity/calculator/becquerel-%5BBq%5D-to-curie-%5BCi%5D/

Radioactivity and Health: A History J. Newell Stannard 1988, Battelle Press ,

The Health Physics and Radiological Health Handbook, Bernard Schleien (ed.), Scinta Press, (1998)

A Guidebook to Nuclear Reactors, A. V. Nero 1979 University of California Press

New York Code of Rules and Regulations (NYCRR), Part 16

Introduction to Health Physics, Herman Cember, Pergammon Press (1998)

The Biological Basis of Radiation Protection Practice, Mills, Mossman (eds) Williams and Wilkins (1992)

Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V), National Academy of Sciences (1990)

Source and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (1993/1994)

Radiation Damage in DNA, Fuciarelli & Zimbrick (eds.), Battelle Press (1995)

Handbook of Radiobiology**,** Prasad, CRC Press in Boca Raton, Florida

APPENDIX B: PHYSICAL INFORMATION FOR SELECTED RADIONUCLIDES

Nuclide	half-life	Decay/emission (energy)+	Γ^* (R/hr)/Ci	μ/ρ (soil)	formation method	use
^{3}H	12.27 y	β- (18 KeV)	N/A	N/A for β	n capture, cosmogenic	research
^{14}C	5715 y	β- (156 KeV)	N/A	N/A	cosmogenic	research
^{16}N	7.1 sec	γ (6.13 MeV)	1.47	0.027	n capture	none
^{24}Na	15 hrs	β (1.39 MeV) γ (1.3, 2.8 MeV)	1.94	0.0365	n capture	in vivo n dosimetry
^{40}K	1.28x10^{9} y	β-(1.31 MeV) γ (1.46 MeV)	0.0817	0.052	primordial NORM	geologic dating
^{60}Co	5.27 y	2γ (1.17,1.33 MeV)	1.37	0.055	n capture	radiation therapy
^{90}Sr	28.6 yrs	β-(546 KeV) γ (480 KeV)	0.487	0.087	fission fragment	instrument check source
^{99m}Tc	6.0 hrs	γ (141 KeV)	0.123	0.14	^{99}Mo decay (fiss. Frag.)	medical
^{131}I	8.0 d	β-(606 KeV) γ (364 KeV)	0.283	0.83	fission fragment	thyroid treatments
^{137}Cs	30.17 yrs	β- (512 KeV) γ (662 KeV)	0.382	0.082	fission fragment	soil density gages
^{208}Tl	3.05 min	β (1.79 MeV) γ (2.6 MeV)	1.70	0.0407	^{232}Th decay series	none
^{222}Rn	3.8 days	α(5.49 MeV) γ (512 KeV)	2.73x10^{-4}	0.087	^{238}U decay series	patent medicines
^{226}Ra	1600 yrs	α(4.78 MeV) γ (186 KeV)	0.0121	0.13	^{238}U decay series	luminous products
^{232}Th	1.4x10^{10} yrs	α(4.01 MeV) γ (12 KeV)	0.0684	15	primordial NORM	gas lantern mantles
^{235}U	7.04x10^{8} yrs	α(4.40 MeV) γ (186 KeV)	0.339	0.13	primordial NORM	nuclear reactor fuel,
^{238}U	4.47x10^{9} yrs	α(4.20 MeV) γ (13 KeV)	0.0652	13	primordial NORM	military uses (armor, shells)
^{238}Pu	87.8 yrs	α(5.50 MeV) γ (13.6 KeV)	0.0790	12	n capture	pacemakers, RTGs
^{239}Pu	24,100 yrs	α(5.16 MeV) γ (13.6 KeV)	0.0301	12	n capture	nuclear weapons
^{241}Am	432.2 yrs	α(5.49 MeV) γ (13.9 KeV)	0.314	11	n capture	smoke detectors

+ - beta energies given are maximum decay energy, alpha and gamma energies are for the most probable decay energy

* - given gamma constant reflects radiation dose in air as distance of one meter

APPENDIX C: USEFUL EQUATIONS

The Law of Radioactive Decay

$$N_t = N_o \times e^{-\lambda t}$$

Where N_o and N_t are the number of atoms of a radioactive isotope originally and at any given time (t)

λ is the isotope's decay constant and is equal to the natural logarithm of 2 divided by the half-life of the isotope

t is the elapsed time between the two measurements.

The Law of Radioactivity

$$A = \lambda N$$

This can be combined with the Law of Radioactive Decay to produce the following:

$$A_t = A_o \times e^{-\lambda t}$$

Radiation attenuation due to shielding

$$I_{sh} = I_o \times e^{-(\mu/\rho)(\rho)x}$$

Radiation dose from a point source

$$D_2 = D_1 \times \frac{r_2^2}{r_1^2}$$

Where D_1 and D_2 are the radiation dose at distances r_1 and r_2, respectively.

Radiation dose from a line source

$$D_2 = \frac{D_1}{r_1} \times \left(\tan^{-1} \frac{L_1}{r} + \tan^{-1} \frac{L_2}{r} \right)$$

Where L_1 and L_2 are the distance from both ends of the line source to a perpendicular line extending to the measuring location.

Radiation dose from a disk (or plane) source

$$D_2 = D_1 \times \ln\left(\frac{h^2 + r^2}{h^2}\right)$$

Where r is the radius of the disk and h is the distance from the center of the disk.

For an irregularly-shaped area an effective radius is calculated by determining the area of the source, dividing by three, and calculating the square root.

Radiation dose in air from radioactive material

$$D = \frac{A\Gamma}{r}$$

Where A is the source activity in Bq and D is the dose rate in mSv/hr

APPENDIX D: DOSE CONVERSION FACTORS AND RISK FACTORS FOR SELECTED RADIONUCLIDES

Nuclide	Ingestion Dose Conversion Factor* (mrem/μCi)	Inhalation Dose Conversion Factor+ (mrem/μCi)	Risk Factor (μCi^{-1})
^{3}H	0.064 (whole body**)	0.064 (whole body)	3.84×10^{-8}
^{14}C	2.09 (whole body)	2.09 (whole body)	1.25×10^{-6}
^{60}Co	26.2 (lower large intestinal wall)	208 (lung)	1.57×10^{-5}
^{131}I	88.5 (thyroid)	54.5 (thyroid)	1.43×10^{-5}
^{40}K	18.6 (stomach wall)	12.3 (lungs)	7.46×10^{-6}
^{90}Sr	115 (bone surface)	1300 (lungs)	9.13×10^{-4}
^{99m}Tc	7.41×10^{-2} (thyroid)	3.02×10^{-2} (lungs)	1.98×10^{-8}
^{137}Cs	49.8 (whole body)	31.7 (whole body)	1.91×10^{-5}
^{226}Ra	831 (bone surface)	8020 (lungs, bone surface)	5.50×10^{-3}
^{232}Th	1370 (bone surface, red marrow)	7.83×10^{5} (lungs, red marrow)	6.32×10^{-4}
^{235}U	101 (bone surface, kidneys)	1.23×10^{5} (lungs)	5.43×10^{-5}
^{238}U	95.5 (bone surface, kidneys)	1.18×10^{5} (lungs)	5.07×10^{-5}
^{238}Pu	1890 (liver, bone surface)	2.28×10^{5} (lungs, bone, liver)	8.02×10^{-4}
^{239}Pu	2080 (bone surface, liver)	2.40×10^{5} (lungs, bone, liver)	8.85×10^{-4}
^{241}Am	2140 (liver, bone surface)	2.62×10^{5} (liver, bone, gonads)	9.12×10^{-4}

***** This assumes maximum transfer fraction from gastro-intestinal tract to blood

+ This assumes lung residence time of years (most conservative estimate)

****** The organ(s) named are the critical organs (the organs receiving the highest dose) The dose conversion factor given is the dose to the whole body from nuclide uptake

APPENDIX E: INFORMATION AND GOOD HANDLING PRACTICES FOR SPECIFIC ISOTOPES

Isotope:	**Tritium (H-3)**
Decay mode and energy:	beta, 0.018 MeV (18 KeV) max energy 0.006 MeV (6 KeV) ave. energy
Maximum range in air:	6 mm (0.25 inches)
Maximum range in tissue:	6 microns
Radiotoxicity classification:	low
Physical half-life:	12.27 years
Effective Biological half-life:	10 days (for elemental form of isotope)
Critical organ:	whole body (for elemental form of isotope)
Personnel monitoring:	urinalysis (radiation will not activate dosimetry)
Shielding:	none required
Survey instrument:	Liquid scintillation counter (LSC)
Allowable limit for intake:	80 μCi ($3x10^9$ Bq)

Special considerations:

1. Can only monitor for H-3 with smear wipes
2. Many compounds readily penetrate gloves and skin
3. Large quantities may generate bremsstrahlung x-rays
4. Tritiated DNA precursors are considered more toxic than tritiated water but are less volatile and present a similar hazard

Isotope:	**Carbon-14 (C-14)**
Decay mode and energy:	beta, 0.156 MeV (156 KeV) maximum energy 0.052 MeV (52 KeV) average energy
Maximum range in air:	9 inches (24 cm)
Maximum range in tissue:	0.32 mm
Radiotoxicity classification:	medium-low
Physical half-life:	5715 years
Effective Biological half-life:	12 days (for elemental form of isotope)
Critical organ:	whole body, body fat (for elemental form of isotope)
Personnel monitoring:	urine bioassay (radiation will not activate dosimetry)
Shielding:	3 mm Plexiglas (1 cm required for rigidity)
Survey instruments:	G-M “pancake” detector Liquid Scintillation Counter (Preferred)
Allowable limit for intake:	2 Ci ($7x10^{10}$ Bq) as inhaled CO 200 mCi ($7x10^{9}$ Bq) as inhaled CO_2

Special considerations:

1. Detection of C-14 by handheld instruments requires care because of low detection efficiency of most instruments
2. Some C-14 labeled compounds may penetrate skin and gloves
3. Take special caution when handling C-14 labeled halogenated acids

Isotope:	**P-32**
Decay mode and energy:	beta 1.71 MeV maximum energy 0.570 MeV (570 KeV) average energy
Maximum range in air:	6 meters (19 feet)
Maximum range in tissue:	8 mm
Radiotoxicity classification:	medium-low
Physical half-life:	14.29 days
Effective Biological half-life:	10-14 days (depending on chemical form)
Critical organ:	bone, lungs, intestine (for elemental form of isotope)
Personnel monitoring:	dosimetry badge, urinalysis (in case of uptake)
Shielding:	0.5 inches of Plexiglas
Allowable limit for intake:	4 mCi (10^7 Bq) by ingestion or inhalation

Special considerations:

1. P-32 beta particles have sufficient energy to penetrate gloves and skin
2. Contamination is easily detected with G-M “pancake” detector
3. When handling mCi quantities of P-32, avoid standing directly over open container to reduce radiation dose
4. Avoid glove or skin contamination or survey hands frequently and change gloves immediately if contamination is detected
5. May receive high local dose (10 rads in 15 minutes or less) from 1 microCurie of skin contamination
6. Safety glasses provide eye protection from high-energy beta particles
7. Can produce relatively high levels of bremsstrahlung radiation if shielded with lead

Isotope:	**P-33**
Decay mode and energy:	beta 0.248 MeV (248 KeV) maximum energy 0.083 MeV (83 KeV) average energy
Maximum range in air:	1.6 feet (0.5 meters)
Maximum range in tissue:	1 mm
Radiotoxicity classification:	medium-low
Physical half-life:	24.4 days
Effective Biological half-life:	10-14 days (for elemental form of isotope)
Critical organ:	bone, lungs, intestine (for elemental form of isotope)
Personnel monitoring:	dosimetry badge or urinalysis (in case of uptake)
Shielding:	0.25 inches (0.3 cm) Plexiglas
Survey instrument:	G-M “pancake” detector, liquid scintillation counting
Allowable limit for intake:	3 mCi (10^8 Bq) by inhalation 6 mCi ($2x10^8$ Bq) by ingestion

Special considerations:

1. Detection of P-33 by direct survey (frisk) requires care because of low detection efficiency. Use of a liquid scintillation counter (LSC) is preferred.

Isotope:	**S-35**
Decay mode and energy:	beta 0.167 MeV (167 KeV) maximum energy 0.056 MeV (56 KeV) average energy
Maximum range in air:	10 inches (24 cm)
Maximum range in tissue:	0.32 mm
Radiotoxicity classification:	medium-low
Physical half-life:	89.4 days
Effective Biological half-life:	77 days (for elemental form of isotope)
Critical organ:	whole body, testis (for elemental form of isotope)
Personnel monitoring:	urinalysis (low energy will not activate dosimeter)
Shielding:	3 mm Plexiglas (1 cm required for rigidity)
Survey instrument:	G-M “pancake” detector, liquid scintillation counter
Allowable limit for intake:	10 mCi ($4x10^8$ Bq) inorganic compounds 5 mCi ($2x10^8$ Bq) elemental sulphur

Special considerations:

1. Detection of S-35 using hand-held instruments requires care because of the low beta energy. Use of a liquid scintillation counter is preferred.
2. Volatile. Use in hood. Avoid inhalation.

Isotope:	**Cl-36**
Decay mode and energy:	beta 0.71 MeV (710 KeV) maximum energy 0.233 MeV (233 KeV) average energy
Maximum range in air:	7 feet (2 meters)
Maximum range in tissue:	2.6 mm
Radiotoxicity classification:	high-medium
Physical half-life:	300,000 years
Effective Biological half-life:	10-29 days (depending on chemical form)
Critical organ:	Whole body for transportable compounds Lung for inhalation Lower large intestine if ingested (for elemental form of isotope)
Personnel monitoring:	dosimetry badge and urinalysis (for uptake)
Shielding:	0.25 inches (0.6 cm) Plexiglas
Survey instruments:	G-M “pancake” probe, liquid scintillation counter
Allowable limit for intake:	0.2 mCi (10^6 Bq) inhalation 2 mCi (10^7Bq) ingestion

Special considerations:

1. Cl-36 beta particles have sufficient energy to penetrate cloves and skin
2. Contamination is easily detected with G-M “pancake” detector
3. When handling mCi quantities of Cl-36, avoid standing directly over open container to reduce radiation dose
4. Avoid glove or skin contamination or survey hands frequently and change gloves immediately if contamination is detected
5. May receive high local dose (10 rads in 20 minutes or less) from 1 microCurie of skin contamination
6. Safety glasses provide eye protection from high-energy beta particles
7. Can produce relatively high levels of bremsstrahlung radiation if shielded with lead

Isotope:	**Ca-45**
Decay mode and energy:	beta 0.257 MeV (257 KeV) maximum energy 0.075 MeV (75 KeV) average energy
Maximum range in air:	20 inches (52 cm)
Maximum range in tissue:	0.62 mm
Radiotoxicity classification:	high
Physical half-life:	163 days
Effective Biological half-life:	163 days (for elemental form of isotope)
Critical organ:	bone (for elemental form of isotope)
Personnel monitoring:	urinalysis
Shielding:	3 mm Plexiglas (1 cm required for rigidity)
Survey instruments:	G-M “pancake” detector, LSC
Allowable limit for intake:	8 mCi ($3x10^7$ Bq) inhalation 2 mCi (10^7 Bq) ingestion

Special considerations:

1. Detection of Ca-45 using a G-M pancake detector is difficult due to low beta energy. Use of liquid scintillation counter (LSC) is preferred

Isotope:	**Cr-51**
Decay mode and energy:	electron capture gamma, x-ray, Auger electron Gamma 0.32 MeV (320 KeV) 9.8% X-ray 0.005 MeV (5 KeV) 22% Auger electron 0.004 MeV (4 KeV) 66.9%
Maximum range in air:	gamma, x-ray not applicable to photons Auger electron 5 mm
Maximum range in tissue:	gamma, x-ray whole body Auger electron 5 microns
Radiotoxicity classification:	medium-low
Physical half-life:	27.7 days
Effective Biological half-life:	27 days (for elemental form of isotope)
Critical organ:	lower large intestine, lungs (for elemental form)
Personnel monitoring:	dosimetry badge, urinalysis
Shielding:	3.2 mm of lead will reduce dose by ½
Survey instruments:	1”x1” sodium iodide scintillation detector
Allowable limit for intake:	20 mCi ($7x10^8$ Bq) inhalation or ingestion

Special considerations:

1. Use thin window G-M, 1”x1” NaI solid scintillator, or liquid scintillation counter for detection

Isotope:	**I-125**
Decay mode and energy:	Electron capture with gamma and x-ray emission Gamma 0.035 MeV (35 KeV) 6.5% X-ray 0.027 MeV (27 KeV) 112.5% X-ray 0.031 MeV (31 KeV) 25.4%
Maximum range in air:	Not applicable to photons
Maximum range in tissue:	Whole body
Radiotoxicity classification:	medium-high
Physical half-life:	60.1 days
Effective Biological half-life:	42 days (for elemental form of isotope)
Critical organ:	thyroid (for elemental form of isotope)
Personnel monitoring:	radiation dosimetry, thyroid bioassay
Shielding:	0.25 mm lead will reduce radiation dose by ½
Survey instruments:	thin crystal (1”x1mm) sodium iodide scintillation detector
Allowable limit for intake:	0.06 mCi ($2x10^6$ Bq) inhalation 0.04 mCi (10^6 Bq) ingestion

Special considerations:

1. Volatilization of NaI or elemental Iodine can be a significant source of exposure. Accordingly, iodinations may only be performed in a fume hood.
2. Iodinations of more than 1 mCi must be performed in a fume hood with filtered exhaust
3. Simply opening a stock vial of iodinated compound can cause aerosol-sized droplets to become airborne
4. I-125 is NOT detectable with a G-M detector
5. Solutions containing iodide ions should not be made acidic
6. Solutions containing iodide ions should not be frozen in storage
7. Wear two pairs of gloves or polyethylene gloves over rubber because some iodine compounds can penetrate surgical rubber gloves
8. All personnel using more than 1 mCi of I-125 at a time MUST report to Radiation Safety between 24 and 72 hours of use for a thyroid bioassay

Isotope:	**I-131**	
Decay mode and energy:	Beta	0.606 MeV (606 KeV) maximum energy 0.248 MeV (248 KeV) average energy
	Gamma	0.364 MeV, 0.637 MeV, 0.284 MeV
Maximum range in air:	Beta	6 feet (1.8 meters)
	Gamma	Not applicable for photons
Maximum range in tissue:	Beta	3 mm
	Gamma	whole body
Radiotoxicity classification:	medium-high	
Physical half-life:	8.04 days	
Effective Biological half-life:	7.6 days (for elemental form of isotope)	
Critical organ:	thyroid (for elemental form of isotope)	
Personnel monitoring:	radiation dosimetry, thyroid bioassay	
Shielding:	2.3 mm lead will reduce gamma radiation dose by ½ 0.25 inches (0.6 cm) Plexiglas will attenuate betas	
Survey instruments:	G-M “pancake” detector, 1”x1” NaI scintillation probe, liquid scintillation counter	
Allowable limit for intake:	0.05 mCi ($2x10^6$ Bq) inhalation 0.03 mCi (10^6 Bq) ingestion	

Special considerations:

1. Volatilization of NaI or elemental Iodine can be a significant source of exposure. Accordingly, iodinations may only be performed in a fume hood.
2. Iodinations of more than 1 mCi must be performed in a fume hood with filtered exhaust
3. Simply opening a stock vial of iodinated compound can cause aerosol-sized droplets to become airborne
4. Solutions containing iodide ions should not be made acidic
5. Solutions containing iodide ions should not be frozen in storage
6. Wear two pairs of gloves or polyethylene gloves over rubber because some iodine compounds can penetrate surgical rubber gloves
7. All personnel using more than 1 mCi of I-131 at a time MUST report to Radiation Safety between 24 and 72 hours of use for a thyroid bioassay

APPENDIX F: EXAMPLES OF PROPERLY COMPLETED ADMINISTRATIVE FORMS

The following pages contain examples of how commonly used forms should be filled out. These forms may be changed at any time at the discretion of the Radiation Safety Department. PI's are responsible for using the most updated version. Forms can be located on our waterfall outside our office or through our web site.

Forms included are:

- Application For Authorization To Use Radioactive Materials (Non-human use)
- Amendment Form
    - Changes to Authorized Isotopes, Activity Limits, or Rooms Authorized For Radioactivity.
    - PI is Leaving the University or Terminating Permit
- Requisition Form – New Form
- Requisition Form – Old Form
- Isotope Use Record
- Waste Sheet

14.1 Application For Authorization To Use Radioactive Materials (Non-human use)

PART A APPLICATION FOR AUTHORIZATION TO USE RADIOACTIVE MATERIALS (NON-HUMAN USE)

1. **Principal Investigator:** Eigor Brown
2. **Date:** 12 / 2 / 03
3. **Department:** Center for Cardiovascular RESE
4. **Office Extension:** x52974
5. **Lab Extension:** -
6. **E-mail Address:** eigor_brown@urmc.rochester.edu
7. **SS#:** 092 - 59 - 5793
8. **Date of Birth:** 10 / 12 / 63
9. **Room(s) where isotopes are used /stored** MRBX 2-11305 10. **Intramural Box** 679

Radionuclide	Source Limit (per stock vial)	Activity Limit (Maximum possession amount)	Physical and Chemical Form
P-32	0.25 mCi	2 mCi	liquid

(Requisition of the above isotope(s) must be placed under the Principal Investigators name).

10. **PERSONNEL** (***Please attach to this form a completed RADIATION WORKER INFOMATION FORM (5C) for each radiation worker and for the PI): Do you or your lab staff require dosimetry?***_____

11. **FACILITIES**: ***please provide a layout of the laboratory spaces to include the following information***:
    a. *Area(s) where radioisotope is used*
    b. *Area(s) where radioisotope is stored*
    c. *Show any shielding, hoods, or other safety features that are applicable*
    d. *Show location of waste containers*

Note: Liquid containers require secondary containment

12. **CONTAMINATION / RADIATION MONITORING EQUIPEMENT**
    List all contamination and radiation detection equipment below indicate departmental/shared equipment

INSTRUMENT MANUFACTURER	INSTRUMENT MODEL AND SERIAL NUMBERS	TYPE OF PROBE MODEL AND SERIAL NUMBERS	INSTRUMENT CALIBRATION DATES
Ludlum	Model 3 / 84496	44-9 / 143579	6/20/03

LIST ANY EXTERNAL/INTERNAL STANDARDS USED WITH L.S.C. LIST ISOTOPE, ACTIVITY, ASSAY DATES

13. **HOODS** (Note: A hood is not necessarily required for all types of radioactive material usage)
    a. are radioactive materials used in a hood? no b. Stored in hood? no
    c. Indicate the date of the last flow test was performed and the fpm reading_____/_____/____ f.p.m._____

(***Note: The Principal Investigator is responsible for strict inventory control of all Radioactive compounds. If the applicant wishes to delegate this responsibility, please indicate responsible Authorized User***

_____

I have read the Radiation Safety Manual and agree to follow All University and State regulations.

Principal Investigators Signature _____**Dated** ____/____/____

Approval_____ **Dated** ____/____/___ **Approval** _____**Dated** ___/_____/____

Radiation Safety Officer Chair, Radiation Safety Committee

NEW PRINCIPAL INVESTIGATORS MUST ALSO SUMIT A CIRRICULUM VITAE

FORM 5A COMPLETED_____ FORM 5B COMPLETED FOR EACH EXPERIMENT____C.V.ATTACHED_____
RAD WORKER INFO SHEET FOR ALL APPLICABLE STAFF_____DIAGRAM OF LAB SPACE____

PART B PROCEDURE SUMMARY FORM

1. **Principal Investigator** Eigor Brown 2. **Date** 12/2/03

3. **Department** Center for Cardiovascular RESE 4. **Lab. #** MRBX 2-11305

5. **Radionuclide(s)** P-32 5a. **Intramural Box** 679

6. If this part is not accompanied by Part A, supply the following:
   (a) Maximum possession amount**:** _____ mCi (b) Physical and Chemical Form:_____

7. **USE IN ANIMALS**

   (a) Species of animals: N/A (b) Where housed: N/A
   (c) Number of animals per day, week, or month: N/A
   (d) Max. injection dose in uCi per animal: N/A (e) Biological half -life: N/A
   (f) Special animal handling procedures to be used: N/A

8. **IN VITRO OR OTHER USE**

   (a) Unit of use (test tube, culture, etc.) 1μCi / tube (PCR), 50μCi / tube (probe labeling)
   (b) Number of above units per day, week, or month: Up to 20 μCi /day (PCR), 200 μCi/week (probe)
   (c) Maximum concentration in microcuries/unit: 10 μCi/μl (α-dctp), diluted 10fold in probe labeling
   500fold in PCR

9. **HUMAN USE:** (Approval of Human Use Committee is required)

   (a) Number of patients per month: N/A
   (b) Maximum injection dose in microcuries/patient N/A

10. Describe procedures used in the experiment (brief protocol, purpose, counting method, and any special isotope handling or storage procedures):

11. **RADIOACTIVE WASTE MATERIAL ESTIMATE:** Describe and estimate the amount of waste that will generated from the use described above.:

   (a) Non-burnable solid: 0 cu./ft./month
   (b) Burnable solid: 12 cu./ft./month
   (c) Animal carcasses: 0 number month _____microcuries/carcass
   (d) Tissue (describe): None
   (e) Liquid: 5 gal/month 100 % water 0 % flammable
   (f) Other (describe)_____

Principal Investigator's Signature _____ **Dated** ____/____/____

Approval_____ **Dated** ____/____/__
Radiation Safety Officer

14.2 Amendment Form – Changes to Authorized Isotopes, Activity Limits, or Rooms Authorized For Radioactivity.

AMEND FORM Application for Amendment to Radioactive Materials Permit

---

Principal Investigator: John Smith **Permit No.:** 287

Department: Center for Cardiovascular RESE **Date:** 7/15/2004

Box # 679 **Phone** 275-1579

Please include a Part B procedure summary form with your amendment application if the requested change is due to the addition of a radionuclide, increase in Source / Possession limits, or the expansion of an existing protocol.

ADDING A RADIONUCLIDE OR CHANGING ACTIVITY LIMITS (Please list only the radionuclides to be added or changed):

	Limit per stock vial	Total activity limit		
Radionuclide*	Current Source Limit	Current Possession Limit	Requested Source Limit	Requested Possession Limit
P-32	1 mCi	1mCi	2 mCi	5 mCi

*****New radionuclides (Hard Beta and Gamma) require survey meter. Please specify make, model, and type of detector probe below:

ADDING/DELETING ROOMS: If this change represents a significant change to your licensed facilities, or your work here will involve the use of radioactive material or volatile materials, please include a layout of the new area(s) which indicates work areas, hot sinks, fume hood, radioactive waste areas, and entrances.

Room Additions		Room Deletions	
Building	Room	Building	Room
MRBX	2-11579	MC	1-5987

INACTIVATING LICENSE: ____ **TERMINATING LICENSE OR DELETING ROOM**:_____

(COMPLETE checklist on reverse)

SUBMIT ALL ITEMS FOR LICENSE TERMINATION ALONG WITH A COPY OF YOUR FINAL SURVEY

SIGN AND DATE NUMBERS 2,3,4,& 6 AND ATTACH A COPY OF YOUR FINAL SURVEY FOR ALL ROOM DELETIONS.

Principal Investigator's Signature _____**Dated** ____/____/___

Approval_____**Dated**_____/____/_____
Radiation Safety Officer

Principal Investigators Responsibilities Prior To Terminating Radioactive Materials Permit Or Deleting a Room From Permit –Complete all that apply

1. **Cancel dosimetry badges with radiation department secretary for applicable staff**
   Date Completed _____/_____/_____ Completed by_____
2. **All radioactive materials transferred to an authorized permit, or disposed via supplied waste containers and removed from your lab(s).**
   Date Completed _____/_____/_____ Completed by_____
3. **All radioactive material storage/work spaces and equipment used have been surveyed and documented.**
   Date Completed ___7___/__13____/__04_____ Completed by__Susan Green___
4. **All radioactive material labels need to be removed as applicable.**
   Date Completed _____/_____/_____ Completed by_____
5. **Radioactive material log book inventory reconciled prior to radiation safety inspection.**
   Date Completed _____/_____/_____ Completed by_____
6. **Forward this original completed form to the Radiation Safety office (keep a copy for your records)**
   Date Completed ___7__/___15___/__04_____ Completed by: Susan Green____

For questions regarding:

Dosimetry: Secretary 275-3781
Existing Permits: Technician 275-1477
Waste Disposal: Technician 275-1474
Final Billings: Program Administrator 275-3783

14.3 Amendment Form – PI is Leaving the University or Terminating Permit

AMEND FORM Application for Amendment to Radioactive Materials Permit

---

Principal Investigator: Jim Brown **Permit No.:** 246

Department: Center for Cardiovascular RESE **Date:** 5/15/2004

Box # 679 **Phone** 275-1832

Please include a Part B procedure summary form with your amendment application if the requested change is due to the addition of a radionuclide, increase in Possession /Annual limits, or the expansion of an existing protocol.

ADDING A RADIONUCLIDE OR CHANGING ACTIVITY LIMITS (Please address only the radionuclides to be added or changed):

Radionuclide*	Current Source Limit	Current Possession Limit	Requested Source Limit	Requested Possession Limit

*New radionuclides (Hard Beta and Gamma) require survey meter. Please specify make, model, and type of detector probe below:

ADDING/DELETING ROOMS ***(If this change represents a significant change to your licensed facilities, or your work here will involve the use of radioactive material or volatile materials, please include a layout of the new area(s) which indicates work areas, hot sinks, fume hood, radioactive waste areas, and entrances.)***

Room Additions		Room Deletions	
Building	Room	Building	Room
		MC	24132
		MC	2-4135

INACTIVATING LICENSE: ____ **TERMINATING LICENSE OR DELETING ROOM**:_____

(COMPLETE checklist on reverse)

SUBMIT ALL ITEMS FOR LICENSE TERMINATION ALONG WITH A COPY OF YOUR FINAL SURVEY

SIGN AND DATE NUMBERS 2,3,4,& 6 AND ATTACH A COPY OF YOUR FINAL SURVEY FOR ALL ROOM DELETIONS.

Principal Investigator's Signature _____**Dated** ____/____/___

Approval_____**Dated**_____/____/_____
Radiation Safety Officer

Principal Investigators Responsibilities Prior To Terminating Radioactive Materials Permit Or Deleting a Room From Permit – Complete all that apply

7. **Cancel dosimetry badges with radiation department secretary for applicable staff**
   Date completed ____/____/____ Completed by: _____

8. **All radioactive materials transferred to an authorized permit, or disposed via supplied waste containers and removed from your lab(s).**
   Date Completed 5 / 13 / 04 Completed by: Jane Smith

9. **All radioactive material storage/work spaces and equipment used have been surveyed and documented.**
   Date Completed 5 / 13 / 04 Completed by: Jane Smith

10. **All radioactive material labels need to be removed as applicable.**
    Date Completed 5 / 13 / 04 Completed by: Jane Smith

11. **Radioactive material log book inventory reconciled prior to radiation safety inspection.**
    Date Completed 5 / 13 / 04 Completed by: Jane Smith

12. **Forward this original completed form to the Radiation Safety office (keep a copy for your records)**
    Date Completed 5 / 15 / 04 Completed by: Jane Smith

For questions regarding:

Dosimetry: Secretary 275-3781
Existing Permits: Technician 275-1477
Waste Disposal: Technician 275-1474
Final Billings: Program Administrator 275-3783

14.4 Requisition Form – New Form

312 REQUISITION *FOR INTERNAL USE ONLY*
(see instructions on back)

Red captioned areas inside bold rules are REQUIRED FIELDS to be filled out.
THIS IS NOT A PURCHASE ORDER. Grey shaded areas are for Corporate Purchasing use. All commitments of funds must be made on official purchase orders.

PLEASE CHECK ONE BOX: ☒ UNIVERSITY OF ROCHESTER ☐ STRONG HEALTH HIGHLAND HOSPITAL

REQUISITION 999999 new form

SHIP TO DEPT:	**SHIP TO CODE:**	Suggested Supplier: List Supplier here	**SUPPLIER CODE:**
Address: Brown lab Room #: 1-6328 Box #: Bldg: MC		Order to Address:	
City: State: Zip:		City: ST: Zip:	
Attn: Phone: Fax:		Attn: Phone: Fax:	
PROJECT	**TYPE:** UC HC R B S MC	**RECEIVING NOTES**	**PO NOTES** / **STD. COMMENTS**

ESI ITEM #	SUPPLIER CATALOG #	QTY	UNIT OF MEASURE	DESCRIPTION (PLEASE ATTACH SUPPLIER QUOTE TO REQUISITION WHEN REFERENCING.)	UNIT COST	TOTAL	CATEGORY
	BLU513H	1	0.25mCi	α(P32) dCTP			
				PI Eigor Brown			

☐ Supplier Price Justification Form attached (orders > $10,000 or single source)
☐ Price verified with _____ ☐ Quotes attached - # of quotes _____

DESIRED DELIVERY DATE 7/29/04 **NOT-TO-EXCEED TOTAL** _____

Requested by: Contact Person Date: 7/28/04	Department Administrator/PI Signature: PI's Signature Date: 7/28/04		
Department: Phone: Your Phone #	Division Administration Signature: Date:		
Intramural Address: Box #: Your Box #	Senior Administrator Approval: Date:		New P.O. # _____
E-Mail Address:			Replaces P.O. # _____

REQUISITION 999999	Account Name Charged:	Account No.(s) 5 - 99999 - 9999 % 100	**CAPITAL EXPENDITURE** ☐ YES ☐ NO
	Account Name Credited:	Account No.(s) - - %	HIGHLAND HOSPITAL CODE
		- - %	

Rev. 2/04

ORIGINAL

14.5 Requisition Form – Old Form

312 REQUISITION (see instructions on back)

FOR INTERNAL USE ONLY

THIS IS NOT A PURCHASE ORDER. Shaded areas are for Purchasing Services use.
All commitments of funds must be made on official purchase orders.

PLEASE CHECK ONE BOX: ☒ UNIVERSITY OF ROCHESTER ☐ STRONG HEALTH HIGHLAND HOSPITAL

REQUISITION 999999

old form

SHIP TO DEPT: | **SHIP TO CODE:** | Suggested Vendor: List Vendor here | VENDOR CODE:

Address: Brown Lab | Rm/Box #: 1-6328 | Bldg: MC | Order to Address:

City: | State: | Zip: | City: | ST: | Zip:

Attn: | Phone: | Fax: | Attention: | Phone: | Fax:

MISC. | PROJECT | CATALOGS

ESI ITEM #	VENDOR CATALOG #	QTY	UNIT OF MEASURE	DESCRIPTION (PLEASE ATTACH VENDOR QUOTE TO REQUISITION WHEN REFERENCING.)	UNIT COST	TOTAL	PRODUCT CODE
	PLU513H	1	0.25mCi	α(P32) dCTP			
				PI Eigor Brown			

DESIRED DELIVERY DATE 7/29/04 **NOT-TO-EXCEED TOTAL** _____

Requested by: Contact Person | Date: 7/28/04 | Authorized Signature(s) (1) PI's Signature | Date: 7/28/04

Department: | Phone: Your Phone # | (2) | Date:

Intramural Address: | Box #: Your Box # | ORPA/SMH Approval | Date:

FAX: | E-Mail Address: | Principal Investigator | Date:

DEPT

New P.O. # _____

Replaces P.O. # _____

REQUISITION 999999

Account Name Charged: | Account No.(s) 5 - 99999 - 9999 % 100

Account Name Credited: | Account No.(s) - - %

CAPITAL EXPENDITURE ☐ YES ☐ NO

HIGHLAND HOSPITAL CODE

PURCHASING SERVICES Rev. 12/99

14.6 Isotope Use Record

Isotope Use Record

AU: AU Name **Isotope:** P-32 **Phys. Form:** Liquid **Act. (mCi):** 5.00E-01 **Source Number:** AU# - Sequential # - C

Description: neg513z-43995 **Half-Life (days):** 14.29 **Assay Date:** 8/31/2004 **Date Received:** 8/25/2004

Storage Location: MC 3-7533 **Use Location:** MC 3-7533 **Activity Recd. (mCi):** 6.69E-01

Date	Starting Activity (mCi)	Activity Sent to Waste (mCi)							Remaining Activity (mCi)	Initials
		Solid Waste	Aqueous Liquid	Organic Liquid	LS Vials	Biological/ Animal	Sharps	Other		
8/31/04	0.5	0.05	0.1						0.35	VG

Comments: The other column can be used to account for decay

14.7 Waste Sheet

Radioactive Waste Container Log

Date: 2 / 23 / 04

PI Name: XXXXXXXX **PI #:** YYYY **Bldg-Rm #:** MRB G-9804 **Lab Phone Number** 5-8796 **Contact Person** J.Smith **Page** 1 **Of** 1

Radionuclide(s) P-32,Cr-51 **Half-Life (hrs, days, yrs):** 14days / 27days **Waste Type: Solid / (Aqueous Liquid) / Organic Liquid**
Other: _____

Isotope	Source Number, from Isotope Use Record	Lot Number, From Isotope Use Record Description	Date of RAM waste to Container	Permit Number	Description of Waste List any secondary hazards associated with the description of waste	Activity Entered In mCi	Activity After Decay In mCi
Balance Brought Forward In mCi _____ **Date of last transaction** ___/___/___							
P-32	YYYY-00532-00		1/1/04		Liquid	0.25	0.0191
P-32	YYYY-00535-00		1/5/04		Liquid	0.125	0.0116
P-32	YYYY-00537-00		2/11/04		Liquid	250 µCi	140 µCi
Cr-51	YYYY-00538-00		2/18/04		Liquid	50 µCi	44.1 µCi

Date Container Disposed ___/___/___ **Total Decayed Activity** 0.2148 **mCi**

RSU Form 017
Created 6/24/04

Radiation Worker Training

University of Rochester
Radiation Safety Unit
MC Box HPH, Room G-8842
Office 275-3781
RSO 275-1473
http://extranet.urmc.rochester.edu/radiationSafety/

Training Topics

- Regulatory framework
- Scientific and technical basis for radiation safety
- Administrative issues
- Working safely with radioactivity

Regulatory Framework

- NRC is responsible for nationwide radiation regulation
- NY State has agreement with NRC to regulate radiation in-state
- U of R has broad-scope academic/medical license
  - This gives us a high degree of flexibility in how we run our program

This Training:

- Is required by state and federal laws
- Will last about 2 1/2 hours
- At the end is a take-home, open-book exam (passing grade is 70%)
- After this training and passing the exam, you will be able to work with radioactive materials

Radiation Safety Unit

- 6 Technical and 2 Administrative staff
- Responsible for the safe and legal use of radiation and radioactivity
- Provides radiological services to U of R

Scientific/Technical Basis

- Definitions
- Radiation properties
- Background sources of radiation
- Biological effects and risks

Radiation

- General - Transfer of energy from one point to another
- Ionizing Radiation transfers electron or atomic excitation energy by emission of high-energy photons, electrons, or other particles
- Average energy for ion pair formation in tissue is 33 eV

Definitions and Conversions

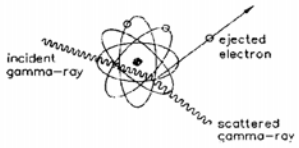
- 1 Curie (Ci) = 3.7×10^{10} dps
- 1 Ci = 2.22×10^{12} dpm
- 1 Bequerel (Bq) = 1 dps
- 1 Ci = 37 GBq
- 1 mCi = 37 MBq
- 250 μCi = 9.25 MBq
- 1 μCi = 37 kBq

Half Life

- Amount of time for ½ of the activity in radioactive material to decay

- C-14: 5715 years
- H-3: 12 years
- S-35: 87 days
- I-125: 59 days
- P-32: 14 days
- I-131: 8 days

Ionizing Radiation – Compton Effect



http://www.triumf.ca/safety/rpt/rpt_2/node19.html

Types of Radiation

	Mass	Charge	QF	Pen. Ability	Shield
Alpha (α)	4 amu	+2	20	<5 μm	None
Beta (β)	1/2000 amu	+/- 1	1	<1 cm	Plastic
Gamma (γ)	0	0	1	Whole body	Lead

Radiation Dose

- Measure of energy deposition by ionizing radiation
- rad = radiation absorbed dose
- 1 rad = 100 ergs/gm in any absorber
- 1 rad = 6.242×10^7 MeV/g
- 1 gray = 100 rad = 1 joule per kg
- rem = rad x QF
  - rem measures biological damage, **NOT** merely the amount of energy deposited
  - different radiations have different quality factors
- 1 sievert = 100 rem

Background Radiation (mrem/yr)

⌘Radon	200
⌘Rocks and soil	28
⌘Biochemistry	40
⌘Cosmic	27
⌘Medical	53
⌘Consumer products	10
⌘Other	2
⌘Total	360 mrem/yr

Dose Limits

⌘Rad workers	5000 mrem/yr
⌘Public	100 mrem/yr
⌘Lens of eye	15 rem/yr
⌘Any organ	50 rem/yr
⌘Extremities	50 rem/yr
⌘Pregnant workers (dose to fetus)	500 mrem/pregnancy 50 mrem/month

Note: 1 rem = 1,000 mrem

ALARA

⌘Maintain your dose
As **L**ow **A**s **R**easonably **A**chievable

⌘That is - dose limits are limits, not goals!

⌘Given the relatively low risk, extreme actions to reduce dose are not reasonable

To Minimize Dose:

⌘Minimize time spent working with RAM

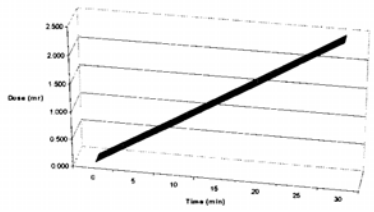
⌘Work at the greatest practical distance from RAM or waste containers

⌘Use shielding when necessary

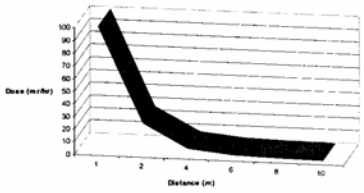
⌘Wear lab coat, gloves, long pants (no skirts or shorts) and no open-toe shoes

⌘No eating, drinking, or food storage in posted labs

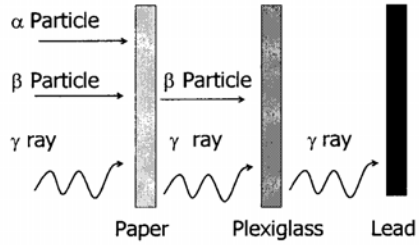
Dose vs Time



Dose vs Distance



Shielding



Bremsstrahlung

- Secondary radiation emitted when charged particles pass a heavy atom
- Bremsstrahlung emitted is proportional to the charge on the nucleus
- Using "light" materials will reduce, but not eliminate bremsstrahlung
- So - beta emitters should be shielded with **plastic, *not*** lead

Biological Effects Acute vs Chronic

- Acute health effects – Prompt radiation effects (Those that are observable within a short period of time) in which the severity of the effect varies with the dose. These are threshold based.
- Chronic Exposure – The absorption or intake of radioactive materials over a long period of time (i.e. over a lifetime). These effects are stochastic.

Biological Effects - Acute

~1 rad	chromosomal changes
25 rad	blood cell count changes
100 rad	radiation sickness
450 rad	LD_{50} (without treatment)
1000 rad	LD_{100}

- These refer to whole-body exposure

Sources of Acute Exposure

- Medical equipment - fluoroscopes, radiation therapy irradiators, medical accelerators
- X-ray diffraction equipment
- Research irradiators
- Laboratory for Laser Energetics
- All require added training and have safety devices installed

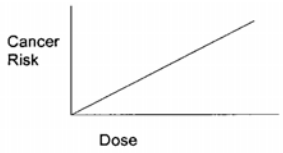
Chronic Exposure

- Greatest risk is chance of cancer probably caused by mutations in DNA
- With an exposure of 100-200 mrem/yr, risk is about the same as any other occupational hazard (NRC: 4×10^{-4} increased risk of death per 1 rem exposure)
- The shape of the dose-response curve at low levels of exposure is not known in detail

Linear, No-Threshold Dose Response Curve

- Forms basis for all regulations in the world
- Claims that all exposure to radiation is harmful
- Risk of getting cancer is directly proportional to dose
- Probably not scientifically accurate, but likely over-estimates risk (so actual risk is lower)

LNT model



Administrative Issues

- Radioactive Materials Permits
- Log Books
- Posted Labs
- Laboratory Inspections
- Inventory Control
- Radioactive Waste Management and Disposal

Radioactive Materials Permits

- Anyone with an independent research program that uses radioactivity is required to have a permit
- Permit application is reviewed and approved by RSO and RSC Chair
- Permit holder will meet with RSO
- RSU will post lab, bring waste containers, and help set up for "hot" work

Permits

- Permit holder's name
- Room(s) authorized for RAM storage/use
- Isotope(s) and activity approved for use

- Permits must be kept in the lab's radioactive materials log book, which is to be kept in the primary lab area

Example of a Permit

5

Log Book Should Contain:

- Permit
- Training Certificates
- Inventory Sheets
- Meter Calibration Records
- Weekly Survey Forms
- Waste Sheets

Posted Labs

- Radioactive material use or storage locations must be posted
- There can be **NO** eating, drinking, smoking, food storage, or application of cosmetics in a posted lab (state regulations)
- Door posting includes radiation symbol and emergency contact information

Laboratory Inspections

- Performed quarterly or semi-annually depending on lab's violation history
- Includes audit of paperwork, survey, observation of work practices, verbal quiz
- May contain major or minor violations
- 4 major violations in 6 months requires review by Radiation Safety Committee

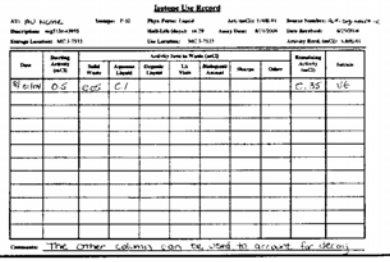
Examples of Violations

- Major violations:
  - Failure to perform and document weekly radioactive contamination surveys during weeks in which radioactive materials were used
  - Use of radioactive materials in an unposted lab or room
  - Failure to wear proper PPE
- Minor violations:
  - Evidence of eating or drinking in a posted room
  - Failure to report a radiological incident
  - Survey Meter out of calibration

Inventory Control

- Isotopes may only be ordered by RSU
- Isotopes may only be delivered to RSU
- Each stock vial has accompanying stock vial inventory sheet
- Each waste container has accompanying waste container log
- These sheets MUST be maintained to show activity currently present

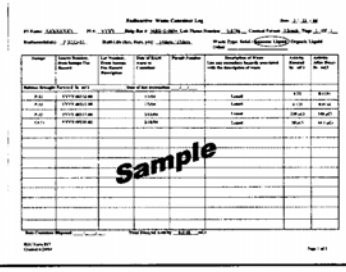
Example of Stock Vial Inventory Sheet


Isotope Use Record

Date	Remaining Activity (mCi)	Solid Waste	Aqueous Liquid	Organic Liquid	Lic Vials	Biological Animal	Sharps	Other	Remaining Activity (mCi)	Initials
9/6/04	0.5	0.05	0.1						0.35	VE

Comments: The other columns can be used to account for decay...

Example of Waste Sheet



Radioactive Waste

- Must adhere to waste package safety requirements
- Waste must be segregated
- Waste sheets must be properly filled out and placed with radioactive waste container
- **No liquid waste is to be poured down the drain**

Safety Requirements

- Liquid waste containers cannot be overly full (filled no higher than 4" from top)
- **No sharps** are permitted in solid waste containers
  - Sharps include broken glass, razor blades, needles, and anything else that can cause bleeding
  - Sharps must be kept in sharps shelter

Waste Segregation - Liquid

- Aqueous (about $34 per gallon)
- Exempt vials (about $10 per gallon)
- Mixed ($80-$180 per gallon)
  - 5 gallon minimum $1250
  - 30 or 55 gallon drum $3000 minimum
- **Segregate aqueous and organic waste**
- Do not include mixed waste with aqueous or organic waste
- Mixed waste disposal charges will be billed back to P.I.

Waste Segregation - Solid

- Segregate by half life
- **Short-lived** (half-life <90 days)
  - Half life < 30 days (P-32, P-33, Cr51)
  - Half life > 50 days (S-35, I-125)
- **Long-lived** (half-live >90 days)
  - Incinerable - paper and soft plastics
  - Non-incinerable - metal, glass, hard plastics

Waste Disposal

- Liquid Waste:
  Call x 5-3781 to schedule a liquid pick-up
- Solid Waste (including vials):
  Bring to MC B-5730 (key-carded)

Working Safely with Radioactivity

- Radiation surveys
- Radiological work areas
- Radiological incidents and emergencies
  - Spills of radioactive materials
  - Skin contamination

Check Your Meter Before Use!

- Correct detector for isotope being used
  - e.g.: GM detector for P-32 or NaI(Tl) for I-125
- Calibrated within the last year
- Battery is OK
- Physical condition of meter is good (including cable)
- Response to source is +/- 20% of average
- Audible switch on, "F/S" switch in "F" (fast) position

Detectors

- G-M tube sensitive to medium and high energy beta and gamma radiation
- Operates at ~950 volts

- NaI detector sensitive to gamma radiation
- Operates at ~750 volts

- **DO NOT use G-M for I-125!**

When to Survey

- Weekly (must be documented per state regulations) - entire laboratory
- After every use of isotope - work area
- During work with isotope - hands
- **Surveying is the easiest way to find problems**
- Failure to survey properly is responsible for more than half of our violations and almost all of our suspensions

Where to Survey

- **Hands** - frequently during "hot" work
- **Work area –** before and after every use and weekly
- **Hands, forearms** - after *every* use
- **Refrigerators, fume hoods, RAM storage areas** - weekly
- **Light switches, telephones, doorknobs, and other frequently-touched items** - weekly

Required Surveys

- When only low energy beta emitters (H-3, C-14, S-35, Ni-63 etc) are used – smear wipes for removable contamination is all that is required
- For all other isotopes (P-32, P-33, Cl-36, Tc-99m, I-131, I-125, Cs-137 etc) smear wipes and survey with an appropriate meter is required
- If gamma emitting radionuclides are used (Cr-51, Tc-99m, I-131, Cs-137 etc) a field measurement survey in mr/hr must also be performed and documented

How to Survey: Meter Survey

- Can use survey meter if detection efficiency is **>10%** for isotopes in use
- Hold detector <1 cm from surface
- Move detector at 3-5 cm/sec
- **DON'T** look at meter face - listen to beeps until you hear the count rate go up
- Record results in CPM, **NOT** mr/hr

Ion Chamber Survey

- Slowly sweep meter from side to side while holding it away from the body.
- Note highest reading at several points in the room.
- Note a contact and 30 cm (12 inch) reading from source.

How to Survey: Smear Wipe Survey

- Dry filter paper (Wattman or Millipore)
- Wipe 100 square cm
- Count in liquid scintillation counter (LSC)
- **Must** use smear wipes for all isotopes. Wipes are the only means of detection if meter has **<10%** counting efficiency (i.e. H-3, C-14, S-35)
- Smear wipes will detect all nuclides used

Smear Wipe Surveys (cont.)

- Do not use a smear wipe for more than one location
- Be careful not to cross-contaminate wipes
- Do not use a single smear wipe for surveying very large areas

Reporting Results

- Report net counts, not gross counts
  - Subtract out background counts
- Report in DPM, not CPM
  - DPM = CPM/meter efficiency
- Note any locations where count rate is more than 2x background levels (GM) or more than 200 cpm>bkg (NaI)

Example

- Assume
  - background = 50 cpm
  - location = 130 cpm
  - meter efficiency = 40%
- Net count rate = 130-50 = 80 cpm
- DPM = 80/0.40 = 200 dpm

Action Levels

- 200 dpm/100 cm^2 - clean up
- 500 dpm/100 cm^2 - call Radiation Safety if unable to decontaminate below this level
- These values apply to fixed surfaces - equipment may be more contaminated when in use, provided it is labeled radioactive and decontaminated periodically

Work Area

- Should be non-porous
- Cover with plastic-backed absorbent
- Set up to minimize chance of contamination
- Use appropriate shielding when working with P-32 and gamma emitting nuclides

During "hot" work

- Survey your hands frequently
- Be aware that anything in your work area is potentially contaminated
- Re-cap your stock vial as soon as possible after withdrawing your aliquot

After Completing "hot" work

- Survey the tops and bottoms of both hands
- Survey all equipment you used
- Survey to about 20 cm from the edge of your work area
- Survey your arms up to the elbow
- If your lab coat is contaminated, remove it and re-survey your arm

Radiological Incidents

- Spill
- Skin contamination or clothing contamination
- Fire or Flooding in a posted area
- Inhalation/ingestion/personal injury while using RAM
- Loss of radioactive materials

Actions for a spill: SWIM

- **Stop** spill by containing spilled liquid and capping (or containing) container
- **Warn** others, including Radiation Safety
- **Isolate** the spill area with tape, ropes, or other physical barriers
- **Minimize** exposure to spilled material while cleaning it. Use common sense.

Isolating a spill

- Set up spill boundaries at least 1 meter in all directions. Verify boundaries.
- **NOBODY** may enter the spill area unless they are wearing gloves, shoe covers, and a lab coat
- **NOBODY** who is in the spill area at the time of the spill may leave the spill area until surveyed by Radiation Safety or until Radiation Safety has given approval

Cleaning up a spill

- Use commercial cleaner (Formula 409, Windex, Radout, Radiac Wash, etc.)
- Clean from the outside towards the inside of the spill
- Clean from the top to the bottom (or benchtop to floor) for more interesting spills

Skin Contamination

- Notify Radiation Safety immediately
- Obtain a count rate of the contaminated skin - write this down
- Begin decontamination with mild soap and cool or luke warm water
- Survey every 3-4 washes to see if count rate is going down
- Continue cleaning until RS staff arrive or until count rate stops going down

Summary

- The amounts of radiation you work with will not hurt you
- However, you still need to treat it with respect
- If you have any questions or concerns, contact Radiation Safety and we'll try to help you out

Emergency Contact Information

- Radiation Safety: x5-3781
- Security (after hours): x13