QAM-R-100

TIAER Laboratory

Radiochemistry Program

Rev. 4

Approval:

______________________________ 12-2-20

Laboratory Manager Date

______________________________ 11/9/20

Concurrence by RSO Date

Effective Date: 12-11-20

Renewal Date: ____________________ Initials: ____________

1. Applicability and Purpose

1.1. This procedure applies to the radiochemistry program at the Texas Institute for Applied Environmental Research (TIAER), Tarleton State University, Stephenville, Texas. The purpose of this procedure and associated methods is to outline a program that ensures safe and quality performance of duties assigned to the analysts and technicians in compliance with the National Environmental Laboratory Accreditation Conference (NELAC) Standard, Department of State Health Services (Texas DSHS), Texas Commission on Environmental Quality (TCEQ), United States Nuclear Regulatory Commission (NRC), project requirements, and TIAER procedures.

1.2. TIAER maintains an environmental testing laboratory accredited by the National Environmental Laboratory Accreditation Program (NELAP) and administered by the TCEQ. The procedures outlined in this and other sections of the TIAER Quality Assurance Manual define the Radiation Protection Program and the responsibilities thereof for the TIAER Laboratory at Tarleton State University's main campus and TIAER's mobile laboratory at offsite facilities. These procedures are followed by all TIAER Laboratory personnel and by any other personnel of other organizations that utilize TIAER facilities; who receive, possess, use, transfer, own, or acquire any source of ionizing/non-ionizing radiation or radiation producing device within TIAER at Tarleton State University.

1.2.1. **NOTE**: It is not anticipated that TIAER will ever have, use, ship or be in control of Category 1 or 2 radioactive wastes, samples or materials. Definitions and references to these are not provided in this procedure.

1.3. The TIAER Radiochemistry Lab has offices and records housed in the Hydrology Building at Tarleton State, a counting room and sample receipt area in the Hydrology Annex, and a sample preparation, radwaste and wet work area in the Mobile Lab (ML). The TIAER ML is in a locked and gated area with razor wire, motion sensor security lighting and camera monitoring, and is accessed by controlled key. Alarms are on the ML entry door. The Annex and Hydrology building are accessed by controlled key with alarmed doors. Only authorized personnel are allowed in any TIAER Lab sections. The area is monitored by the Tarleton Police Department. If used offsite, the ML is kept in fenced and gated areas only and will be alarmed and monitored by camera. All digital records are backed up daily on a server separated from collection and use. Paper data are kept in a fire proof file cabinet in the RSO's office when not in use.

1.4. The ML has a dedicated ventilation hood for radioisotope and sample preparation. All radioactive standards are kept in a locked, lead lined box with controlled access. The counting room has a locked pass-through window for transfer of prepared samples from the ML in the secured area. Some mobile equipment may be transported from the counting room into the ML for off-site response and monitoring activities. All areas are properly placarded with appropriate signage in cyan and magenta as required. Refer to the appropriate Instrument or Chemistry procedure for calibration, maintenance and other aspects of operation and quality control. Refer to Attachment 5 for specific directions on transport of radioactive materials.

2. <u>Definitions</u>

2.1. Refer to the TIAER Quality Assurance Manual (QAM-Q-100) and chapters QAM-Q-101, "Laboratory Quality Control", QAM-S-101, "Laboratory Safety", QAM-W-101, "Laboratory Waste", and any method specific SOP for more definitions.

2.2. The current **TIAER Radiation Safety Officer** is Mark Murphy. James Hunter, the Laboratory Manager, is also a trained RSO. Contact information and CV are found in Attachment 1.

2.3. Absorbed dose--The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the gray (Gy) and the rad.

2.4. Access control--A system for allowing only approved individuals to have unescorted access to a security zone and for ensuring that all other individuals are subject to escorted access.
2.5. Activity--The rate of disintegration or transformation or decay of radioactive material. The units of activity are the Becquerel (Bq) and the curie (Ci).
2.6. Adult--An individual 18 or more years of age.
2.7. Airborne radioactive material--Any radioactive material dispersed in the air in the form of dusts, fumes, particulates, mists, vapors, or gases.
2.8. Airborne radioactivity area--A room, enclosure, or area in which airborne radioactive materials may exist.
2.9. As low as is reasonably achievable (ALARA)--Making every reasonable effort to maintain exposures to radiation as far below the dose limits in these regulations as is practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of ionizing radiation and licensed sources of radiation in the public interest.
2.10. Background radiation- Radiation from cosmic sources; non-technologically enhanced naturally occurring radioactive material, including radon, except as a decay product of source or special nuclear material, and including global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents, such as Chernobyl, that contribute to background radiation and are not under the control of the licensee. "Background radiation" does not include radiation from sources of radiation regulated by the agency.
2.11. Becquerel (Bq)--The International System of Units (SI) unit of activity. One Becquerel is equal to 1 disintegration or transformation per second (dps or tps). Commonly used

multiples of the Becquerel are the kBq (kilobecquerel, 10^3 Bq), MBq (megabecquerel, 10^6 Bq), GBq (gigabecquerel, 10^9 Bq), and TBq (terabecquerel, 10^{12} Bq). 1 Ci = 37 GBq.

2.12. Byproduct material--Byproduct material is defined as:

2.12.1. any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material

2.12.2. the tailings or wastes produced by or resulting from the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute "byproduct material" within this definition

2.12.3. any discrete source of radium-226 that is produced, extracted, or converted after extraction, before, on, or after August 8, 2005, for use for a commercial, medical, or research activity; or

2.12.4. any material that has been made radioactive by use of a particle accelerator; and is produced, extracted, or converted after extraction, before, on, or after August 8, 2005, for use for a commercial, medical, or research activity; and

2.12.5. any discrete source of naturally occurring radioactive material, other than source material, that is extracted or converted after extraction before, on, or after August 8, 2005, for use in a commercial, medical, or research activity and that the United States NRC, in consultation with the Administrator of the United States Environmental Protection Agency (EPA), the United States Secretary of Energy, the United States Secretary of Homeland Security, and the head of any other appropriate Federal agency, determines would pose a threat similar to the threat posed by a discrete source of radium-226 to the public health and safety or the common defense and security.

2.13. Collective dose--The sum of the individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.

2.14. Critical group--The group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances.

2.15. Curie (Ci)--A unit of measurement of radioactivity. One curie (Ci) is that quantity of radioactive material that decays at the rate of 3.7×10^{10} disintegrations per second (dps). Commonly used submultiples of the curie are the millicurie (mCi) and the microcurie (μCi). One mCi = 1×10^{-3} Ci = 3.7×10^{7} dps. One μCi = 1×10^{-6} Ci = 3.7×10^{4} dps. One nanocurie (nCi) = 1×10^{-9} Ci = 3.7×10^{1} dps. One picocurie (pCi) = 1×10^{-12} Ci = 3.7×10^{-2} dps.

2.16. Decommission--To remove a facility or site safely from service and reduce residual radioactivity to a level that permits the following:

2.16.1. Release of the property for unrestricted use and/or termination of license; or

2.16.2. Release of the property under alternate requirements for license termination.

2.17. Depleted uranium--The source material uranium in which the isotope uranium-235 is less than 0.711 weight percent of the total uranium present. Depleted uranium does not include special nuclear material.

2.18. Discrete source--A radionuclide that has been processed so that its concentration within a material has been purposely increased for use for commercial, medical, or research activities.

2.19. Distinguishable from background--The detectable concentration of a radionuclide is statistically different from the background concentration of that radionuclide in the vicinity of the site, or, in the case of structures or equipment, in similar materials using adequate measurement technology, survey, and statistical techniques.

2.20. Dose--A generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, total organ dose equivalent, or total effective dose equivalent. For purposes of this procedure, "radiation dose" is an equivalent term.

2.21. Dose equivalent (HT)--The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the sievert (Sv) and rem.

2.22. Dose limits--The permissible upper bounds of radiation doses established in accordance with this procedure. For purposes of this procedure, "limits" is an equivalent term.

2.23. Embryo/fetus--The developing human organism from conception until the time of birth.

2.24. Entrance or access point--Any opening through which an individual or extremity of an individual could gain access to radiation areas or to licensed sources of radiation. This includes portals of sufficient size to permit human access, irrespective of their intended use.

2.25. Escorted access--Accompaniment while in a security zone by an approved individual who maintains continuous direct visual surveillance at all times over an individual who is not approved for unescorted access.

2.26. External dose--That portion of the dose equivalent received from any source of radiation outside the body.

2.27. Extremity--Hand, elbow, arm below the elbow, foot, knee, and leg below the knee. The arm above the elbow and the leg above the knee are considered part of the whole body.

2.28. Frisking—The use of a survey instrument (i.e. Model 3 with pancake probe) to survey hands, feet, extremities and whole body exposure to non-fixed radioisotopes

2.29. Generally applicable environmental radiation standards--Standards issued by the United States Environmental Protection Agency (EPA) under the authority of the Atomic Energy Act of 1954, as amended, that impose limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive material.

2.30. Gray (Gy)--The SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule per kilogram (J/kg) or 100 rad.

2.31. High radiation area--An area, accessible to individuals, in which radiation levels from sources of radiation external to the body could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 millisievert (mSv)) in one hour at 30 cm from any source of radiation or from any surface that the radiation penetrates.

2.32. Human use--The internal or external administration of radiation or radioactive material to human beings for healing arts purposes or research and/or development specifically authorized by the agency.

2.33. Individual--Any human being.

2.34. Individual monitoring--The assessment of:

2.34.1. Dose equivalent to an individual by the use of individual monitoring devices; or

2.34.2. Committed effective dose equivalent to an individual by bioassay or by determination of the time-weighted air concentrations to which an individual has been exposed, that is, DAC-hours. (See the definition for DAC-hours in §289.202(c) of 25 TAC); or

2.34.3. Dose equivalent to an individual by the use of survey data.

2.35. Individual monitoring devices-Devices designed to be worn by a single individual for the assessment of dose equivalent. For purposes of this procedure, "personnel dosimeter" and "dosimeter" are equivalent terms. Examples of individual monitoring devices include, but are not limited to, film badges, thermoluminescence dosimeters (TLDs), optically stimulated luminescence dosimeters (OSLs), pocket ionization chambers (pocket dosimeters), electronic personal dosimeters, and personal air sampling devices.

2.36. Inspection--An official examination and/or observation including, but not limited to, records, tests, surveys, and monitoring to determine compliance with the Act and rules, orders, requirements, and conditions of the agency.
2.37. Internal dose--That portion of the dose equivalent received from radioactive material taken into the body.
2.38. Ionizing radiation--Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter. Ionizing radiation includes gamma rays and x rays, alpha and beta particles, high-speed electrons, neutrons, and other nuclear particles.
2.39. Land disposal facility--The land, buildings, and equipment that are intended to be used for the disposal of low-level radioactive waste (LLRW) into the subsurface of the land.
2.40. Lens dose equivalent--The external dose equivalent to the lens of the eye at a tissue depth of 0.3 cm (300 mg/cm2).
2.41. License--A form of permission given by the agency to an applicant who has met the requirements for licensing set out in 25 TAC §289.
2.42. Licensed material--Radioactive material received, possessed, used, or transferred under a general or specific license issued by the agency.
2.43. Licensee--Any person who is licensed by the agency in accordance with the Act and this procedure.
2.44. Lost or missing radioactive material--Radioactive material whose location is unknown. This definition includes licensed material that has been shipped but has not reached its planned destination and whose location cannot be readily traced in the transportation system.

2.45. Low-level radioactive waste (LLRW)--Radioactive material that meets the following criteria:

2.45.1. LLRW is radioactive material that is:

2.45.1.1. discarded or unwanted and is not exempt by rule adopted under the Texas Radiation Control Act (Act), HSC, §401.106;

2.45.1.2. waste, as that term is defined in Title 10, CFR, §61.2; and

2.45.1.2.1. Concentration limits established in Title 10, CFR, §61.55, or compatible rules adopted by the agency or the Texas Commission on Environmental Quality (TCEQ), as applicable; and

2.45.1.2.2. Disposal criteria established in Title 10, CFR, or established by the agency or TCEQ, as applicable.

2.45.2. LLRW does not include:

2.45.2.1. high-level radioactive waste as defined by Title 10, CFR, §60.2;

2.45.2.2. spent nuclear fuel as defined by Title 10, CFR, §72.3;

2.45.2.3. byproduct material defined in the Act, HSC, §401.003(3)(B);

2.45.2.4. naturally occurring radioactive material (NORM) waste that is not oil and gas NORM waste;

2.45.2.5. oil and gas NORM waste; or

2.45.2.6. transuranics greater than 100 nanocuries per gram.

2.46. Manufacture--To fabricate or mechanically produce.

2.47. Member of the public--Any individual, except when that individual is receiving an occupational dose.

2.48. Minor--An individual less than 18 years of age.

2.49. Mobile device--A piece of equipment containing licensed radioactive material that either is mounted on a permanent base with wheels and/or casters, or otherwise equipped for moving while completely assembled and without dismounting; or is a portable device. Mobile devices do not include stationary equipment installed in a fixed location.

2.50. Monitoring--The measurement of radiation, radioactive material concentrations, surface area activities, or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses. For purposes of this procedure, “radiation monitoring” and “radiation protection monitoring” are equivalent terms.

2.51. Movement control center--An operations center that is remote from transport activity and that maintains position information on the movement of radioactive material, receives reports of attempted attacks or thefts, provides a means for reporting these and other problems to appropriate agencies and can request and coordinate appropriate aid.

2.52. NORM--Any naturally occurring or accelerator-produced radioactive material except source material or special nuclear material.

2.53. Natural radioactivity--Radioactivity of naturally occurring nuclides whose location and chemical and physical form have not been altered by man.

2.54. NRC--The United States Nuclear Regulatory Commission or its duly authorized representatives.

2.55. Occupational dose--The dose received by an individual in the course of employment in which the individual’s assigned duties involve exposure to sources of radiation from licensed/registered and unlicensed/unregistered sources of radiation, whether in the possession of the licensee/registrant or other person. Occupational dose does not include dose received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released in accordance with this procedure, from voluntary participation in medical research programs, or as a member of the public.

2.56. Person--Any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, agency, local government, any other state or political subdivision or agency thereof, or any other legal entity, and any legal successor, representative, agent, or agency of the foregoing, other than NRC, and other than federal government agencies licensed or exempted by NRC.

2.57. Personnel monitoring equipment (See definition for individual monitoring devices.)

2.58. Principal activities--Activities authorized by the license that are essential to achieving the purpose(s) for which the license was issued or amended. Storage during which no licensed material is accessed for use or disposal and activities incidental to decontamination or decommissioning are not principal activities.

2.59. Public dose--The dose received by a member of the public from exposure to sources of radiation released by a licensee, or to any other source of radiation under the control of a licensee/registrant. It does not include occupational dose or doses received from background radiation.

2.60. Quality factor (Q)--The modifying factor that is used to derive dose equivalent from absorbed dose.

2.61. Quarter (calendar quarter)--A period of time equal to one-fourth of the year observed by the licensee, approximately 13 consecutive weeks, providing that the beginning of the first quarter in a year coincides with the starting date of the year and that no day is omitted or duplicated in consecutive quarters.

2.62. Rad--The special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs per gram (erg/g) or 0.01 J/kg (0.01 Gy).

2.63. Radiation--One or more of the following:

2.63.1. gamma and x rays; alpha and beta particles and other atomic or nuclear particles or rays;

2.63.2. emission of radiation from any electronic device to such energy density levels as to reasonably cause bodily harm; or

2.63.3. sonic, ultrasonic, or infrasonic waves from any electronic device or resulting from the operation of an electronic circuit in an electronic device in the energy range to reasonably cause detectable bodily harm.

2.64. Radiation area--Any area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (5 millirem or 0.05 mSv) in one hour at 30 cm from the source of radiation or from any surface that the radiation penetrates.

2.65. Radiation safety officer (RSO)--An individual who has a knowledge of and the authority and responsibility to apply appropriate radiation protection rules, standards, and practices, who must be specifically authorized on a radioactive material license, and who is the primary contact with the agency. Specific training and responsibilities for an RSO are listed in 25 TAC §289.252, §289.253(relating to Radiation Safety Requirements for Well Logging Service Operations and Tracer Studies), §289.255 (relating to Radiation Safety Requirements and Licensing and Registration Procedures for Industrial Radiography), and §289.256 (relating to Medical and Veterinary Use of Radioactive Material).

2.66. Radioactive material--Any material (solid, liquid, or gas) that emits radiation spontaneously.

2.67. Radioactive waste--For purposes of this procedure, this term is equivalent to LLRW.

2.68. Radioactivity--The disintegration of unstable atomic nuclei with the emission of radiation.

2.69. Regulations of the United States Department of Transportation (DOT)--The requirements in Title 49, CFR, Parts 100 - 189.

2.70. Rem (Roentgen Equivalent-Man)--The special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor (1 rem = 0.01 sievert (Sv)).

2.71. Research and development--Research and development is defined as:

2.71.1. theoretical analysis, exploration, or experimentation; or

2.71.2. the extension of investigative findings and theories of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, devices, equipment, materials, and processes.

2.72. Residual radioactivity--The radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the licensee's control. This includes radioactivity from all licensed and unlicensed sources used by the licensee, but excludes background radiation. It also includes radioactive materials remaining at the site as a result of routine or accidental releases of radioactive material at the site and previous burials at the site, even if those burials were made in accordance with the provisions of Title 10, CFR, Part 20.

2.73. Restricted area--An area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to sources of radiation. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart as a restricted area.

2.74. Roentgen (R)--The special unit of exposure. One roentgen (R) equals 2.58×10^{-4} C/kg of air. (See definition for exposure.)

2.75. Rule (as defined in the Government Code, Chapters 2001 and 2002, as amended)--Any agency statement of general applicability that implements, interprets, or prescribes law or policy, or describes the procedure or practice requirements of an agency. The term includes the amendment or repeal of a prior section but does not include statements concerning only the internal management or organization of any agency and not affecting private rights or procedures. The word “rule” was formerly referred to as “regulation.”

2.76. Sealed source--Radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material.

2.77. SI--The abbreviation for the International System of Units.

2.78. Sievert--The SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sievert is equal to the absorbed dose in gray multiplied by the quality factor (1 Sv = 100 rem).

2.79. Site boundary--That line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee.

2.80. Source material--Source material is defined as:

2.80.1. uranium or thorium, or any combination thereof, in any physical or chemical form; or

2.80.2. ores that contain by weight 0.05% or more of uranium, thorium, or any combination thereof; and

2.80.3. does not include special nuclear material.

2.81. Source of radiation--Any radioactive material, or any device or equipment emitting or capable of producing radiation.

2.82. Special form radioactive material--Radioactive material that satisfies the following conditions.

2.82.1. It is either a single solid piece or is contained in a sealed capsule that can be opened only by destroying the capsule;

2.82.2. The piece or capsule has at least one dimension not less than 5 millimeters (mm) (0.2 inch); and

2.82.3. It satisfies the requirements specified by NRC. A special form encapsulation designed in accordance with NRC requirements in effect on June 30, 1983, and constructed prior to July 1, 1985, may continue to be used. A special form encapsulation designed in accordance with NRC requirements in effect on March 31, 1996, and constructed prior to April 1, 1998, may continue to be used. A special form encapsulation either designed or constructed after April 1, 1998, must meet the requirements of this definition applicable at the time of its design or construction.

2.83. Special nuclear material--Special nuclear material is defined as:

2.83.1. plutonium (Pu), uranium-233 (U-233), uranium enriched in the isotope 233 or in the isotope 235, and any other material that NRC, in accordance with the provisions of the Atomic Energy Act of 1954, §51 as amended, determines to be special nuclear material, but does not include source material; or

2.83.2. any material artificially enriched by any of the foregoing, but does not include source material.

2.83.3. Special nuclear material in quantities not sufficient to form a critical mass (**NOTE: TIAER IS NOT ANTICIPATING CONTACT WITH THIS TYPE OF MATERIAL IN ANY FORM**)-- Uranium enriched in the isotope 235 in quantities not exceeding 350 grams (g) of contained uranium-235; uranium-233 in quantities not exceeding 200 g; plutonium in quantities not exceeding 200 g; or any combination of these.

2.84. Special units--The conventional units historically used by licensees, for example, curie (activity), rad (absorbed dose), and rem (dose equivalent).

2.85. Survey--An evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, and/or presence of sources of radiation. When appropriate, such survey includes, but is not limited to, tests, physical examination of location of materials and equipment, measurements of levels of radiation or concentration of radioactive material present, and evaluation of administrative and/or engineered controls.

2.86. Swipes (or wipes)—physical collection of an area of contamination (normally 100 cm^2) upon a filter or piece of cloth in order to determined loose surface isotope presence.

2.87. TAC- Texas Administrative Code

2.88. Termination--A release by the agency of the obligations and authorizations of the licensee under the terms of the license. It does not relieve a person of duties and responsibilities imposed by law.

2.89. Test--A method of determining the characteristics or condition of sources of radiation or components thereof.

2.90. Texas Regulations for Control of Radiation (TRCR)--All sections of Title 25 TAC, Chapter 289.

2.91. Unrestricted area (uncontrolled area)--An area, or access to, which is neither limited nor controlled by the licensee. For purposes of this procedure, “uncontrolled area” is an equivalent term.

2.92. Very high radiation area—(**NOT ANTICIPATED AT TIAER**) An area, accessible to individuals, in which radiation levels from sources of radiation external to the body could result in an individual receiving an absorbed dose in excess of 500 rads (5 Gy in one hour at 1 meter (m) from a source of radiation or from any surface that the radiation penetrates. At very high doses received at high dose rates, units of absorbed dose, gray and rad, are appropriate, rather than units of dose equivalent, Sv and rem.

2.93. Waste--Low-level radioactive wastes containing source, special nuclear, or byproduct material that are acceptable for disposal in a land disposal facility. For the purposes of this definition, low-level radioactive waste means radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material.

2.94. Week--Seven consecutive days starting on Sunday.

2.95. Whole body--For purposes of external exposure, head, trunk including male gonads, arms above the elbow, or legs above the knee.

2.96. Worker--An individual (analyst, technician, etc.) engaged in work under a license or certificate of registration issued by the agency and controlled by a licensee or registrant, but does not include the licensee or registrant.

3. Equipment, Reagents, and Standards

Refer to individual analytical SOPs for specifics related to individual chemical methods.

4. Procedure

4.1. The University and TIAER are required by Texas Department of State Health Services, Radiation Control Program to:

4.1.1. Establish an appropriate administrative organization to handle matters dealing with radiation on campus.

4.1.2. Establish and maintain exposure records for personnel that work with ionizing radiation.

4.1.3. Assure that recognized safety and health procedures are followed.

4.1.4. Designate an institutional contact person to the Texas Department of Health.

4.2. Tarleton State University operates under a specific license issued by the Texas Department of State Health Services (DSHS), Radiation Control Program. This license covers the procurement, use and disposal of radioactive material in accordance with the rules as identified in 25 TAC 289. Licensure of all radioactive material including naturally occurring, isotope standards and samples, and all other radionuclides is required.

4.3. The RSO within the Department of Risk Management and Compliance or the TIAER RSO will submit any requests, applications or documents to the Texas DSHS, Radiation Control Program. Authorization from the Texas DSHS must be granted prior to beginning any work with these materials or equipment.

4.4. The President of Tarleton State University has designated the following organizational structure to insure compliance with all safety aspects of the Radiation Protection Program:

4.4.1. Office of the President

4.4.2. Department of Risk Management and Compliance

4.4.3. TIAER Radiation Safety Officer

4.4.4. Dr. Daniel Marble, Professor of Physics and Director of the Texas Physics Consortium, serves in an advisory capacity for the TIAER Laboratory Radiochemistry Program. Tarleton State University is a member of the Nuclear Power Institute (NPI). Dr. Marble leads the Tarleton academic and research effort for the NPI.

4.5. The responsibility and authority of these are further explained as follows: The President is the responsible officer of the University in all decisions and procedures must be consistent with established regulations and standards and with University policy and/or individual decisions made by the President. The Department of Risk Management and Compliance of Tarleton State University has been designated by the President to direct the university's overall Radiation Protection Program. The TIAER RSO serves as the custodian and monitors departmental compliance efforts, and therefore maintains the following TIAER records, reports, and documents:

4.5.1. The original copies of the *Radioactive Material License* and the *Certificate of Registration* as issued by the Texas DSHS, Radiation Control Program to TIAER.

4.5.2. Copies of records of TIAER personnel radiation exposure. Dosimetry and monitoring are described in the Training Program attached. A confidential log is maintained by the RSO on form S-101-3.

4.5.3. Survey instrument calibration records.

4.5.4. Quarterly inventory reports of radioactive materials.

4.5.5. Disposal reports for radioactive materials.

4.5.6. Incidents reports involving radioactive materials.

4.5.7. Reports of wipe test(s) and area surveys.

4.5.8. Equipment installation locations and monthly surveys.

4.6. The TIAER RSO also performs the necessary office and administrative duties relating to the Radiation Protection Program.

4.7. The TIAER RSO acts under the authority of the University President and Tarleton Risk Management, and is charged to oversee the Radiation Protection Program at TIAER including the main laboratory and all other university controlled sites operated by TIAER. The RSO shall be responsible for all administrative duties associated with the University's Radiation Protection Program at TIAER.

4.8. The TIAER RSO will submit any document requests related to program changes, licensing, etc. to the Director of Risk Management and Compliance. Upon review, the Director may choose to obtain a third-party review prior to approval to ensure appropriate controls and regulatory requirements have been met.

4.9. The primary purposes of the Radiation Protection Program are to:

4.9.1. Ensure the safety of all personnel that use radioactive materials.

4.9.2. Ensure that members of the public will not be exposed to excessive radiation.

4.9.3. Ensure that a healthful environment is maintained in all areas of TIAER including those in which radioactivity is a factor.

4.9.4. Ensure that sources of ionizing radiation will be procured, used and disposed of in accordance with regulations and standards established by the Texas DSHS, Radiation Control Program as found in 25 TAC 289.

4.9.5. Conduct inspections at appropriate intervals and locations to ensure that individual project(s) utilizing radiation are in compliance with stated procedures and with regulations established by the Texas DSHS. All safety inspections are documented on form S-101-2 and maintained on file by the RSO.

4.9.6. Ensure that all usage of radioactive materials is being conducted under the supervision of a qualified, properly licensed or registered user.

4.10. Both scheduled and unannounced safety inspections are made by the TIAER RSO and as requested by the Department of Risk Management and Compliance. Suggested methods for performing surveys are given below. Records of these surveys are maintained for inspection by outside agencies and for reference to determine whether the radiation levels or the contamination levels remain constant or increase over a period of time.

4.10.1. Radiation Level Surveys (QAM-S-101) - A survey meter capable of measuring levels as low as 0.1 mR/h is used and the results recorded in the Radiation Survey Logbook (S-101-2) showing location, date, person performing survey, instrument used, exposure levels, and corrective actions taken (in comments), if any. A sketch or description of the area is used to make an easily prepared and easily understood survey record when annotated with this information.

4.10.2. Contamination Level Surveys (SOP-RC-111) - A series of swipes using filter papers or swatches of cloth are taken from those surfaces where contamination could be expected to exist or where radiation levels may be higher than background. (Areas where solutions are prepared, incoming packages received, pipetting is performed, etc., are areas that may be contaminated.) The swipes should be numbered or labeled and their location indicated on the sketch record as described above. The swipes should each be rubbed over a surface area of about 100 square centimeters to maintain a consistent means of determining the amount of removable contamination. The swipes are counted using a gamma scintillation well counter, a Geiger counter, or any other approved procedure and detector capable of detecting the small amount of contamination on the sample.

4.11. Surveys and swipes are taken at least monthly by the TIAER RSO or trained designee for at least three random areas of laboratory work or radioactive material handling. Each area is documented separately on a Radiation Safety and Survey Report form (S-100-2). Area surveys and swipe tests are also performed if there is evidence of a damaged sealed source, to document radiation levels around sealed source storage locations, and to survey areas to document clean up where open sources, standards or samples have been used. Swipes and surveys are also taken on outside of shipping containers or ice chests in accordance with QAM-Q-110, "Sample Receipt and Login" and QAM-Q-102, "Material Acceptance Criteria".

4.11.1. Radiation Levels - In no area that is unrestricted (uncontrolled) do radiation levels exist such that a person could receive 100 mR in any one year, or 2 mR in any one hour. If such areas are found, measures are taken immediately to eliminate the excessive radiation levels. Additional shielding or relocation of radioactive material may be required. Radiation levels are kept as low as reasonably achievable.

4.11.2. Contamination Limits - If the wipe samples counted indicate more than 1,000 disintegrations per minute (dpm), or twice the background level (whichever is lower), the area should be cleaned until the contamination has been removed (QAM-S-101). Since it is difficult to determine exactly when a wipe sample has 1,000 dpm, it is recommended that, when such samples show an easily detectable amount of activity above background, the contaminated areas be cleaned. This action should help prevent the spread of contamination and ingestion of activity by personnel whose hands or clothing become contaminated.

4.11. Personnel are required to frisk hands, feet and whole body for contamination when leaving the radiochemistry working area, or after working with radioactive material. A frisking station is maintained at the entrance/exit of each area. A calibrated pancake style probe with a Model 3 survey meter (or equivalent) is used. The RSO is responsible for training personnel how to frisk as part of this program and only personnel authorized by the RSO are allowed clearance to perform any activities for handling radioactive materials.

4.12. Those analytical instruments that are calibrated in-house are done by personnel trained in accordance with QAM-Q-107. Only personnel authorized in writing by the RSO on the Personnel Training Form are allowed to work in radiochemistry lab areas.

4.13. All records of instrument calibration are maintained for a minimum of five years in the office of the TIAER RSO. Other Time Requirements for Record Retention are found in Attachment 3.

4.14. No food is to be prepared, stored, or consumed within the TIAER laboratory.

4.14.1. Hands are thoroughly cleaned prior to eating and following work with radioactive materials.

4.15. Smoking and the use of smokeless tobacco is not allowed within Tarleton State University buildings.

4.16. No animal facilities are incorporated or associated with the TIAER Lab operation.

5. <u>Quality Control and Safety Aspects</u>

5.1. All aspects of this procedure are conducted in accordance with QAM-Q-101, "Laboratory Quality Control" and QAM-S-101, "Laboratory Safety".

5.2. All workers are required to have training (Attachment 2) administered by the TIAER RSO and documented on form Q-107-2 prior to working with any radioactive materials.

5.3. Any discrepancies or non-conformances that affect data quality are addressed and documented in accordance with QAM-Q-105, "Corrective Actions".

5.4. Signage complying with RC Form 203-1, "Notice to Employees" is posted at every access to areas of radioactive material storage or use.

5.5. Emergency Procedures

5.5.1. In the event of a radiological incident or emergency, the TIAER RSO is notified immediately. In instances where there is doubt whether such notification is necessary, contact is made to allow the RSO to assess the situation and initiate an appropriate response. In serious emergencies or spills, as determined by the TIAER RSO, the Tarleton Risk Management and Compliance Department is notified and is on-call for emergency response 24-hours per day, seven days per week.

5.5.1.1. Emergency responders in the City of Stephenville are trained to respond to radiological incidents and hold drill scenarios at least annually with the nearby nuclear power plant.

5.5.1.2. During normal business hours contact: (254)-968-9237

5.5.1.3. After normal business hours, weekends, and holidays contact:
University Control Center at (254)-968-9265
University Police Department at (911)

5.6. The following are a list of cases that would qualify as an incident or emergency

5.6.1. Loss or theft of any radioactive material.

5.6.2. High or potentially high radiation exposure to an individual or to a member of the public. **There is not expected to be any such level of radioactivity at TIAER.**

5.6.3. Intake or potential intake of radioactive materials by inhalation, ingestion, absorption through skin, or injection through skin or wound. This is especially significant for alpha emitting isotopes.

5.6.4. Deceptive or potentially deceptive exposure of a dosimeter.

5.6.5. Personnel contamination that cannot be completely removed after two washes with soap and water.

5.6.6. Spills involving any quantity of alpha emitting radionuclide or more than 10 microcuries of any other radionuclide.

5.6.7. Any spill which is not or cannot be completely decontaminated before the end of that work day.

5.6.8. Identification of any contamination which is outside of the restricted area, such as spills tracked or otherwise spread into offices, hallways, vehicles, etc.

5.6.9. Accidental releases of radioactive materials to the environment.

5.6.10. Fires or floods which threaten to release radioactive materials to the environment or which threaten to expose emergency response personnel.

5.6.11. Any transportation accident, whether on-campus or off, involving radioactive materials and TIAER personnel or equipment.

5.6.12. Any personnel injuries which may involve radioactive contamination or radiation exposure.

5.7. Personnel Injury Involving Actual or Suspected Contamination or Exposure to Radiation

5.2.2.11. Provide first aid immediately for serious injuries.

5.2.2.12. Call 911 from a University phone or cell phone.

5.2.2.13. Notify University Control Center

5.2.2.14. As possible, without doing harm to the individual and remove contaminated clothing and gross personal contamination.

5.8. Decontamination of Personnel

5.8.1. Remove and bag all contaminated clothing.

5.8.2. Skin contamination should be cleaned using mild soap and tepid water. Use portable survey meter to monitor for remaining contamination. If not free of contamination, rewash and resurvey. Decontamination solutions which are formulated for use on skin may be used, if available.

5.8.3. Survey for contamination elsewhere on body as well as on clothes, shoes, floor, door handles, telephone, etc. Surveys are documented on the log S-101-2.

5.8.4. If the contamination is in a wound rinse the wound with copious amounts of water.

5.9. Radioactive Spills or Releases

5.9.1. Oversite of decontamination is the responsibility of the TIAER RSO. For large spills (i.e., greater than 10 microcuries) or spills that are difficult to clean up, the work should be carried out under the direction of RSO through guidance from Tarleton Risk Management. Appropriate protective clothing shall be worn during decontamination activities.

5.9.2. Steps to respond to incidents are:

5.9.2.1. Stop work and confine spill immediately using absorbent, enclosure, etc. Call RMS.

5.9.2.2. Warn others of the hazard and isolate the area.

5.9.2.3. Monitor personnel during and after cleanup for contamination.

5.9.2.4. Collect all used cleanup materials as radioactive waste. Remove and bag all contaminated clothing or cleanable items for removal by the TIAER RSO. All waste is stored and segregated in the Mobile Lab in accordance with QAM-W-101.

5.9.2.5. Commence wipe surveys and decontamination. Ensure wipe surveys of surrounding areas are performed to ensure all contaminated items are identified.

5.9.2.6. Document all actions taken, measurements and disposal methods.

6. References

6.1. National Environmental Laboratory Accreditation Conference (NELAC) Standard, 2016, The NELAC Institute (TNI).
6.2. TIAER Quality Assurance Manual and chapters.
6.3. TIAER Quality Standard Operating Procedures.
6.4. Tarleton State University Radiation Safety Program
6.5. QAM-Q-100, “TIAER Quality Assurance Manual”, including all procedure subsections and SOPs.
6.6. QAM-S-101, “Laboratory Safety”
6.7. Texas Administrative Code 289.202, Forms 202-2, 202-3.
6.8. Texas Radiation Control Act, Health and Safety Code (HSC), Chapter 401
6.9. 25 Texas Administrative Code (TAC) §289.201, General Provisions for Radioactive Material.

7. Attachments

7.1. Resume/Vita for Radiation Safety Officer
7.2. Radiation Training for Laboratory Workers
7.3. Time Requirements for Record Retention
7.4. Quarterly Radioactive Material Inventory Form (R-100-1)
7.5. Transport Procedure for Radioactive Materials

Attachment 7.1

Resume/Vita for Radiation Safety Officer

Mark A. Murphy

810 Tepee Trail

Granbury, TX 76048

817-219-6957

murphy@tarleton.edu

Summary: Over thirty years' experience in environmental, laboratory, regulatory, quality assurance, emergency response and field group management to obtain valuable supervisory abilities, teaching and technical skills in water treatment, analytical chemistry, radiochemistry, site assessment and hazardous waste characterization. Background for effective management of consulting projects, laboratories producing legally defensible data, an environmental facility or department, and valuable training for personnel producing safe and high quality work product under ISO 17025, EPA, NRC, TCEQ and NELAP requirements.

Technical Profile:

Instrumentation

Proficient in ICP, AA, and UV-Vis spectrophotometry, Ion and Gas Chromatography, Wet Chemistry including TOC, Autoanalyzers, COD, BOD, titrimetry, microbiology. Working proficiency of GC/MS, HPLC and radiometric analyses including gamma spectroscopy, alpha spectroscopy, liquid scintillation and alpha/beta counters. Supervision and review of GC and GC/MS data including volatiles, semivolatiles, BTEX/TPH, pesticides/herbicides and PCBs. Also familiar with many types of field, sampling and in-line plant instrumentation including reverse osmosis and demineralizer water treatment units.

Software

LIMS and database management and custom development, ChromPerfect, PlasmaLab, IRIS, LabMaster, ChemStation, MS Office including latest versions of Word, Excel, Access and Powerpoint, multiple Windows versions, Ubuntu/Linux. Database including BT LIMS, Rbase, Access and other instrumentation software. Website development.

Employment History:

1994 to present: Texas Institute for Applied Environmental Research, Stephenville, TX. Laboratory Manager, NELAP Recognized Technical Director, Laboratory Quality Assurance Officer, Radiation Safety Officer, Hazardous Waste Officer, Regulatory Compliance. Management of subordinate supervisors, biologists, chemists and technicians for environmental analyses utilizing EPA protocols and national accreditation through NELAP. Voting member of TNI (The NELAP Institute). Responsible for budgets, purchasing, employee hiring, merit reviews and disciplinary procedures. Focus areas include stormwater runoff, point and non-point source pollution, artificial wetland remediation and waste field applications, all including mobile laboratory deployment. Interfacing with state and federal environmental authorities, writing and reviewing Quality Assurance Project Plans, grant proposals, technical and data reports for agency programs. Business marketing, customer service, database management, audits, inspections, technical review of analytical data and troubleshooting. Developing and writing procedural systems for analyses, safety, hazardous waste and training. Innovations in laboratory methods for many aspects of water quality including analysis, treatment and remediation. Deliver presentations to public groups, trade shows and conferences on environmental laboratory research. Member of the EPA Environmental Response Laboratory Network and Water Laboratory Alliance.

1990 to 1994: Scientech, Inc., Carrollton, TX. Laboratory Manager, Special Projects Manager, Safety Officer. Supervision of chemists, biologists and technicians in an environmental testing laboratory utilizing EPA protocols SW846 and CLP, OSHA, NRC, DOD, DOE and state regulations for hazardous and radioactive mixed waste, procedure writing and development, site assessment, development of monitoring, personnel training and safety programs. Client relations and customer service, contract proposals and marketing, interfacing with state and federal regulatory entities including Quality Assurance audits from the states of Texas, New York and Utah, and Superfund contractors. All aspects of technical supervision, personnel management, budgeting and expenditures in hazardous waste and radioactive mixed waste analysis. Example projects include remediation of the Rocky Flats Arsenal Plant (DOD) and lead smelter sites for the EPA.

1987 to 1990: United States Peace Corps, Western Samoa, South Pacific. Science Teacher/Principal, Teacher trainer. Supervision of students and teachers, budgeting, parent conferencing and meetings spoken in Samoan language (near fluency). Designed and built a teaching laboratory from grant funds obtained by proposals submitted to international agencies. Secondary projects and grants received include a village water supply system and sanitary landfill. Volunteer Advisory Council representative to Country Director.

1981 to 1987: Texas Utilities Generating Company, Comanche Peak SES, Glen Rose, TX. Laboratory Coordinator, Nuclear Chemistry/Environmental Technician, Safety Officer. Responsible for environmental and in-plant monitoring, chemical systems control and radiochemical testing in a commercial nuclear plant. Helped set up initial counting room, hot lab, and sampling procedures for radiochemical analyses including gamma spectroscopy and gas flow proportional counters. Emergency Response Team member for accidental releases with constant training and drills. Site assessments, field sampling and water treatment systems operation. Laboratory supervision, procedure writing and development using EPA and NRC protocols.

Education and Training:

- Understanding Radiochemistry Testing and the 2016 TNI Standard-ASTM D7283 & EPA 906.0, TNI, August 2018.
- Alpha Spectroscopy, Canberra, Aiken, South Carolina, 2015.
- Nuclear Facility Decommissioning, Argonne National Laboratories (ANL), 2014.
- Calibration and Minor Repair of Ludlum Measurements Instruments, 2014.
- 40 Hour Radiation Safety Officer Course, Oak Ridge Associated Universities (ORAU), 2014.
- Radiation Safety Training for Technicians, Radiation Technology, Inc., 2015.
- 40 Hour HAZWOPER Certification, National Spill Control School, 1999 and subsequent refreshers.
- B.S. Biology 1980, Tarleton State University, with Honors.
- B.S. Chemistry 1981, Tarleton State University, final GPA 3.36.
- M.S. Environmental Science, 1999, Tarleton State University, GPA 3.78.
- Partial coursework towards Ph.D. in Environmental Science and Engineering, University of Texas at Arlington.
- Certified Hazardous Waste Manager, Lion Technology, 1994.
- Environmental Protection Agency Seminars: Quality Management Plans, Quality Assurance Management, Data Quality Objectives, Quality Assurance Project Plans, annual 1995 through 1999, then periodically afterwards.
- Prevention and Response, to Suicide Bombing Incidents, Performance Level Training, Incident Response to Terrorist Bombings, New Mexico Tech Energetic Materials Research and Testing Center, 2006.

- Continuity of Operations Plan (COOP) Template Training, EPA, Water Laboratory Alliance, 2015.
- Onsite nuclear facility training, Maguire Nuclear Station, Huntersville, NC, 1986.
- Onsite nuclear facility training, Wolf Creek Generating Station, Burlington, KS, 1987.
- Onsite nuclear facility training, Comanche Peak SES, Glen Rose, TX 1981-1987

Sample Publications:

- Laboratory Evaluation of Fluorometry for Determination of Optical Brighteners, prepared for Texas Commission on Environmental Quality TMDL Team, 2008.
- Reduced Laboratory Detection Limits for Spectrophotometrically Measured Soluble Reactive Phosphorus: A Modified Method, TIAER, 2002.

Texas Institute for Applied Environmental Research

Tarleton State University

Adapted from the Radiation Safety program at the University of Wisconsin at Milwaukee

Radiation Training for Laboratory Workers

Chapter 1: Radiation and Radioisotopes

Radiation and Radioisotopes

Radiation is simply the movement of energy through space or another media in the form of waves, particles, or rays. Radioactivity is the name given to the natural breakup of atoms which spontaneously emit particles or gamma/X energies following unstable atomic configuration of the nucleus, electron capture or spontaneous fission.

Atomic Structure

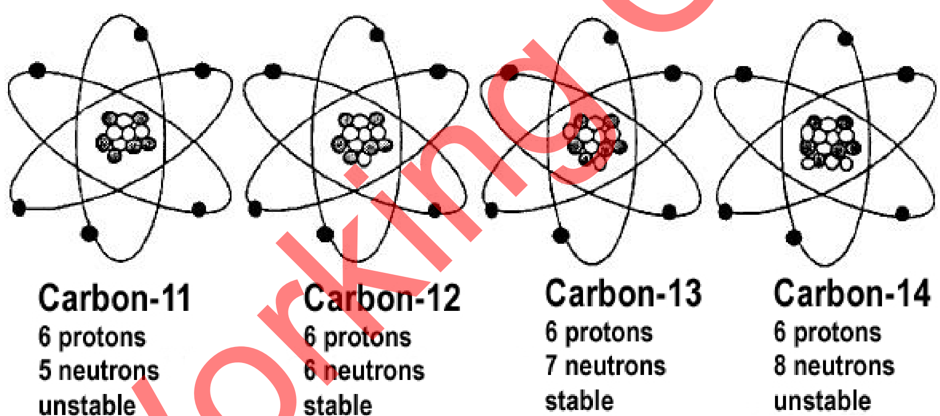
The universe is filled with matter composed of elements and compounds. Elements are substances that cannot be broken down into simpler substances by ordinary chemical processes (e.g., oxygen) while compounds consist of two or more elements chemically linked in definite proportions. Water, a compound, consists of two hydrogen and one oxygen atom as shown in its formula H_2O. While it may appear that the atom is the basic building block of nature, the atom itself is composed of three smaller, more fundamental particles called protons, neutrons and electrons. The proton (p) is a positively charged particle with a magnitude one charge unit (1.602×10^{-19} coulomb) and a mass of approximately one atomic mass unit ($1 \text{ amu} = 1.66\times10^{-24}$ gram). The electron (e-) is a negatively charged particle and has the same magnitude charge (1.602×10^{-19} coulomb) as the proton. The electron has a negligible mass of only 1/1840 atomic mass units. The neutron, (n) is an uncharged particle that is often thought of as a combination of a proton and an electron because it is electrically neutral and has a mass of approximately one atomic mass unit. Neutrons are thought to be the "glue" which binds the nucleus together.

Combinations of the fundamental particles following certain strict natural laws result in the formation of atoms. In concept, the neutrons and protons form a dense, central core or nucleus around which the electrons rotate in various orbits. Nearly all of an atom's mass is located in the nucleus. Natural law specifies that each atom has the same number of protons as it has electrons. This means that the total positive charge in the nucleus is equal to the total negative charge of the orbiting electrons and this produces an electrically neutral atom.

Each element has a unique number of protons (and corresponding neutrons) that determine its chemical properties. The number of protons in an atom is its atomic number, represented by the symbol Z. Thus, for carbon, which has 6 protons, Z=6. When the chemical symbol for an element is used with its atomic number, the atomic number is subscripted, e.g., ^{6}C. Thus, all atoms with an atomic number of 1 are hydrogen atoms (^{1}H); 2 are helium atoms (^{2}He); 3 atoms are lithium (^{3}Li); 4 are beryllium atoms (^{4}Be); etc.

The chemical properties of an atom are determined by the number of protons contained in the nucleus. For example, every atom which has six protons in its nucleus is a carbon atom. However, while all the atoms of a particular element have the same number of protons, they may have different numbers of neutrons. For carbon, there can be five, six, seven, or eight neutrons. Each of these atoms is a different isotope of carbon. Figure 1 illustrates the isotopes of carbon. All the isotopes of carbon are chemically identical, because the chemical properties are dictated by the atomic number (number of protons) of the element. The term nuclide means any isotope of any element.

Figure 1. The Isotopes of Carbon



Chapter 2: Radiation Detectors

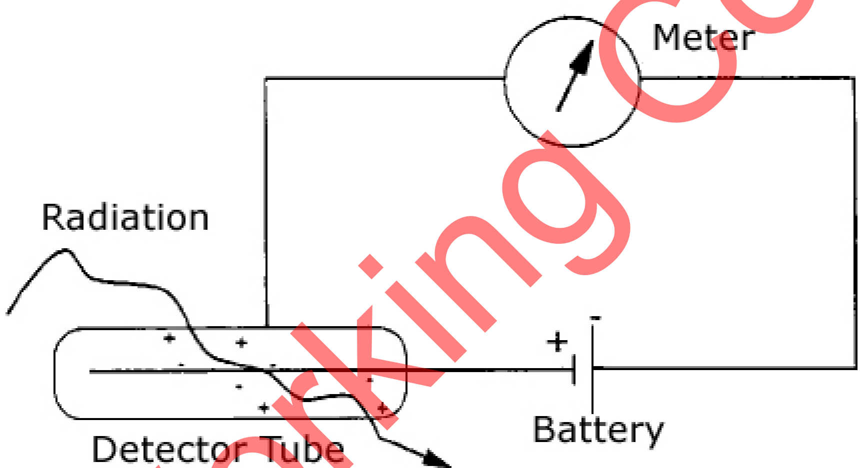
Radiation Detectors

Because human beings cannot see or feel radiation it is necessary to rely on monitoring and detecting equipment to measure the amount of radioactivity present. A variety of instrumentation is available for that purpose. Radiation is detected using special detectors which measure the amount or number of ionizations or excitation events that occur within the device. The radiation detection system can be either active or passive, depending upon the device and the mechanism used to determine the number of ionizations. Active devices provide an immediate indication of the amount of radiation or radioactivity present. Passive devices are usually processed at a special processing facility before the amount of radiation exposure can be reported. Portable radiation survey meters and laboratory counting equipment are active devices, while radiation dosimeters used in determining individual exposure to radiation and radon detectors are passive devices. At the end of this chapter, Table 1, lists expected efficiencies for commonly used radioisotopes using different types of survey equipment.

Survey Meters (refer to appropriate SOP)

Figure 2 illustrates the basic principle used by portable instruments in the detection and measurement of ionizing radiation. The detector tube (i.e. Geiger counter) is simply a gas filled, cylindrical tube with a long central wire that has a 900-volt positive charge applied to it and is then connected, through a meter, to the walls of the tube. Radiation enters the tube and produces ion pairs in the gas. The electron part of the ion pair is attracted to the positively charged central wire where it enters the electric circuit. The meter then shows this flow of electrons (i.e. the number of ionizing events) in counts per minute (cpm).

Figure 2. RADIATION DETECTION



The only prerequisite for the detection of radiation with a survey meter is that the radiation must have sufficient energy to penetrate the walls of the detector tube and create ionizations in the gas. Particulate (alpha and beta) radiations have a limited range in solid materials so, radiation detectors designed for these radiations must be constructed of thin walls that allow the radiation to penetrate. The most common types of portable radiation survey meters used in research labs are the thin window Geiger-Mueller (GM), Low energy Gamma (LEG), and Ion Chamber survey meters.

Geiger-Mueller (GM) Survey Meters

GM survey meters are radiation detection devices used to detect radiation or to monitor for radioactive contamination. GM detectors usually have "window" either at the end or on the side of the detector to allow alpha or beta particles to enter the detector. These detectors may have a variety of window thicknesses but, if the radiation cannot penetrate the "window" it cannot be detected. Depending upon the "window" thickness, GM systems can detect x-ray, gamma, alpha, and/or beta radiation. Common radioactive materials that emit these types of radiation (e.g. ^{22}Na, ^{32}P, ^{35}S, ^{51}Cr, ^{137}Cs) can usually be detected using GM survey meters. Because GM detectors are more sensitive to x-rays, gamma rays, and high energy beta particles and less sensitive to low energy beta and alpha particles, they are usually not used to detect alpha radiation or very low energy beta radiation. Thus, GM survey meters are usually not useful for monitoring ^{3}H or ^{63}Ni, nor are they sensitive enough to detect small amounts (< 1 µCi) of radionuclides that emit low energy beta or gamma radiation such as ^{14}C or ^{125}I. GM meter readings are usually expressed in counts per minute (cpm) for particle radiation or milliroentgen per hour (mR/hr) for X- or gamma rays.

Low Energy GAMMA (LEG) or Scintillation Survey Meters

LEG survey meters are radiation detection systems used to monitor radionuclides that emit low energy gamma radiation (e.g., ^{51}Cr, ^{125}I). They cannot detect alpha particles nor low energy beta particles but they can detect radionuclides that emit high energy gamma (^{22}Na) and/or high energy beta (^{32}P) radiation. The meter is usually read in counts per minute. When measuring ^{125}I with a LEG survey meter, a reading of approximately 1,000,000 cpm corresponds to a gamma exposure rate of about 1 mR/hr.

Ion Chamber Survey Meters

Ion chamber survey meters are radiation detection devices designed to collect all of the ion pairs produced in the detector tube and then measure the current flow. These meters are primarily used to measure X- and γ-ray exposure in air and the readings are usually expressed as milliroentgen per hour (mR/hr) or roentgen per hour. Ion chambers are most often used for measuring high levels of X- or gamma radiation exposure and are not often used in research labs.

Liquid Scintillation Counters

A scintillator is a material which gives off a photon (flash) of light when struck by radiation. Liquid scintillation counting is a method of assaying a radioactive sample by dissolving it in a mixture of chemicals called scintillation fluid or cocktail. When the radioactive decay energy is absorbed by the solution, the cocktail emits light. The light flashes are converted to electrical signals by a detector called a photomultiplier tube (PMT). These electrical signals are directly related to the absorbed energy allowing the sample to be quantified. Liquid scintillation counters (LSC) are usually used to quantify radioactivity and to measure removable radioactive contamination. They are ideal for counting radionuclides that decay by alpha and beta particle emission (^{3}H, ^{14}C, ^{32}P, ^{35}S) and are also used to measure some low energy gamma emitters (^{125}I) which emit auger electrons as part of their decay.

Radiation Dosimeters

Because it would be quite impractical to follow each worker around with a survey meter to try to keep track of the radiation exposure fields they enter, Radiation Safety monitors a worker's external radiation exposure with a personal dosimeter or radiation badge. These devices essentially store-up the radiation energy over the period it is used and is then sent to a vendor to read the exposure and report the results. There are several types of radiation dosimeters commonly used, although the most common are film badges, thermoluminescent dosimeters and the new optically stimulated luminescent dosimeter.

Film Badges

Film is the oldest personal monitoring device and, world-wide is the most common type of personal dosimeter primarily because of its simplicity and ease of use. X-rays and gamma rays, along with beta particles, can darken photographic film just as visible light does. This property is the basis for the common film badge. Several different designs are available, but they all have essentially the same components. A piece of film wrapped in paper is inserted into a plastic holder. An "open window" in the plastic allows the passage of low-energy betas which would not penetrate the plastic holder. (Note: tritium betas are so weak they cannot penetrate the paper wrapper of the film, so exposure to tritium cannot be detected on a film badge).

Small pieces of aluminum, cadmium or copper, and lead are molded into the plastic holder to act as filters to help differentiate and quantify the energies of radiation the film was exposed to. For example, some gamma rays that penetrate the aluminum may be stopped by the copper, cadmium, or lead. When the film is developed, different areas of blackness appear under the different metals. The film badge vendor can analyze the darkness patterns on the film to determine both the type and amount of radiation which the badge has been exposed to.

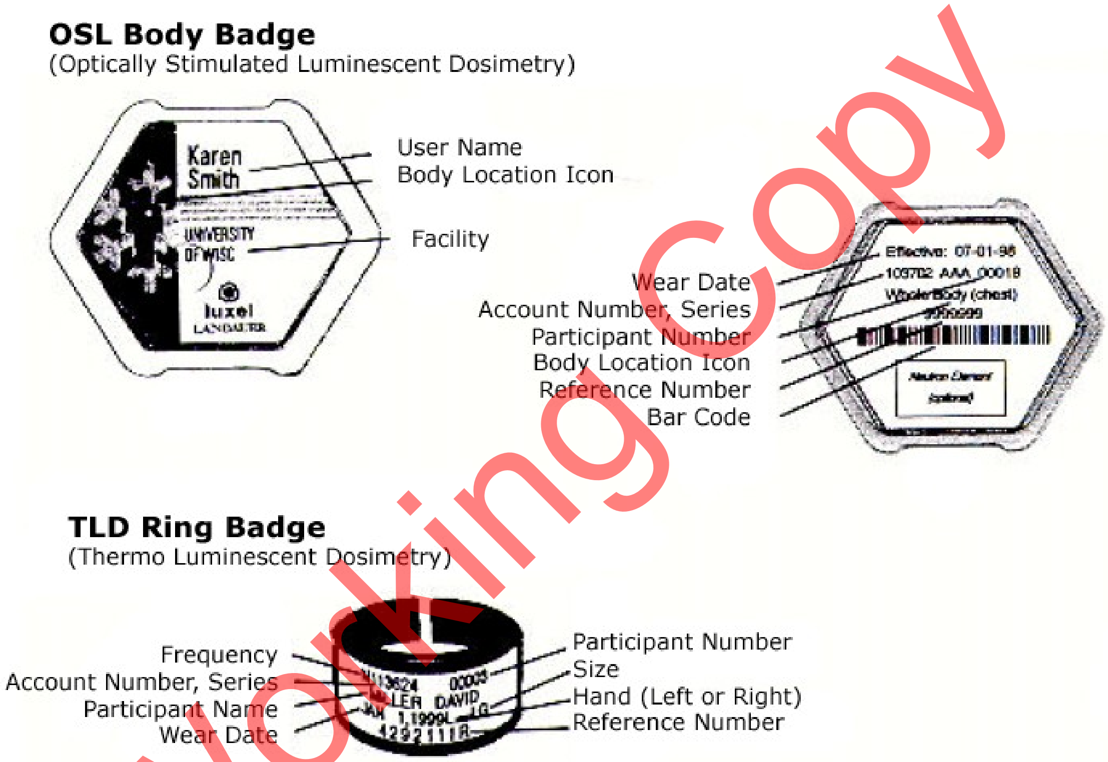
Thermoluminescent Dosimeter (TLD)

In 1953 it was proposed that thermoluminescence be used as a radiation detector. The TLD contains several mineral crystals or "chips" coated with a radiation-sensitive material. There are several different TLD crystals in use depending upon the application but, one commonly used thermoluminescent material is lithium fluoride activated with magnesium and titanium. The chips are enclosed in a plastic case that has an open window area to admit beta particles and three filtered areas to measure the penetration of any gamma doses. When exposed to radiation the TLD absorbs energy from the source which raises the molecular energy of the detector material to a metastable state. The molecules remain in these excited states until, through processing by the vendor, they are heated to a temperature high enough to cause the material to return to its normal state. When this occurs, light is emitted. The amount of light emitted is proportional to the dose received by the TLD. The emitted light is measured with a photomultiplier tube and the dose reading is derived.

Optically Stimulated Luminescence Dosimeters (OSL)

Most dosimetry products currently in use at TIAER are the optically stimulated luminescence (OSL) dosimeter. This dosimeter measures radiation through a thin layer of aluminum oxide. In the OSL dosimeter an aluminum oxide strip is enclosed in a blister pack that has an open window area to admit beta particles and three filtered areas to measure the penetration of any gamma doses. During analysis, the aluminum oxide is stimulated with selected frequencies of laser light, which cause it to become luminescent in proportion to the amount of radiation exposure. The luminescence is measured and a report of exposure results is generated.

Figure 3. Personnel Dosimeters



Personal Dosimetry Program

Unlike active detectors, the TLD has no readout or display. Radiation workers wear the dosimeter for a given period of time (monthly or quarterly) and return the dosimeter so it can be processed by a vendor. Thus, the worker learns of his/her radiation exposure several weeks after it has occurred.

"Radiation badges" (dosimeters) are generally used to monitor personnel and areas where radiation sources are used. The Nuclear Regulatory Commission (NRC) requires that personnel monitoring be performed if a worker is "likely to receive, in 1 year...doses in excess of 10 percent of the applicable limits." TIAER policy requires personnel to wear radiation badges when using more than 1 mCi of radioactive material which decays by gamma or beta emission with E_{max} > 200 keV. These dosimeters are used to monitor not just whole body exposure, but also exposure to a worker's hands. Extremity monitors are ring badges with a single chip.

Persons working with small amounts of radioactivity or low energy emitters such as ^{14}C, ^{3}H or ^{63}Ni do not need to wear a dosimeter.

If you have been issued a dosimeter to monitor your radiation exposure, you should follow a few simple rules to insure that the dosimeter accurately records your radiation exposure.

Wear only your assigned dosimeter; never wear another worker's badge.

Wear your whole body badge between your collar and waist. Wear your ring badge beneath your gloves with the label on the palm side of the hand with the greatest potential for exposure, usually the hand that handles the radiation source.

- Do not store your badge near radiation sources or heat sources.
- If you suspect contamination on your badge, return it immediately to the RSO; you will be given a new, uncontaminated badge.
- Never intentionally expose your badge to any radiation.
- Do not wear your badge when receiving medical radiation exposure (e.g., x-rays, tests, nuclear medicine procedures, mammograms, etc.)
- Return your badge(s) to the RSO at the end of the monitoring period. Snap the “body badge” out of the holder and retain the holder for your replacement dosimeter. Return the complete TLD ring.

The vendor sends all dosimetry reports to the Radiation Safety Officer. You will be notified immediately of any overexposure or of levels that warrant investigation. Permanent records of actual doses recorded by the dosimeters assigned to individuals during their affiliation with TIAER are maintained by the RSO and are kept confidential. You can request your exposure history at any time from the RSO/LM.

Monitoring for internal exposure and accidental ingestion will be accomplished by urine testing as determined by the RSO, with possible consulting by physicians. If necessary, blood and other medical monitoring services may be required. Again, all results are kept confidential except as required for reporting by law.

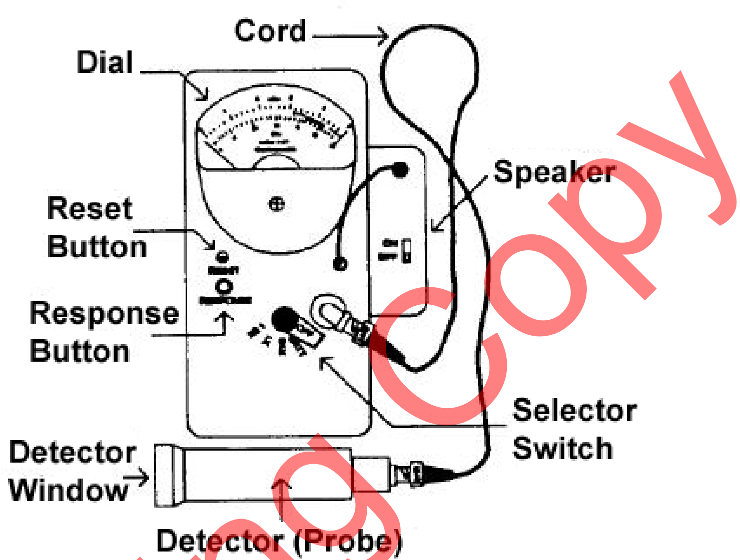
Radiation Detection and Measurement Techniques

Because radioactive material may pose a potential risk to users, all personnel who work with radioactive materials must understand how to use the various types of radiation detection systems to verify that their work place continues to be contamination free. To measure radiation, a workers must first understand how a detector works and then how to use it.

Survey Meters

All survey meters have certain controls in common. Figure 4 shows the basic components of a survey meter.

Figure 4. Portable Radiation Survey meter



The detector or probe is the device which produces electrical signals when exposed to radiation. It usually has a window through which beta radiation can penetrate its cavity.

The dial or readout is the gauge which indicates the amount of radiation exposure present. It often has two scales, mR/hr and/or CPM. The selector switch is a switch to turn the meter on- off, check the meter batteries, or select a scale multiplier.

The scale multiplier is a number (i.e., 0.1, 1.0, 10, etc.) by which the meter readings must be multiplied to calculate radiation exposure or the number of counts per minute.

The reset button allows the meter reading to be zeroed. When the level of radiation or the number of counts exceeds the highest reading at a particular scale multiplier, switch the scale multiplier to a higher range and push the reset button. This causes the readout needle to reset to zero so the user can accurately determine the count rate.

The response button adjusts the response time of the meter. When this switch is fully clockwise the meter will have a faster response but, the meter readings will be less stable. For response times in the microseconds range, this switch should be turned fully counterclockwise. For routine work set the response button to the slow mode.

The speaker is an audible device connected to the radiation monitor. It may be located outside or inside the meter and may have its own battery. The speaker is in-line with the detector so each count produces an audible click on the speaker.

Operating Procedures for Radiation Survey Meters(refer to appropriate SOP)

- Read the instrument's operating manual to gain familiarity with the controls and operating characteristics.
- Check the meter for any physical damage. Look at the calibration certificate and check the date the meter was calibrated. Note that meters are required to be calibrated at least once a year.
- Check the batteries. Turn the selector switch to BATT position. The needle must be within BATT OK range. If not, the batteries are weak and must be replaced. Remember to turn off the instrument when not in use. When storing the meter for extended periods of time remember to remove the batteries and have the instrument recalibrated before resuming use.
- Check the operability of the detector. The RSO places a check source on all meters and records the meter's response with the detector on the source on the calibration sticker. With the meter and speaker turned on, position the selector switch to the appropriate scale, place the detector window over the check source, and measure the radiation of the source. Compare the response with that recorded on the calibration sticker. This response should be within + 20% of the indicated response.
- Determine the operating background. With the meter turned on and the selector switch on its lowest scale, point the detector away and/or move away from any radiation fields and measure the background radiation. Note that the meter reading must be multiplied by the selector switch scale (i.e., x 1, x 10, x 100, etc.). The result is the background reading. Normal background readings are about 0.02 mR/hr or 20 to 40 cpm for GM meters, and about 150-200 CPM for LEG meters.
- With the speaker on, point the probe window at the area or equipment you wish to monitor for radiation exposure or radioactive contamination. Unless contamination is expected, place the selector switch on the lowest scale. When surveying or entering contaminated areas with unknown radiation levels, turn the meter on outside the area, place the selector switch on the highest range setting and adjust the switch downward to the appropriate scale. Multiply the meter reading by the selector switch scale - if the needle is on 2 mR/hr, and the selector switch is on the x 10 scale, the radiation exposure is 20 mR/hr.

Liquid Scintillation Counters

LSC's come in a variety of shapes and types and manufacturers may use different terminologies, but an overview of terms basic to scintillation counting follows.

Cocktail:

The scintillation fluid. A mixture of chemicals which emits light flashes when it absorbs the energy of radioactive decay.

CPM:

Counts per minute. This is the number of light flashes or counts the LSC registered per minute. The number of decays produced by the radioactivity is usually more than the number of counts registered. Discriminator A circuit which distinguishes signal pulses according to their pulse height. It is used to exclude noise or background radiation counts.

DPM:

Disintegration per minute. This is the number of decays per minute.

Efficiency:

The ratio, CPM/DPM, of measured counts to the number of decays which occurred during a measurement time.

Emulsifier:

A chemical component of the liquid scintillation cocktail that absorbs the UV light emitted by the solvent and emits a flash of blue light.

Fluors:

Chemicals present in the liquid scintillation cocktail that convert the energy of the beta decay to flashes of light.

PMT:

The Photo-Multiplier Tube is the device that detects and measures the blue light flashes from the fluor and converts it into an electrical pulse.

Pulse:

Electrical signal of the PMT; its size is proportional to the radiation energy absorbed by the cocktail.

Quenching:

Anything which interferes with the conversion of decay energy emitted from the sample vial into blue light photons. This usually results in reduction in counting efficiency.

QIP:

The Quenching Index Parameter is a value that indicates the sample's level of quenching. Another parameter that describes the amount of quenching present is the transformed Spectral Index of External Standard (tSIE) or "H" number.

Solvent:

A chemical component of the liquid scintillation cocktail that dissolves the sample, absorbs excitation energy and emits UV light which is absorbed by the fluors.

Basic Operating Procedures for LSC'S (refer to appropriate SOP)

- Read the instrument operating manual to gain familiarity with the controls and operating characteristics.
- Place your sample into a liquid scintillation vial and add the appropriate amount of liquid scintillation cocktail.
- Prepare at least one background vial. This vial ideally contains a non-radioactive sample similar to your radioactive samples mixed with scintillation cocktail.
- Place your sample vials along with the background vial into an LSC tray and place the tray into the LSC.
- Review the instrument settings and/or counting program to ensure they appropriate for the type of radiation you are counting.
- Begin instrument counting cycle.

Contact the RSO/LM for more information on the theory and mechanisms for liquid scintillation counting.

TABLE 1. Detector Efficiencies for Common Radioisotopes

Isotope	Radiation[1]	Energy (MeV)	Counting Method[2]	Typical Efficiency[3]
Hydrogen-3	ß-	0.01	LSC	40%
Carbon-14	ß-	0.15	LSC GM	85%
Sodium-22	ß+	0.54	LSC GM	95%
Sodium-22	γ	1.27	LEG	5%
Phosphorus-32	ß-	1.71	LSC GM	95%
Phosphorus-33	ß-	0.24	LSC GM	85%
Sulfur-35	ß-	0.16	LSC GM	85%
Calcium-45	ß-	0.25	LSC GM	90%
Chromium-51	γ	0.320	LEG LSC	10%
Cobalt-57	γ	0.122	LEG LSC	40%
Nickel-63	ß-	0.06	LSC	60%
Zinc-65	γ	1.115	LEG LSC	5%
Iodine-125	γ	0.035	LEG LSC	90%
Cesium-137	ß-	0.51	LSC GM	95%
Cesium-137	γ	0.66	LEG	7%

[1]Electrons are either Auger or conversion electrons, the efficiency given accounts for abundance

[2]GM - GM thin end-window probe; pancake has slightly higher efficiency

LEG - Low Energy Gamma Probe LSC - Liquid Scintillation Counter

[3]LSC efficiency will depend on the amount of quenching present in the sample. Values listed are based on 50% quench. GM efficiency is based on the probe's end-cap being "off", efficiency with the cap on is 1/2 these values.

Chapter 3: Biological Effects of Radiation

Hazard Classification

In radiation safety, the major goal is to insure that most of the ionizations which occur as a result of a radiation's energy deposition do not occur in either radiation workers or in the general public. Radiation which can deposit energy within healthy tissue may carry some risk. In assessing the radiation work area it is important to distinguish between the two types of radiation hazards, external and internal.

An external radiation hazard is a type of radiation which has sufficient energy that, from outside of the body, it is capable of penetrating through the protective layer of the skin and deposit its energy deep (>0.07 cm) inside the body. External hazards are type and energy dependent.

There are three major types of external hazards: (1) X- and γ-rays, (2) neutrons and (3) higher energy (>200keV) ß particles. Each of these types of radiation is considered penetrating. While the high energy ß particles are capable of penetrating the skin, the uncharged particles and rays can also interact with tissues deep in the body.

An internal radiation hazard arises from radioactive material being taken into the body either by inhalation, ingestion, or absorption through the skin, then metabolized and stored in body compartments which utilize the particular chemical or elemental form. For example, radioiodine in the form of NaI, is capable of volatilizing. If inhaled, approximately 20% to 30% will be metabolized and stored in the thyroid gland. Radioactive material stored in the body is capable of irradiating surrounding healthy tissues. While all radiations pose a potential hazard, it has been found that the types of radiations which are not penetrating (e.g., a- and low energy ß- particles) have the greatest potential to damage those tissues if ingested, inhaled or absorbed.

External Radiation Exposure

As we have seen, the principal difference between nuclear radiation and other types of radiation such as heat or light is that nuclear radiation deposits its energy which produces ion pairs (ionizations) as it passes through matter. The ionization of living cells can lead to molecular changes which damage the cell's chromosomes. Radiation can cause several different types of damage to cells such as small physical displacement of molecules or the production of ion pairs. If the energy deposited is high enough, biological damage can occur (e.g., chemical bonds can be broken and cells can be damaged or killed). There are several possible results from cellular radiation interactions:

The damaged cells can repair themselves so no damage is caused. This is the normal outcome for low doses of radiation commonly encountered in the workplace.

The cells can die, like millions of normal cells, and be replaced through the normal biological process. A change may occur in the cell's reproductive structure in which the cell may mutate and subsequently be repaired with no effect, or they can form precancerous cells, which may then become cancerous.

Generally, the most radiosensitive cells are those that are rapidly dividing and undifferentiated. Examples include immature blood cells, intestinal crypt cells, etc. Damage to these cells is manifested by clinical symptoms such as decreased blood counts, radiation sickness, cataracts or, in the long term, cancer.

Biological Effects

The effects on the human body as the result of damage to individual cells are divided into two classes, somatic and genetic. Somatic effects are dose dependent, arising from damage to the body's cells and are only seen in the irradiated person. Genetic effects result from damage to reproductive cells where it is possible to pass on the damage to the irradiated person's children and to later generations.

Immediate Somatic Effects/ Acute Radiation Syndrome

As previously mentioned, somatic effects are entirely dose dependent. To date, detrimental effects have only been seen for acute exposures, large doses of radiation received in a short period of time. Acute whole body exposures in excess of 100 rem (i.e., much higher that is allowed for workers to receive in a lifetime of radiation work) may damage a sufficient number of radiosensitive cells to produce symptoms of radiation sickness within a short period of time, perhaps a few hours to a few weeks. These symptoms may include blood changes, nausea, vomiting, hair loss, diarrhea, dizziness, nervous disorders, hemorrhage, and maybe death.

Without medical care, half of the people exposed to a whole body acute exposure of 400 rem may die within 60 days (LD50/60). Regardless of care, persons exposed to a whole body acute exposure exceeding 700 rem are not likely to survive (LD100). Exposed individuals who survive acute whole body exposure may develop other delayed somatic effects such as cataracts and/or cancers.

Table 2. Radiation Injury vs Whole Body Acute Exposure

Dose (rem)	Result
0-25	No clinically detectable effects
50	Slight blood changes
100	Blood changes
200	Blood changes, plus nausea, vomiting, fatigue
400	Above plus anorexia, diarrhea, some deaths in 2-6
700	Probable death for 100% of those exposed within 2

Delayed Somatic Effects

Radiation damage to somatic cells may result in cell mutations and the manifestation of cancer. However, these delayed effects cannot be measured at low radiation doses received by radiation workers. In fact, radiation worker populations exposed to currently allowed standards have not been shown to have increased cancer rates when compared to the rest of the population. The estimate of any (statistically) small increased cancer risk is complicated by the facts that:

There is a long, variable latent period (about 5 to 30 years or more) between radiation exposure and cancer manifestation

A radiation-induced cancer is indistinguishable from spontaneous cancers

The effects vary from person to person

The normal incidence of cancer is relatively high (i.e., the fatal cancer risk from all causes in the U.S. is about 20% or one person in five)

Most regulators take a conservative approach to radiation-induced cancer risk, assuming the risk from radiation is linearly related to the radiation exposure and that there is no threshold for effects. For that reason, workers should aim to keep their exposure ALARA (As Low As Reasonably Achievable). As an estimate, a single exposure of 1 rem carries with it an increased chance of eventually producing cancer in 2 - 4 of 10,000 exposed persons. Lengthening the time for the same exposure should lower the expected number of cancers because of cellular repair (a factor not considered in the establishing the dose limits).

Genetic Effects

Genetic effects from radiation exposure could result from damage of chromosomes in the exposed person's reproductive cells. These effects may then show up as genetic mutations, birth defects or other conditions in the future children of the exposed individual and succeeding generations. Again, as with cancer induction, radiation-induced mutations are indistinguishable from naturally occurring mutations. Chromosome damage is continually occurring throughout a worker's lifetime from natural causes and mutagenic agents such as chemicals, pollutants, etc. There is a normal incidence of birth defects in approximately 5 - 10% of all live births. Excess genetic effects clearly caused by radiation have not been observed in human populations exposed to radiation. However, because ionizing radiation has the potential to increase this mutation rate (e.g., an exposure of 1 rem carries with it an increased chance for genetic effects of 5 - 75 per 1,000,000 exposed persons), it is essential to control the use of radioactive materials, prevent the spread of radiation from the work place, and ensure that exposure of all workers is maintained ALARA.

Mutations become genetic effects as they are carried through to succeeding generations by genes. Exposure to radiation of a person beyond child bearing age will have no genetic effect on future populations because they cannot pass on damaged chromosomes to their offspring.

Internal Radiation Exposure

As previously discussed, not all radiation is equally penetrating. When exposed to external sources of ionizing radiation, only high-energy beta particles and gamma/X-rays are potentially hazardous. Table 3 lists some commonly encountered, low-energy beta emitting radioisotopes which are not external hazards. Generally, beta emitters which have maximum beta energies of less than 200 keV are not external radiation hazards.

Table 3. Common Low Energy Beta Emitters

Isotope	Symbol	Half- life	Decay Product	Energy, keV
Tritium	^{3}H	12.3 yrs	ß	18.6
Carbon-14	^{14}C	5700 yrs	ß	157
Sulphur- 35	^{35}S	88 days	ß	167
Nickel-63	^{63}Ni	92 yrs	ß	67

However, once inside the body, radioisotopes emitting particulate radiations are extremely hazardous. Radioisotopes can enter the body by workers eating or drinking in an area where radioactive materials are used, by breathing in vapors or aerosols from volatile radioactive compounds, or absorption into the body through cuts or wounds in the skin. The body treats these radioisotopes as it does similar, non-radioactive elements. Some is excreted through normal body processes, but some may be metabolized and incorporated in organs which have an affinity for that element.

The hazard an internal radionuclide poses is directly related to the length of time it spends in the body. Radioactive material not incorporated in an organ is rapidly excreted, thus the hazard is less than if it remains inside the body for a long time as part of the body tissue. Radioisotopes incorporated in organs are more slowly excreted. Different organs have different affinities for certain radionuclides, so the excretion rate depends on the organ involved. This natural elimination rate, the biological half-life, is the time required for the body to naturally reduce the amount of a chemical or elemental substance in the body to one-half of its original amount. However, all the time the radioisotope is in the body it is also decaying so, even if none of the isotope is excreted the amount in the body is still continually decreasing. Specific organs may have different biological half-lives, and the biological half-life and the physical half-life can be different. The combination of the biological half-life and the physical half-life is called the effective half-life. Table 4 gives the physical, biological and effective half-lives of some common radioisotopes. The value listed as the biological half-life is the whole body half-life, not organ specific.

Table 4. Half-Lives of Common Radioisotopes

Isotope	Physical	Biological Half-life	Effective Half-life
Tritium	12.3 years	12 days	12 days
Carbon-14	5700 years	10 days	10 days
Sodium-22	2.6 years	11 days	11 days
Phosphorus-32	14.3 days	257 days	13.5 days
Phosphorus-33	25.3 days	257 days	23.0 days
Sulfur-35	88 days	90 days	44.3 days
Chromium-51	27.7 days	616 days	26.6 days
Cobalt-57	271.8 days	9.5 days	9.2 days
Nickel-63	92 years	667 days	655 days
Iodine-125	60 days	138 days	42 days
Iodine-131	8 days	138 days	7.6 days
Cesium-137	30.2 years	70 days	69.5 days

Radiation Exposure during Pregnancy

The embryo/fetus is especially sensitive to radiation during the first three months of pregnancy when there is rapid cell division and organ development taking place. Radiation damage at this time could produce abnormalities that would result in birth defects or fetal death.

Most of the research on fetal radiation effects has been performed on laboratory animals exposed to very high radiation levels. Some studies of children who were exposed to low levels of radiation (during medical procedures or tests) as fetuses have suggested that even at the levels allowed for radiation workers (5 rem TEDE/year) there may be an increased risk for fetal damage. Therefore, Federal regulatory agencies require that the radiation dose to the embryo/fetus as a result of the occupational exposure to the expectant mother should not exceed 0.5 rem TEDE (10% of the normal limit) during the duration of the pregnancy. Workers who are pregnant or are trying to become pregnant can inform the Radiation Safety Officer. Once a worker has declared her pregnancy in writing, Radiation Safety Program staff will provide additional information on actions to take to ensure that the "declared" pregnant worker maintains her radiation exposure ALARA, and within the 500 mrem limit. Additional information on the various risks to the fetus from radiation can be found in several of the Nuclear Regulatory Commission's pregnancy guides, including Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure."

Biological Hazards from Radioactive Compounds

Some of the lab work conducted at TIAER uses compounds that may have radioactive elements as components of the compound. This type of material is specially synthesized to provide information about metabolism or other cell processes. If taken into the body these compounds, unlike "pure" radioactive elements, will then be processed by the body differently and perhaps will be stored for even longer periods of time. For example, it is estimated that ^{3}H ingested in the form of thymidine is 9 times more hazardous than ^{3}H ingested in the form of water. Thus, those radionuclides which are incorporated into nucleic acids are of particular concern in radiation safety.

Damage to a cell's genetic material, particularly to the DNA, is the major harmful effect of radiation and can lead to cell death, mutations, and other detrimental effects. Compounds which contain radiolabeled nucleic acids have the potential, if ingested by a worker or entering the body through cuts, needle sticks, or breaks in the skin, of exposing the worker's DNA to radiation that may affect cell replication or cause a change in genetic function. The nucleic acids which use ^{3}H, ^{14}C, ^{32}P, ^{35}S and ^{125}I are of concern not only because the radioactive material can be incorporated into a cell's nucleus, but also because the radiation emitted will be absorbed primarily within the cell, increasing the possibility that harmful effects will occur. Therefore, individuals who work with these radioactive compounds must take great caution to ensure the material remains outside the body where they pose only a minor hazard. Good housekeeping and cleanliness are crucial. Wear gloves and never mouth pipette any solutions, radioactive or otherwise. Additionally, at the completion of work with a radioactive compound, wash your hands and forearms thoroughly and use appropriate radiation survey instruments to check your hands, feet, clothing, and work area for radioactive contamination before leaving the lab.

Chapter 4: Current Standards and Dose Limits

Background Radiation

The radiation exposure that we receive in any given time period does not just come from manmade sources. Besides man-made radiation we are constantly bombarded by a low level of natural background radiation. In the United States the average radiation exposure of the population to both natural and man-made-sources is approximately 357 mrem per year. Of that total 294 mrem per year is attributed to natural sources and 63 mrem per year from man-made sources. The natural background sources of radiation are derived from four different sources.

Table 5 provides a summary of the average U.S. population exposure to these sources.

Table 5. Average U.S. Population Radiation Exposure

Natural Background Sources	Average Exposure
Cosmic Rays	27
Terrestrial	28
Radon	200
Internal	39
Sub Total: 294 mrem/year	
Man-Made Sources	**Average Exposure**
Medical/Dental Radiation	53
Consumer Products	10
Other	< 1
Sub Total: 63 mrem/year	

Cosmic radiation is high-energy particulate radiation produced in the stars and our own sun which bombards the earth and makes the atoms in the upper atmosphere radioactive. A person exposure to cosmic radiation is dependent on how close they are to outer space.

Terrestrial radiation is radiation resulting from the decay of naturally occurring radioactive materials, like uranium and thorium, in the earth's crust. The exposure is greater if one lives near large sources of naturally occurring materials as in granite-type mountainous areas as opposed to calcite type (limestone) areas.

Radon is a gaseous element resulting from the decay of uranium and escapes the earth's crust through fissures and other natural breaks. As the radon is inhaled, it is deposited in the lungs where the massive energy of the alpha particles can damage the exposed lung cells.

Internal radiation results from naturally occurring radionuclides, like ^{14}C, ^{3}H, and ^{40}K, that are ingested and treated by the body like their non-radioactive isotopes. They are stored in various organ systems and give a long-term, low-level radiation exposure.

History of Current Standards

Radiation safety regulations regarding the use and handling of radioactive materials have evolved significantly during the past century. Initially it was not well known what the effects of radiation were. Many early experimental procedures involved high radiation exposures and resulted in workers and patients suffering prompt, somatic effects such as skin burns and hair loss. As research continued, researchers found that exposure to radiation had the potential to cause long term genetic effects in addition to the somatic effects. Personnel exposed to high levels of radiation or radioactive materials seemed to have an increase in certain types of cancers over people not exposed to radiation. As further studies continued and more was learned about the potential effects of radiation exposure, federal regulators worked to determine what "acceptable risks" radiation workers could assume as they work with radioactive materials.

It must also be noted that society's perception of the risk from radiation is different from a scientist's perception of risk. While researchers were working with radiation and studying its effects, movie goers were watching "The Fly" and other science fiction films which portrayed radiation as universally harmful. Additionally, the generation from 1945 to 1975 saw the effects of radiation weapons on large, unprepared populations, experienced an increase in above ground nuclear testing, and lived with the threat these weapons posed to them. One effect of the above ground nuclear testing was the fear that all the nuclear fallout would have detrimental effects on the world's gene pool, potentially increasing the rate of birth defects and cancers. Thus, when determining radiation exposure levels the regulators needed to consider not just the effects on radiation workers, but society's fears and the potential effects to the entire population.

As the concept of ALARA (As Low As Reasonably Achievable) has been incorporated into federal exposure limits, the goal has been changed from only protecting workers from their radiation work to include reducing the risk of cancers and birth defects in a population which could result from our total radiation exposure.

Current Exposure Limits

Current federal exposure limits address exposure to several groups in the population. Their goal is to weigh the radiation risk to the groups involved with the benefits derived. There is no risk benefit question involved with exposing a person to 500 mrem that allows for a lifesaving medical diagnosis to be made. Nor is there undue concern with giving the population of the U.S. an average of 0.001 mrem/year from smoke detectors because of their early warning benefit.

But, what about exposing laboratory workers to 10 mrem/year in the hope of finding the purpose of a specific DNA site?

Radiation workers do derive some benefit from their work, specifically their livelihood. However, while all jobs carry some risk (e.g., needle sticks in medical care, auto accidents in transportation, etc.) today's worker expects to survive work so they can retire. The permissible exposure limits for workers are thus set so there will be no somatic effects from their radiation exposure, even if the worker is exposed to the maximum allowed exposure year after year.

Additionally, although statistics suggest that the worker population may be at an increased risk for cancer induction, at the permissible exposure level no increases in cancer have been detected in populations of "radiation workers". Table 6 outlines the permissible dose limits for workers.

Table 6. Maximum Permissible Dose Limits

Population	mrem/year
Radiation worker - whole body	5,000
Radiation worker - skin	50,000
Radiation worker - extremities, hands	50,000
Radiation worker - minor (under 18)	500
Unborn Child of Radiation Worker	500[1]
Individual Members of the General Public	100

[1]exposure over entire gestation period

Some workers (i.e., delivery people, clerical staff, and physical plant personnel) are exposed to very small levels of radiation because of incidental exposure. Because these workers do not derive some benefit from this exposure, their allowable limits are less. Exposure to individual members of the general public who do not routinely access radionuclide labs as part of their assigned duties are limited to 100 mrem/year exposure. Unborn children may be exposed when their radiation worker mother is at work. To keep the unborn child's exposure below 500 mrem for the entire gestation period, the radiation exposure of a "declared" pregnant worker is below 500 mrem during her pregnancy.

Radiation Exposure Risks

One common way to assess radiation risk is to compare it to other risks. Several studies have been done comparing the projected average loss of life expectancy from radiation exposure to other health risks. Using these studies, an individual who gets cancer loses an average of 15 years of life expectancy while his/her coworkers suffer no loss. The average US radiation worker exposure in 1992 was 0.3 rem. Using these data we can compare the average number of days of life expectancy lost per rem exposure to other health risks. Thus, we assume 0.3 rem radiation exposure per year from 18 to 65 results in a projected estimate of life expectancy loss of 15 days. Radiation risks are compared with other risks in Tables 7 and 8.

Table 7. Health Risks vs Life Expectancy

Health Risk	Expected Life
Smoking 20 cigarettes a day	6 years
Overweight (by 15%)	2 years
Alcohol consumption (US average)	1 year
Motor Vehicle Accidents	207 days
Home disasters	74 days
Natural disasters (earthquake, flood)	7 days
0.3 rem/year from age 18 to 65	15 days
1 rem/year from age 18 to 65	51 days

Table 8. Industrial Accidents VS Life Expectancy

Industry Type	Estimated Life
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining / Quarrying	167 days
Transportation / Public Utilities	160 days
Government	60 days
Manufacturing	40 days
Trade /Services	27 days

ALARA Program

As a safe-sided estimate, it is believed that exposure to radiation may carry some risk. Therefore, it is the goal of Radiation Safety to keep radiation exposures ALARA (As Low As Reasonably Achievable). Additionally, the radiation safety works to protect radiation workers from predicted cancers and reduce the predicted risk of cancers and birth defects in the population as a whole from radiation exposure. TIAER has implemented an ALARA program aimed to keep radiation exposure to workers and members of the general public ALARA by focusing on the following areas:

- Control the use of radioactive materials. Radioactive material use is strictly controlled. All orders for radioactive material must be approved by the Radiation Safety Officer. Each authorized user is allowed sufficient material to perform research, however there are limits established to insure new receipts of radioactive material are balanced by disposals of on- hand radioactive material.
- Prevent the spread of contamination. All lab workers must be sufficiently trained in both radiation safety and general laboratory procedures to work

competently and insure that accidents with radioactive material are kept to a minimum. Additionally, lab personnel need to be trained in emergency response so that if an accident occurred proper actions would be taken to prevent the spread of contamination off site.

- Audits of Authorized Users. Radiation Safety inspects each authorized user of radioactive materials to insure that the labs record keeping system meets the conditions of our NRC license. These inspections review both the ability of the lab to document their use of radioactive materials and that the adequacy of required surveys. Radiation Safety Program Staff also perform radiation and contamination surveys both in the laboratory and in areas outside the laboratory to insure that radiation exposure of non-radiation workers is kept as low as reasonably achievable.

- Review of dosimetry records. As part of the ALARA program established at UWM, the Radiation Safety Program is required to monitor and investigate, as necessary, worker radiation exposure. Normally, when a worker's monthly exposure (as reported by our dosimetry service) is more than 100 mrem, a member of the Radiation Safety Program staff will investigate the situation to determine why the worker received such a dose and what potential actions can be taken to reduce future doses for similar work.

Internal Doses

Radiation exposure from internal doses to radioactive materials is restricted by defined Annual Limits of Intake (ALI's). The ALI is a derived limit for the amount of radioactive material that, if taken into the body of an adult worker by inhalation or ingestion in one year, would expose an individual to the occupational limits. Table 9 lists the Annual Limits of Intake (ALI'S) of some commonly used radionuclides.

Table 9. Annual Limits of Intake for Various Radionuclides

Radionuclide	**ALI in mCi**
Tritium	80.0
Carbon-14	2.0
Sodium-22	0.4
Phosphorus-32	0.6
Phosphorus-33	6.0
Sulfur-35	10.0
Calcium-45	2.0
Chromium-51	40.0
Magnesium-54	2.0
Iron-59	0.9
Nickel-63	9.0
Iodine-125	0.1
Cesium-137	0.1

The NRC requires that any individual who may receive, in a year, an intake in excess of 10% of the applicable ALI must be monitored for internal exposure. **It is not anticipated that TIAER employees will receive anything near to this level of ALI**. To ensure regulatory limits are not exceeded, urine samples or other bioassay methods to monitor an individual's intake of beta or gamma emitters will be required when working with unsealed sources of radionuclides that exceed certain quantities. Additionally, other random bioassays may be required of individuals working with radioactive materials to ensure that the occupational limits are not being exceeded.

Radioactivity

Naturally occurring elements often have several different isotopes. While most of these naturally occurring isotopes are stable, some are unstable. Usually an atom is unstable because the ratio of neutrons to protons produces a nuclear imbalance (i.e., too many protons or too many neutrons in the nucleus). These unstable atoms attempt to become stable by rearranging the number of protons and neutrons in the nucleus to achieve a more stable ratio. The excess energy from this rearrangement is ejected from the nucleus as kinetic energy. In this rearrangement, the isotope usually changes atomic number and sheds any excess energy by emitting secondary particles and or electromagnetic rays/photons. This change in the nucleus is called nuclear disintegration. The entire process of unstable isotopes disintegrating and emitting energy is called radioactive decay or decay and an isotope capable of undergoing radioactive decay is said to be radioactive.

Most of the isotopes encountered in nature are not radioactive. However, there are mechanisms to inject energy into an isotope's nucleus causing it to become unstable. To activate an isotope is to make it radioactive. This can be accomplished in a nuclear reactor where the nucleus can be bombarded by neutrons or in an accelerator where high speed electrons, protons, or larger particles can be injected into the nucleus. If something merely touches a radioisotope, it does not become radioactive, but it may become contaminated with radioactive material.

Unstable nuclei are radioactive. Unlike chemical processes which occur at the electron level and can be affected by external forces like heat, there is no known way to alter radioactive decay. Radioactive decay cannot be artificially accelerated or slowed down because radioactive instability involves extremely strong nuclear forces. Each isotope decays at a rate that is unique among all other nuclides. Additionally, the type and magnitude of the radioactive energy emitted depends upon the isotope. Thus, there are three parameters that uniquely identify any radionuclide: the type(s) of energy emitted, the magnitude of the energy, and the rate at which the isotope decays.

Types of Emission

When a radioisotope decays it normally emits one or more of four basic types of radiations: alpha particles, beta particles, X- or gamma rays, and neutrons. These radiations interact with atoms and molecules in the environment and deposit their energy. Table 10, at the end of this section, presents some properties of these decay types.

An alpha (a) particle is a massive particle on the atomic scale. It consists of 2 neutrons and 2 protons and carries an electrical charge of +2. It is identical to a helium nucleus. Because the alpha particle is massive and highly charged it has a very short range and travels less than 5 cm in air or 0.044 cm in tissue before expending its energy, stopping, picking up two electrons to become a stable helium atom. Thus alpha particles are generally not a hazard to workers unless they get inside the body where they may cause much greater cellular damage than beta or gamma radiation.

A beta (ß) particle is a fast electron with a single charge. Depending on the isotope and mechanism of decay, the beta particle can have a negative or positive charge. The positively charged beta particle is called a positron (+ß). It usually results when the neutron: proton ratio is too low but when the alpha emission is not energetically possible. Positron emission produces a daughter nucleus which has the same atomic mass but is one less atomic number. The negatively charged beta particle is properly called an electron (e-) and, in every day usage the term beta radiation usually refers to the negative type, -ß. Beta (-ß) emission occurs when the neutron: proton ratio is too high.

Figure 5. Beta Decay Spectrum

$${}^{18}_{9}\mathrm{F} \text{ ------->} \; {}^{18}_{8}\mathrm{O} + {}^{0}_{+1}\beta + \nu \qquad {}^{32}_{15}\mathrm{P} \text{ ------->} \; {}^{32}_{16}\mathrm{S} + {}^{0}_{-1}\beta + \nu$$

positron ($^{+}\beta$) electron ($^{-}\beta$)

Because beta radiation is a small particle with only a single charge, a beta particle has a much greater range than an alpha particle with the same energy. Low energy beta particles, energies less than 200 keV, are easily shielded and only pose a potential hazard if they get inside the body. Thus, the beta particle emitted from ^3H with a maximum energy of 18 keV only travels about 6 mm in air and less than 0.00052 cm in tissue. Beta particles with energy less than 70 keV will not penetrate the protective layer of skin. Of the beta particles emitted from 14C or 35S (E_{max} ~ 160 keV), only 11% are capable of penetrating the dead layer of skin (0.007 cm thick). On the other hand, high energy beta particles have longer ranges. The range of beta particles in air is approximately 12 ft per MeV. Therefore, the beta from 32P ejected with a maximum energy of 1.7 MeV could travel up to 20 feet in air and 95% of the beta particles can penetrate the dead layer of skin, so 32P may pose a potential radiation hazard even from outside the body. Shielding large quantities of high energy beta particle emitters is usually done with plastic or plexiglass because when the beta particles are shielded with dense materials like lead, bremsstrahlung X-rays are produced.

A gamma (γ) ray is an electromagnetic ray emitted from the nucleus of an excited atom following radioactive disintegrations. Unlike beta particles, which are emitted in a spectrum of energies, gamma rays are emitted at discrete energies and provide a mechanism for the excited nucleus to rid itself of the residual decay energy that was not carried off by the particle emitted in its decay. Thus, many isotopes which decay by beta emission also have gamma rays (or photons) associated with the disintegration. Gamma rays are similar to light but of shorter wavelength and higher energy. Consider activities greater than 1 mCi a radiation hazard and shield with thick, dense material such as lead.

Figure 6. Gamma Ray Decay

$$^{22}_{11}\mathrm{Na} \text{------>} \; ^{22}_{10}\mathrm{Ne} + \, ^{0}_{+1}\text{ß} + \nu + ?$$

An x-ray is an electromagnetic ray, identical to a gamma ray in all respects except for point of origin. Gamma rays are emitted from the nucleus as part of the nuclear decay process. X-rays originate from outside the nucleus normally as part of electron orbital changes. A neutron (n) is an elementary nuclear particle with a mass approximately the same as that of a proton and is electrically neutral. Normally the neutron decays to a proton. Except when bound in the nucleus, the neutron is not a stable particle. A free neutron decays to a proton with the emission of a -ß and an antineutrino. This decay process takes on the average about 12 minutes. There are few naturally occurring neutron emitters. Aside from nuclear-fission reactions, the only way to produce neutron sources is through bombardment of the nuclei with high energy radiation (both particles and rays). Because a neutron is uncharged, it easily passes through the electron cloud and can interact with the nucleus of the atom, often making the atom radioactive.

Table 10. Decay Types

Name	Symb	Range	Shielding Requirements
Alpha particle	a	Short	None
Beta particle	ß	Moderate	Low Density Material, e.g. plastic
Gamma/X- rays	γ/X	Long	High Density Material, e.g. lead
Neutron	n	Long	Hydrogenous Material, e.g. paraffin

Energy

The energy carried away by the radiation is expressed in units of electron volts (eV). The electron volt is a very small quantity of energy (1.6x10-19 Joule). Most radiations are ejected with energies of many thousands or millions of electron volts, listed as either keV (kiloelectron volts - 1000 eV) or MeV (megaelectron volts - 1,000,000 eV). The amount of energy involved and the type of radiation emitted determines the penetrability of the radiation and consequently the shielding thickness and type required to protect workers from radiation. All things being equal, the higher the energy, the more penetrating the radiation. For example, gamma rays have higher decay energy and need more shielding than alpha or beta particles which have lower decay energies.

Activity

The decay of a radioactive sample is statistical. Just as it is not possible to change a specific isotope's rate of decay, it is impossible to predict when a particular atom will disintegrate. Rather, one measures activity as the number of radioactive nuclei that change or decay per unit time (e.g., second). The special unit of activity is the curie (Ci) where 1 curie represents 37 billion (3.7×10^{10}) nuclear disintegrations (decays) per second (dps) or alternately, 2.22×10^{12} disintegrations per minute (dpm). Sub-multiples of the curie are the millicurie (mCi) which represents one-thousandth (3.7×10^{7} dps) of a curie and the microcurie (µCi) which represents one-millionth (3.7×10^{4} dps) of a curie. As will be discussed later in this section, everywhere except in the U.S., the curie unit has been replaced by the bequerel (Bq) unit where 1 Bq is 1 nuclear disintegration or decay per second.

Decay Rate and Half-Life

Radioisotopes are always in a state of decay, emitting energy. Therefore, the amount of radioactivity remaining is continually decreasing. Each radioisotope has a unique decay rate and that decay rate is the physical half-life (T1/2) of the radioisotope. Half-life describes the length of time required for the amount of radioactivity present to decrease to half of its original amount. This decrease in material is not linear. Figure 7 shows a plot of the decay of a radioisotope having a half-life of 1 day so you can see how rapidly the amount decreases.

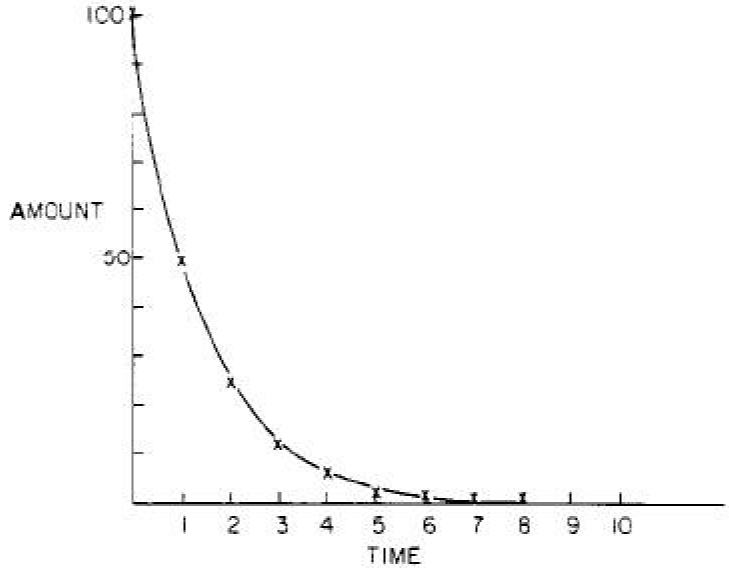


Figure 7. HALF-LIFE

Referring to Figure 7, if we start with 100 microcuries of material, by the end of the second day (two half-lives) we will have only 25 microcuries of material, and at the end of the fourth day only 6.25 microcuries will remain. However, there are still over one quarter million disintegrations per second remaining, even after four half-lives.

From Figure 7 you can see that the greater the number of radioactive atoms that are initially present, the greater the number of nuclei that will decay during a half-life (e.g., if 100 radioactive atoms are present, 50 will decay in one half-life, if 1000 radioactive atoms are present, on average 500 will decay in one half-life). The decay rate or activity of a radioactive sample is proportional to the number of unstable nuclei that are initially present. This relationship is expressed by the universal decay equation where A_0 is the original radioactivity of the sample, A_t is the amount of radioactivity remaining after the elapsed time, t, and 1/2 is the (physical) half-life of the radioisotope. The decay constant, ?, expresses the rate of decay as a factor of the radioactive half-life ($T_{1/2}$), where ? = ln $2/T_{1/2}$.

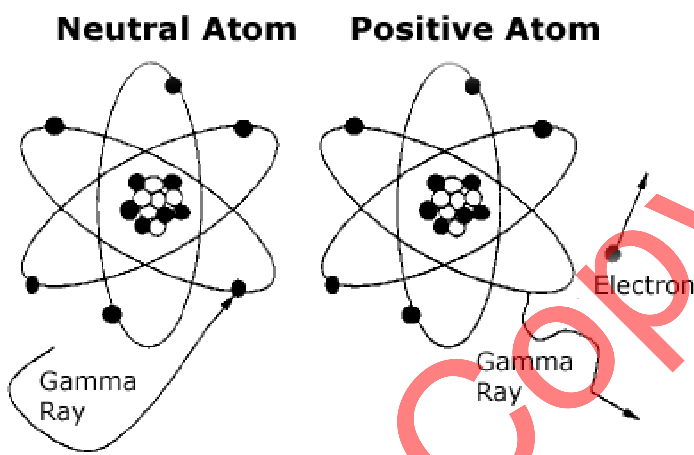
Figure 8. Universal Decay Equation

$$A_t = A_0\, e^{-}\, ?t \; = A_0\, e^{-}\, \ln^2/T_{½}\, t$$

Interactions with Matter

When alpha, beta or gamma radiation passes through matter it interacts with atoms and molecules, depositing energy in the matter until it has spent its kinetic energy and comes to rest or is absorbed. Ionizing radiation interacts at the orbital electron level and results in ionization and excitation of the atoms in the matter. Ionization (Figure 9) is the process where the electrons are knocked out of their orbits producing ion pairs (i.e., a free electron and a positively charged atom or molecule). If sufficient energy is deposited an orbital electron may be excited and on returning to ground state, emit low energy radiation.

Figure 9. Ionization



Radiation Quantities and Units

A quantity is some physically measurable entity (e.g., length, mass, time, electric current, etc.) that needs to be measured. A unit is the amount of quantity to be measured. Units for various quantities are formulated when needed by national or international organizations such as the National Institute of Science and Technology (NIST) or the international General Conference on Weights and Measures (CGPM). Traditional units were formulated by these organizations.

Traditional units used to measure and quantify radioactive materials were developed during late 1800's during early research into radioactive materials. That early research showed that the number of ion pairs produced in a physical substance is related to the amount of radiation energy deposited in the substance. The oldest, still used, radiation unit, the roentgen (R), is based on the number of ion pairs produced in a volume of air traversed by x- or gamma radiation. This unit of x-/γ radiation exposure in air, is defined to be the collection of 2.58×10^{-4} coulombs per kilogram of air. Since each electron carries a charge of 1.6×10^{-19} coulomb, this represents 1,610,000,000,000,000,000 ion pairs in a kilogram of air. Submultiples, the milliroentgen (mR) and the microroentgen (μR) are also frequently used.

Early radiation researchers also investigated the effects of radiation energy on matter. Initially the roentgen was widely used, but because it is limited to x-/γ radiation in air, a second unit, the rad, was defined to be the unit of absorbed dose in any matter. The rad equals 100 ergs of energy deposited per gram of matter. Although the roentgen is a unit of radiation exposure in air and a rad is a unit of exposure in tissue, the two units are very close in magnitude. They are correlated by the fact that 1 roentgen produces 0.96 rad in biological tissue. An easy method for defining is to think of it as the acronym for radiation absorbed dose.

Investigating the effects of radiation at the cellular level, researchers found that for the same quantity of absorbed dose, different types of radiations produced different amounts of cellular damage. For example, the cellular damage from an absorbed dose of 100 rad from alpha particles was significantly more severe than the damage caused by 100 rad from gamma rays. The "quality" of the alpha particle's deposited energy, at the cellular level, is greater than the "quality" of the gamma ray's deposited energy. The rem is the unit of radiation dose equivalence used to equalize the biological effectiveness of the various types of radiation. The radiation absorbed dose in rad, multiplied by the radiation's quality factor, Q, which varies from 1-20 (Table 11), produces the dose equivalent, in rem, of the radiation exposure (i.e., rem = rad x Q). Thus, an absorbed dose of 1 rad to tissue from a radionuclide deposition produces a dose equivalence of 1 rem if the radionuclide is a beta emitter and a dose equivalence of 20 rem if the radionuclide is an alpha emitter. An easy method for defining a rem is to think of it as the acronym for roentgen equivalent man.

Table 11: Quality Factors

Type of Radiation	***Q***
X- /Gamma Rays	1
Beta Particles, electrons	1
Thermal neutrons	2-3
Fast neutrons, protons	10
Alpha Particles	20

In the 1970's an international agreement was developed to make all physical constants convertible by multiplying by units of "1" alone. This system of measurement is called the international system of units or SI (Le Système International d' Unitès). SI units are based on the MKS (meters, kilogram, second) system. Thus, the unit of (radio) activity was changed from the curie which is 3.7 x 10^{10} nuclear disintegrations per second (dps) to the Becquerel (Bq) which is 1 dps. The traditional unit of absorbed dose, the rad, was replaced by a new unit of absorbed dose, the gray (Gy), which is defined as 1 Joule per kilogram, and is equal to 100 rad. Similarly, the unit of dose equivalent was replaced by the Sievert (Sv) which is equal to 100 rem. Table 12 shows the relationship between the traditional and new (SI) units. However, the U.S. has not yet converted to the SI units and all domestic regulations continue to use the traditional (special) units of curie, rad and rem.

Table 12. Radiation Quantities and Units

Traditional		SI Conversion Factor	
Unit	Quantity	Unit	Quantity
Curie	3.7 x 10^{10}	becquerel 1 dps	1 Bq=2.7x10^{-11}Ci
rad	100 erg/gm	gray 1 J/kg	1 Gy = 100 rad
rem	rad x Q	Sievert Gy x Q	1 Sv = 100 rem

Table 13. Metric Prefixes

Prefix	Quantity	Prefix	Quantity
da deka	10^1 10	d deci	10^{-1} 0.1
h hecto	10^2 100	c centi	10^{-2} 0.01
k kilo	10^3 1000	m milli	10^{-3} 0.001
M mega	10^6 1,000,000	µ micro	10^{-6} 0.000 001
G giga	10^9 1,000,000,000	n nano	10^{-9} 0.000 000001
T tera	10^{12} 1,000,000,000,000	p pico	10^{-12} 0.000 000 000 001
P peta	10^{15} 1,000,000,000,000,000	f femto	10^{-15} 0.000 000 000 000 001

Characteristics of Commonly Used Radionuclides

Radioisotope use at TIAER typically consists of small quantities of liquid materials. To ensure worker safety and to prevent accidental exposure, all labs where radioactive materials may be used or stored are conspicuously posted with "Caution - Radioactive Materials" signs. To reduce radiation exposure, workers in these posted areas must understand the characteristics of the radioisotopes. The required “Notice to Workers” is also posted per Texas law.

Characteristics of commonly used radioisotopes are listed in Table 14. This table includes: isotope and chemical symbol (e.g., ^{3} H, ^{32}P); half-life ($T_{½}$); and, most importantly, energy of the major radiations emitted. Because ß particles are emitted in a wide spectrum of energies, the energy listed is the maximum energy that the emitted beta particle can possess.

Table 14. Characteristics of Common Radioisotopes

Isotope	Symbol	Half-Life	Radiation	Energy, MeV
Tritium	^{3}H	12.3 yr	ß	0.157
Sodium-22	^{22}Na	2.6 yr	ß γ	0.546 1.274
Phosphorus-32	^{32}P	14.3 days	ß	1.709
Phosphorus-33	^{33}P	25.3 days	ß	0.249
Sulfur-35	^{35}S	88 days	ß	0.167
Calcium-45	^{45}Ca	163 days	ß	0.258
Chromium-51	^{51}Cr	28 days	γ	0.320
Cobalt-57	^{57}Co	272 days	γ	0.122
Nickel-63	^{63}Ni	92 years	ß	0.067
Iodine-125	^{125}I	60 days	γ	0.035
Iodine-131	^{131}I	8.0 days	ß γ	0.606 0.364
Cesium-137	^{137}Cs	30 years	ß γ	0.514 0.662

This training document is from the University of Wisconsin at Milwaukee.

Adapted for TIAER 7/7/15-8/2/16 mm RSO/LM

Attachment 3

Time Requirements for Record Retention

(Radiochemistry Documents)

Name of Record	Time Interval Required for Record Keeping
Utilization Records for Portable and Mobile Devices	3 years after the record is made
Records at Authorized Use/ Storage Sites	While site is authorized on license/registration
Radiation Protection Programs	Until termination of license/ registration
Program Audits	3 years after the record is made
Routine Surveys, Instrument Calibrations and Package Monitoring	3 years after the record is made
Surveys; Measurements and/or Calculations Used for Dose Determination; Results of Air Sampling, Surveys and Bioassays; Measurements, Calculations Used to Determine Release of Radioactive Effluents	Until termination of license/ registration
Tests for leakage/ contamination of sealed sources	5 years after the record is made
Lifetime Cumulative Occupational Radiation Dose, RC Form 202-2	Until termination of license
Records Used to Prepare RC Form 202-2	3 years after the record is made
Planned Special Exposures	Until termination of license
Individual Monitoring Results; RC Form 202-3	Entries at no > 1 year intervals, by April 30 each year; Maintain until termination of license/registration
Records Used to Prepare RC Form 202-3	3 years after the record is made
Dose to Individual Members of the Public	Until termination of license/registration
Discharge, Treatment, or Transfer for Disposal	Until termination of license/registration

Attachment 4

Quarterly Radioactive Material Inventory Form

(May also be an E-Log)

Identification/ Location	Isotope	Activity	Receipt Date	Half life	Disposition

Performed by: ______________________

Date: _______________________

Review/Approval: ______________________________

R-100-1

Transportation Requirements for Radioactive Materials

From 49 CFR 100-189 and TAC 289.257

1. No activities or quantities shall exceed TIAER's Radioactive Materials License
2. The Movement Control Center (TIAER main laboratory and RSO) shall always be informed of what materials are being moved, to where and when. A complete inventory shall be performed before and after mobilization of the mobile lab when involving radioactive materials.
3. Shipments of low specific activity materials and surface contaminated objects must be loaded so as to avoid spillage and scattering of loose materials.
4. Packages must be so blocked and braced that they cannot change position during conditions normally incident to transportation. Normally this will be mobile lab cabinet storage.
5. External rad levels of any sample container or package shall never exceed 200 mrem/hr at the surface. Any receipt of new packages or containers shall comply with QAM-Q-110 and QAM-Q-102. No shipping paperwork is required other than a copy of the most recent inventory.
6. No more than 50 packages or containers shall be transported together (including radioactive sources, standards or samples).
7. Comprehensive surveys will be taken by the RSO or designee in accordance with SOP-RC-111, Determination of Radioactive Surface Contamination Using Swipe Surveys, upon return of the mobile lab to the main lab campus.
8. Any driver who transports radioactive material must be trained in accordance with QAM-Q-107, including basic hazmat training and laboratory safety. In addition, the driver shall also be trained for: Pre-trip safety inspection; Use of vehicle controls and equipment, including operation of emergency equipment; Operation of vehicle, including turning, backing, braking, parking, handling, and vehicle characteristics including those that affect vehicle stability, such as effects of braking and curves, effects of speed on vehicle control, dangers associated with maneuvering through curves, dangers associated with weather or road conditions that a driver may experience (e.g., blizzards, mountainous terrain, high winds), and high center of gravity; Procedures for maneuvering tunnels, bridges, and railroad crossings; Requirements pertaining to attendance of vehicles, parking, smoking, routing, and incident reporting; and Loading and unloading of materials, including—Compatibility and segregation of cargo in a mixed load; Package handling methods; and Load securement. Such training shall be documented on Form Q-107-1, Personnel Training Record, to include these elements.
9. If there is any question or concern about acceptance or storage levels for a particular isotope, notify the RSO and consults 49 CFR § 173.435 Table of A1 and A2 values for radionuclides.
10. Sealed sources and fixed samples are to remain secured and locked. In addition, unsealed sources, liquid and unfixed solid samples are packaged in sealed plastic, then stored in vermiculite absorbent (sufficient to absorb twice the material volume) in plastic or cardboard containers in the locked area. Proper storage limits loss or dispersal of the radioactive contents; and a significant increase in the radiation levels recorded or calculated at the external surfaces. Containers < 0.5 mrem/hr as surveyed by QAM-R-101 are labeled as "USA DOT TYPE IP-2". From 0.5-200mrem/hr, containers are labeled as "USA DOT TYPE A". In addition, any other known

information is labeled on the outside of the container, such as isotope, activity, receipt date or other identifying data.

11. Any acid or chemical storage is kept secure and segregated from radmat storage.
12. All waste is secured and segregated from standards and samples.
13. The mobile lab is considered a vehicle for exclusive use transport of radmat.
14. These mobile lab shall be stenciled with the words “For Radioactive Materials Use Only” in lettering at least 7.6 cm (3 inches) high in a conspicuous place, on both sides of the exterior of the vehicle when transporting radmat. It shall be kept closed and locked at all times other than loading and unloading.
15. Other criteria for packaging and transport:
    a. The package can be easily handled and properly secured in or on a conveyance during transport. All containers are expected to be small enough to handle easily by hand.
    b. The external surface, as far as practicable, will be free from protruding features and will be easily decontaminated.
    c. The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect.
    d. Each feature that is added to the package will not reduce the safety of the package.
    e. The package will be capable of withstanding the effects of any acceleration, vibration or vibration resonance that may arise under normal conditions of transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use.
    f. The materials of construction of the packaging and any components or structure will be physically and chemically compatible with each other and with the package contents. The behavior of the packaging and the package contents under irradiation will be taken into account.
16. In addition, Type A packages are used to transport small quantities of radioactive material with higher concentrations of radioactivity than those shipped in industrial packaging.
    a. The outside of the packaging incorporates a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened.
    b. The smallest external dimension of the package is not less than 10 cm (4 inches).
    c. Containment and shielding is maintained during transportation and storage in a temperature range of −40 °C (−40 °F) to 70 °C (158 °F). Special attention shall be given to liquid contents and to the potential degradation of the packaging materials within the temperature range.