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Company of Ohio

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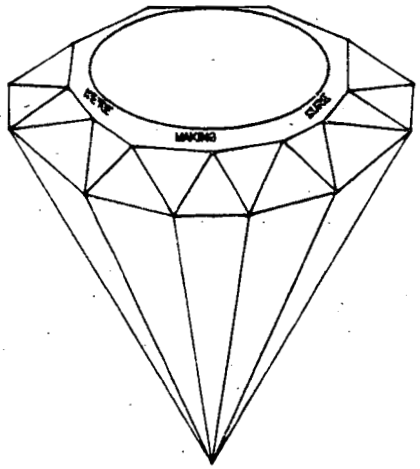

PROCEDURES

QUALITY & SAFETY DEPARTMENT

VOLUME I

360

FMPC-2084
REVISION 2
TOPICAL MANUAL

FMPC RADIATION CONTROL MANUAL

BY

RADIOLOGICAL SAFETY SECTION
QUALITY AND SAFETY DEPARTMENT

AUGUST 4, 1989

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RADIATION CONTROL MANUAL

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TABLE OF ACRONYMS

ACRONYM	DESCRIPTION
AEDO	Assistant Emergency Duty Officer
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
BZ	Breathing Zone
CAM	Constant Air Monitor
CFR	Code of Federal Regulations
DAC	Derived Air Concentrations
D&I	Dosimetry and Instrumentation
DOE	Department of Energy
DOT	Department of Transportation
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ERT	Emergency Response Team
FMPC	Feed Materials Production Center
HEPA	High Efficiency Particulate Air Filter
ICRP	International Commission on Radiological Protection
LSA	Low Specific Activity
MPLB	Maximum Permissible Lung Burden
NCRP	National Council on Radiation Protection and Measurements
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
Q&S	Quality and Safety
PF	Protection Factor
RDA	Radiation Detection Alarm
RS	Radiological Safety
RWP	Radiation Work Permit
SCBA	Self-Contained Breathing Apparatus
SOP	Standard Operating Procedure
SPP	Site Policy and Procedure
TLD	Thermoluminescent Dosimeter
WMCO	Westinghouse Materials Company of Ohio

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SECTION 1

INTRODUCTION AND PURPOSE

1.1 General - Scope

1.2 Summary - Policy and Responsibilities

1.3 Pertinent Terms and Concepts

SECTION 1 - INTRODUCTION AND PURPOSE

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1.1 General - Scope

The Westinghouse Materials Company of Ohio places the safety of its employees and that of the general public first on its list of priorities. Official corporate policy on the subject of safety is as follows:

> No task shall be considered so important or so urgent that employees need risk injury to themselves or others, risk damage to equipment, or risk disruption of operations in carrying out work assignments. Whenever other work objectives may conflict with safety, safety shall be given first consideration.

As defined by Site Policy and Procedure FMPC-505, radiation safety at the FMPC is a line management responsibility.

This manual presents the specific radiation control requirements, responsibilities and protective measures that are employed by Westinghouse Materials Company of Ohio (WMCO) in the operation of the Feed Materials Production Center (FMPC), as well as some of the underlying information that forms the basis for those radiation controls. The requirements of this manual take precedence over any other FMPC topical manuals and departmental procedures on radiological control. Where conflicts exist, the Manager of Radiological Safety shall be contacted.

The radiological safety requirements in this manual are based on the recommendations and requirements of the Department of Energy, the Environmental Protection Agency (which has incorporated the functions of the Federal Radiation Council), the National Council on Radiation Protection and Measurements, the International Commission on Radiological Protection, the Department of Transportation, the U.S. Nuclear Regulatory Commission, the State of Ohio, and on standards which have been reviewed and accepted by the U.S. Public Health Service and U.S. Department of Labor (Occupational Safety and Health Administration). Thus, they compare with radiological safety standards used throughout the United States and the rest of the world. Compliance with the requirements in this manual is mandatory.

Radioactive materials in several forms are present during operations at the FMPC. These materials must be handled carefully by all personnel to avoid unnecessary radiation exposure. The presence of potential hazards from radiation exposure and radioactive contamination in otherwise normal jobs requires the establishment of protective controls. The cost and time required to perform a job are increased by the additional training and equipment, limited working conditions, and added personnel to effect radiological controls. The major purpose of this manual is to establish requirements that will ensure satisfactory control is exercised over exposure of personnel to radiation and radioactive

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contamination. The achievement of lower exposures through ALARA practices represent a balance between work performance and prescribed limitations of cost and manpower .

NOTE: It must be clearly understood that in emergencies where personnel health and safety are involved, life saving actions of personnel take precedence over the radiological controls specified in this manual.

1.2 Summary - Policy and Responsibilities

Radiological controls are necessary at the FMPC to protect personnel in areas where radiation sources are used, radioactive materials are handled and in areas where potentially contaminated materials may be located. The major sources of radioactive contamination and radiation exposure are in the processing and inspection areas of the facility. Additional sources of radiation and radioactive contamination are encountered in the operation of radiation generating devices, certain instruments and the handling and processing of waste materials generated during the production cycle, and the handling of radioactive samples. These operations can cause external radiation exposure to involved personnel and could cause internal deposition of radioactivity if proper controls to prevent the generation and spread of contamination are not followed. The types of radiation encountered may be alpha, beta, gamma, neutron or X ray.

FMPC operations are performed according to operating procedures which contain instructions for handling equipment and materials. These procedures and the designs of equipment involving radiation or radioactivity shall include radiological control considerations. Implementation of the requirements in this manual are required to ensure adequate radiological control.

The radiological control requirements of this manual include but are not limited to:

- Control of external radiation exposure to personnel by means of personnel monitoring, area monitoring, shielding, and planning and execution of radiological work.
- Control of internal radiation exposure to personnel by containing contamination, using anti-contamination clothing (Anti-C clothing) and respiratory protection, and identifying areas and levels for control of surface contamination.
- Control of radioactive wastes.
- Decontamination of radioactively contaminated material.
- Procedures for receiving, transferring, storing and shipping radioactive materials.
- Training of personnel in sound radiological work practices.

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NOTE: The requirements in this manual are the minimum requirements necessary to assure radiological safety under most situations. In unforeseen situations, personnel are expected to perform additional measures and take additional precautions as deemed necessary to provide adequate protection.

Requirements are specified throughout this manual. The word "shall" indicates a requirement and compliance is mandatory. The word "should" indicates a recommendation. Experience has shown that compliance with the "should" has improved radiological controls.

The responsibilities of carrying out the radiation control policy are shared by management and each employee. Employee responsibilities include being aware of radiological conditions and alert to potential radiological problems. Requirements for working in Radiological Areas are described in Section 5.

1.2.1 Management Responsibilities for Radiation Control

The WMCO Management responsibilities include:

- o Provide necessary equipment to safely control radiological conditions.
- o Provide appropriate training in methods and procedures for keeping exposures as low as reasonably achievable (ALARA) and for minimizing or limiting spread of contamination.
- o Maintain records of occupational radiation doses and, upon written request, provide employees with a copy of their historical recorded occupational radiation doses.
- o Provide each employee with an annual summary of his/her recorded occupational radiation doses.
- o Notify each affected employee of any radiation dose which exceeds the DOE occupational dose limits promptly after the dose determination has been made.
- o Inform each employee, upon termination of employment, of the procedure to obtain a written summary of his/her cumulative recorded occupational radiation doses received during employment at the FMPC.
- o Notify employees of the above responsibilities by posting Occupational Safety and Health Protection for DOE Contractor Employees at Government-Owned Contractor-Operated Facility notice DOE-F-5480.5 (9-83).
- o Control the use of radiation sources to keep radiation exposures as low as reasonably achievable (ALARA).

General responsibility for administration of health and safety programs relative to FMPC operations and its surrounding environment rests with WMCO's Quality and Safety (Q&S) Department. Onsite radiological safety functions are centralized in the Radiological Safety Section. A summary of tasks performed by this section are as follows:

- o Conduct routine radiological monitoring of personnel areas, buildings, equipment, materials, vehicles, and trash.
- o Provide radiological monitoring of chemical and metals plant operations, receipts, and shipments of radioactive materials and renovation and construction projects.
- o Evaluate work conditions and practices for adequacy of radiation protection.
- o Plan, initiate, and evaluate programs for air monitoring, contamination control, and radiation exposure reduction.
- o Provide technical support for assessing radiological impact of new or modified facilities and procedures.
- o Conduct radiation safety training program.
- o Operate a sitewide radiation source control program.

1.3 Pertinent Terms and Concepts

Throughout this manual many terms and concepts are frequently used. These are defined within the content of this document. In addition, a glossary of terms appears as an Appendix A to this manual. Though some terms are used less frequently in this manual, they are included for completeness of the material presented.

1.3.1 Airborne Radioactivity Area - Any area within a radiological area where the routine potential exists for airborne radioactivity concentrations greater than 0.8 DAC-hours per shift.

1.3.2 Contamination Area - Any area within a radiological area where high potential for contamination exists, or where known levels of nonwork surface contamination exceed the radiological area limits. Decontamination is mandatory when surface contamination exceeds the contamination area limits.

1.3.3 Controlled Area - Any area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials.

1.3.4 DAC - Derived Airborne Concentration; the average concentration of a radionuclide suspended in air that if inhaled or ingestsed for a 2000-hour working year, would irradiate a person to the limiting radiation dose value for control of the workplace. DAC-hours is the time (hours) at the DAC value.

radiation dose value for control of the workplace. DAC-hours is the time (hours) at the DAC value.

1.3.5 External Exposure - The dose of radiation received by an individual from a source of ionizing radiation outside the body. Measurements of external radiation doses are made for penetrating and nonpenetrating radiation.

1.3.6 Fertile Female - Any female employee below the age of 50, unless exempted by the Medical Services Section.

1.3.7 Internal Exposure - The dose of radiation received to the internal organs of the body from radionuclides ingested, inhaled or absorbed into the body.

1.3.8 Ionizing Radiation - Any radiation capable of displacing electrons either directly or indirectly from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma, X rays, and neutrons.

1.3.9 Nonpenetrating Dose - The radiation dose to the skin at a depth of 0.007 cm.

1.3.10 Nonradiological Area - Any area within the plant or facility which is kept essentially free of surface contamination and/or elevated radiation fields. The annual effective dose equivalent received by individuals from contaminated surfaces in nonradiological areas shall not exceed 100 mrem per year above background.

1.3.11 Nonwork Surface - The surfaces of the following items are considered nonwork surfaces: floors, walls, ceilings, walkways, external surfaces of process enclosures (cell housings, glove boxes, etc.), handrails, doors, windows, electrical utilities, HVAC components, and plumbing fixtures.

1.3.12 Penetrating Dose - The radiation dose penetrating all tissue beyond the skin surface at a depth of 0.007 cm.

1.3.13 Radiation - Energy emitted in the form of alpha, beta, gamma, neutron or X ray during the process of radioactive decay of an unstable atom, or by the operation of a radiation generating device.

1.3.14 Radiation Dose - A quantity (total or accumulated) of energy deposited by ionizing radiation in tissue. The term "dose" is often used in the sense of exposure, expressed in roentgens. This is distinguished from the absorbed dose, given in rads, that represents the energy absorbed from any radiation in a gram of any material. A third quantity, the dose equivalent, given in rem, is a measure of the biological damage to living tissue from the radiation absorbed dose.

1.3.15 Radiation Source - A radionuclide or machine which emits ionizing radiation. Radionuclide sources are classed as sealed or unsealed.

1.3.16 Radiation Worker - Any individual who, in the course employment, is expected to receive 10 percent or more of the annual occupational radiation dose. Also, any individual who works directly with radioactive material or radiation generating devices.

1.3.17 Radiation Work Permit - A permit to administratively control nonroutine tasks or routine tasks which involve the potential for significant radiation exposures.

1.3.18 Radiological Area - Any area within the plant or facility where radioactive materials or elevated radiation fields are present or where access is controlled to protect individuals from radiation or radioactive materials but where operations and job activities are such as to result in limited potential nonwork surface contamination. Radiological areas may include radiation areas, contamination areas, airborne radioactivity areas, and respirator areas. The level of surface contamination may be identified as Zone 2 or Zone 3.

1.3.19 Radiological Control Program - Those programs that have been developed for the safe handling of radioactive material and control of personnel exposure to ionizing radiation.

1.3.20 Radioactive Contamination - A deposit of uncontained or unwanted radioactive material typically on the surface of structures, areas, objects or personnel. It may be carried in air or liquids.

1.3.21 Radioactivity - The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays or X rays, from the nucleus of an unstable atom.

1.3.22 Radioactivity Quantities and Units - Curie is the basic unit used to describe the amount of radioactivity in a sample of material. It is based upon the approximate decay rate of 1 gram of radium which is 37 billion disintegrations per second.

Curie (Ci) = 3.7×10^{10} disintegrations per second = 2.22×10^{12} disintegrations per minute.

Millicuries (mCi) = 3.7×10^{7} disintegrations per second = 2.22×10^{9} disintegrations per minute.

Microcuries (uCi) = 3.7×10^{4} disintegrations per second = 2.22×10^{6} disintegrations per minute.

1.3.23 Work Surface - The surfaces of the following items are considered work surfaces: hand and power tools, process and process support equipment accessible to human contact, equipment to be reworked,

interior surfaces of process enclosures (cell housings, glove boxes, etc.) when accessible to personnel, product and waste storage containers, and related items used in-house to transport, handle, process, fabricate, or store radioactive materials.

1.3.24 Respirator Area - Any area within a radiological area where actual airborne radioactivity concentrations exceed 2.0 DAC-hours per shift when averaged over one calendar quarter or 8.0 DAC-hours during any single shift.

SECTION 2

RADIATION DOSE LIMITS

2.1 Radiation Exposure Limits

2.1.1 Radiation Workers

2.1.2 Occasional Radiation Workers

2.1.3 The Fertile Female

2.1.4 Minors

2.1.5 General Public

SECTION 2 - RADIATION DOSE LIMITS

The radiation dose limits and administrative dose controls identified in this manual are used for controlling personnel occupational radiation exposure (Radiation that is received as a result of medical or dental exams is not included in occupational radiation exposure.). The limits and controls in this section are for exposure to ionizing radiation associated with operation of the FMPC.

These limits are such that no significant difference in biological effects in comparison to the general population are expected, even if exposures extend for a lifetime at these levels. Nevertheless, these radiation protection limits stress maintaining personnel exposure as low as reasonably achievable (ALARA). To this end, WMCO has established administrative dose controls at levels well below the DOE limits to ensure personnel do not exceed the limits and to maintain dose to individuals and the total work force ALARA.

2.1 Radiation Exposure Limits

The radiation dose limits identified in this manual have been promulgated by the DOE and are consistent with the requirements of Federal agencies such as the EPA, NRC and OSHA and recommendations of scientific organizations such as the NCRP. The limits as established by DOE Order 5480.11 are listed in Table 2.1.

The limit for occupational whole body dose can only be exceeded in the event of an unusual situation. During emergency situations personnel may volunteer to exceed normal exposure limits for life saving rescue and other emergency situations. The potential exposures due to the emergency are subject to limits approved by the Emergency Duty Officer.

Limits and administrative dose controls have been established for different categories of individuals which are described below.

2.1.1 Radiation Workers

Radiation workers are individuals that come into contact with ionizing radiation or have the potential of being routinely exposed to levels above the dose limits for the general population in the performance of their job. Due to the nature of their work and the potential to receive an exposure from ionizing radiation, certain limits have been established for the radiation worker and for body organs exposed to radiation. More restrictive limits have been established for the public. The limits are mandated by the DOE and are consistent with those recommended by the NCRP (see Table 2-1). A permanent record of occupational exposures received during the course of employment is kept for each radiation worker.

TABLE 2.1

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RADIATION DOSE EQUIVALENT LIMITS

Exposure Category	Annual Limit (rem)	
	WMCO[3]	DOE[1]
Occupational		
Whole body	3	5[2]
Lens of eye	9	15
All other organs, skin and extremities	30	50
Unborn child (entire gestation period)	0[4]	0.5
General Public		
All Pathways		
Whole body, prolonged period of exposure		0.1
Airborne Emissions Only		
Whole body		0.025
Any organ		0.075

(1) Occupational radiation exposure limits per DOE Order 5480.11; radiation exposure limits to the general public per Draft DOE Order 5480.XX (03/18/88).

(2) Limited to a lifetime effective dose equivalent of 100 rem.

(3) Administrative dose controls established by WMCO.

(4) Restricted to dose equivalent accumulated at the time pregnancy is confirmed.

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The limit for external exposure to the whole body is the most restrictive and it pertains to penetrating exposure. The whole body includes essential blood forming organs and gonads. The limit for radiation exposure to the lens of eye is less restrictive. For all other organs the radiation exposure limit is least restrictive. The limit for all other organs includes exposure to the skin, extremities or the total radiation dose received by internal organs whether from external or internal radiation. Extremities include hands, forearms, feet and legs.

Planned special exposures (non-emergency) are allowed in highly unusual situations where alternatives which would avoid higher exposures are unavailable or impractical. The annual occupational dose received or anticipated to be received in that year, shall not exceed 2 times the annual effective dose equivalent limit. Planned special exposures require the approval of the Head of the DOE Field Organization. Documentation of planned special exposures shall be maintained in the individual's occupational exposure history.

2.1.2 Occasional Radiation Workers

Occasional radiation workers are those individuals who do not routinely work with or are in the proximity of radiation generating devices or radioactive materials but whose duties could occasionally bring them into areas where radiation exposures could occur. Their occupational exposures are routinely kept at less than 10 percent of the occupational dose limits.

2.1.3 The Fertile Female

Radiation exposure of an unborn child shall not exceed 500 mrem from occupational sources. This is achieved by restricting the radiation exposure of the female employee to 500 mrem in a nine month period.

All female employees below the age of 50 years shall be considered as fertile unless exempted by the Medical Services Section. The Radiological Safety (RS) Section shall identify job classifications and work locations in which female employees are likely to receive 500 mrem (or greater) effective dose equivalent in a nine month period.

Fertile females have a responsibility to immediately notify the Medical Services Section to arrange for a pregnancy test when pregnancy is suspected. Upon the verification of pregnancy, RS shall notify the supervisor of any work restrictions. The supervisor has the responsibility to change the work assignment based on recommendations of RS.

When a fertile female's personal dose equivalent level reaches 400 mrem in less than a nine month exposure period, a negative pregnancy test shall be required to verify nonpregnancy and establish a new zero exposure and a new nine month exposure period. Fertile female employees who are expected to receive in any 30 calendar day period exposure in excess of 500 mrem penetrating radiation shall be required to verify nonpregnancy within seven days prior to the authorization of the assignments. After the assignment has been made, reverification of nonpregnancy shall be required at two week intervals or at the discretion of Radiological Safety based upon exposure assessments of the job.

Any female employee confirmed to be pregnant shall be restricted to work areas that do not require the use of dosimetry during the time of pregnancy. She shall meet with the Manager of Radiological Safety or designate who shall explain the potential hazards associated with exposure to ionizing radiation during pregnancy, and answer associated questions that may arise. The necessity for a change in work assignment shall be assessed by Q&S and a restriction letter, if required, forwarded to the supervisor. Every effort should be made to reassign the employee to an available job within the job classification having minimal exposure potential. If assignment is not possible within the employee's classification, the employee should be reassigned to an open position for which the employee is qualified. Any provisions of applicable bargaining agreements shall apply. Work assignments for nursing mothers shall be evaluated by Q&S for radiological conditions. Nursing mothers should generally be restricted from areas and work that could lead to skin contamination or exposure to airborne radioactivity in excess of 1/10 the allowable airborne levels of radioactivity.

2.1.4 Minors

An individual under age 18 shall neither be employed in, nor allowed to enter, Radiological Areas in such a manner that he or she exceeds a limiting value of 0.1 rem per year from the sum of the committed effective dose equivalent from internal irradiation and the annual effective dose equivalent from external irradiation.

2.1.5 General Public

The dose limits to the general public are established by DOE Order 5480.XX (3/15/88) and 5480.11 (12/21/88). The calculation of dose to members of the general public are based upon ICRP Publication 30 models and parameters used by DOE environmental programs. Dose

equivalent limits for any member of the public from all routine DOE operations [1] exclusive of natural background and medical exposures shall not exceed 0.1 rem/yr.

To preclude an individual in the general population from receiving this amount of exposure, action levels have been established for airborne emissions as follows:

	Dose Equivalent Action Levels mrem/year
Whole Body Dose	25
Any Organ	75

These action levels are for routine operations and exclude medical and natural background exposure. This dose value is an administrative limit which will require a specific evaluation of the magnitude of identifiable exposures to an exposed individual by the responsible DOE Field Office.

The effective dose equivalent received by any member of the public resulting from exposure during direct onsite access at the FMPC shall not exceed a limiting value of 0.1 rem per year from the committed effective dose equivalent from internal irradiation plus the effective dose equivalent from any external irradiation. In addition, exposures shall not cause a dose equivalent to any tissue (including the skin and the lens of the eye) to exceed 5 rem per year.

NOTE:

(1) Routine DOE operations means normal planned operations and does not include actual or potential accidental or unplanned releases.

SECTION 3

DOSIMETRY

3.1 External Radiation

3.1.1 Whole Body Dosimetry

3.1.2 Extremity Dosimetry

3.1.3 Nuclear Criticality Accident Dosimetry

3.2 Internal Radiation

3.2.1 Urinalysis

3.2.2 Fecal Monitoring

3.2.3 In Vivo Monitoring

3.2.4 Internal Dose Assessment

3.2.5 Reports to Employees

SECTION 3 - DOSIMETRY

3.1 External Radiation refers to the radiation from sources that are outside the body. Some examples are beta radiation from ingots and derbies as well as gamma radiation from the same sources or X rays from radiation generating devices. In order to control the amount of radiation exposure an individual receives, a means of measurement must be utilized. The principle instrument used at the FMPC for personnel monitoring is the thermoluminescent dosimeter or TLD. This monitoring device shall be worn by all personnel entering the production areas except certain commercial vehicle drivers. The TLD is a multi-chip instrument that responds to gamma, X ray, beta, and neutron radiation. Neutron sensitive elements in the TLD badge are evaluated only in the event of a criticality accident. It shall be worn below the neck and above the waist to be representative of the major portion of the body in measuring the whole body dose. In addition to the multi-chip dosimeters, ring dosimeters are worn by selected employees as determined by Q&S. The dosimeters shall be exchanged at a frequency defined by Q&S. An exposure record shall be maintained for each individual. Individuals may, upon written request, receive an official copy of their cumulative exposure history for work at FMPC. Individual exposure records may be reviewed in the Dosimetry & Instrumentation Section office during the first shift.

The Q&S Department provides dosimeters for FMPC employees, visitors and subcontractors; operates and maintains dosimetry processing equipment; and records and reports dosimetry results. In addition, Q&S identifies personnel for whom dosimetry is required, utilizing information from line management, when required. Appropriate personnel dosimetry is required for radiation workers having the potential to exceed in a year any one of the following from external sources (DOE Order 5480.11):

(a) One hundred mrem annual effective dose equivalent to the whole body;

(b) Five rem annual dose equivalent to the skin;

(c) Five rem annual dose equivalent to any extremity;

(d) One and a half rem annual dose equivalent to the lens of the eye

Q&S also sets external monitoring action levels for investigation, changing work assignments, and restricting personnel from additional radiation exposure; performs exposure investigations; and informs line management of work restrictions.

All FMPC employees, visitors, and subcontractors are responsible for wearing dosimeters whenever they are required in accordance with the usage rules listed below for each type of dosimeter. On occasion individuals may be required to participate in special

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studies which involve the wearing of special dosimeters in addition to their personal TLD. Failure to follow dosimetry procedures is listed as a serious offense under the WMCO Rules of Conduct.

Line management shall provide information on work assignments as requested by Q&S in order to enable evaluations of required participation in the dosimetry program, or evaluations to determine which employees should be issued permanent dosimeters. On occasion line management will make these determinations for their own personnel, utilizing criteria supplied by Q&S. Line management shall be responsible for implementing work restrictions upon notification from Q&S that such restrictions are necessary.

3.1.1 Whole Body Dosimetry Requirements

Whole body thermoluminescent dosimeters (TLDs) are utilized to estimate personnel radiation exposures to "unlimited" areas of the skin, the lens of the eye, and to the whole body. A multi-element dosimeter, with each element covered by different thicknesses of filtration, measures the magnitude of radiation exposure, as well as the manner in which the radiation is attenuated by an absorbing medium. A calculational method, called an algorithm, is used to determine the radiation dose at specific depths into an absorbing medium which correspond to the location of the tissues of interest for internal dosimetry. The specific depths, expressed in density thicknesses, of the tissues of interest are:

Skin	7 mg/cm^2
Lens of eye	300 mg/cm^2
Whole body	1000 mg/cm^2

The Q&S Department is responsible for developing suitable algorithms for the radiation types that exist at FMPC, and for maintaining the quality of the reported radiation exposures. The whole body external dosimetry program is subject to the requirements of the Department of Energy Laboratory Accreditation Program for dosimetry processing (DOELAP), which are contained in DOE Order 5480.15 and the various documents referenced therein.

Requirements for issuing dosimeters, processing dosimeters (including frequency of processing), storing dosimeters, and reporting of dosimetry results are established by Q&S. All FMPC employees, visitors, and subcontractors are responsible for compliance with the requirements listed below for whole body dosimeter usage.

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a. Dosimeters shall be worn at all times in areas where they are required; these areas are posted "TLD Required for Entry" or a similar message.

b. Dosimeters shall be worn on the torso, outside of all clothing unless directed otherwise by Q&S.

c. Personnel shall wear only the dosimeter that has been assigned to them.

d. Dosimeters shall be stored in designated storage racks when not being worn.

e. Dosimeters shall remain at the FMPC.

f. Lost or damaged dosimeters shall be immediately reported to supervision or to Q&S, and a replacement dosimeter obtained from Q&S.

3.1.2 Extremity Dosimetry Requirements

The FMPC extremity monitoring program utilizes single-element thermoluminescent dosimeters mounted in ring badges. On occasion, wrist dosimeters may be used for special studies. Extremity dosimeters are processed and calibrated in order to determine the radiation dose to the skin of the extremity, i.e., at a density thickness 7 mg/cm^2.

Q&S shall identify personnel who are required to wear extremity dosimetry. Requirements for issuing dosimeters, processing dosimeters (including frequency of processing), storing dosimeters, and reporting results are established by Q&S. All FMPC employees, visitors and subcontractors are responsible for compliance with the requirements listed below for extremity dosimeter usage.

a. Dosimeters shall be worn by personnel designated by Q&S as requiring extremity dosimetry.

b. Dosimeters shall be worn on the palm side of the hand, under gloves unless directed otherwise by Q&S.

c. Personnel shall wear only the dosimeters that have been assigned to them.

d. Dosimeters shall be stored in designated storage areas when they are not being worn.

e. Dosimeters shall not be removed from FMPC.

f. Personnel shall immediately report lost or damaged dosimeters to supervision or to Q&S, and obtain replacement dosimeters from Q&S.

3.1.3 Nuclear Criticality Accident Dosimetry

Permanently mounted dosimeter units shall be located by Q&S throughout each work area where enriched nuclear material is handled. These dosimeters contain eight metal foils and three pellets of various materials each of which are activated by a neutron flux such as occurs in a criticality accident. By analyzing the radioactivity in these foils and pellets the amount of neutron absorbed dose in each area can be determined.

3.2 Internal Radiation

Internal radiation monitoring at the FMPC is routinely accomplished by performing in vitro and in vivo bioassay measurements. The Q&S Department defines the internal radiation monitoring program for FMPC employees, visitors and subcontractors. Q&S is responsible for identifying personnel for whom internal monitoring is required, determining what type of bioassay measurements will be performed, setting the frequency of measurements, performing bioassay measurements or arranging for them to be performed by other qualified laboratories, and interpreting bioassay results. In addition, Q&S establishes internal monitoring action levels for investigation, restricting work assignments, and restricting personnel from additional radiation exposure; performs exposure investigations; and informs line management of work restrictions.

Internal radiation monitoring is required for all radiation workers exposed to surface or airborne radioactive contamination where the worker could receive 100 mrem annual effective dose equivalent from all intakes of all radionuclides from occupational sources, or if any organ or tissue dose equivalent could exceed 5 rem annual dose equivalent (DOE Order 5480.11). Q&S shall identify those individuals for whom internal monitoring is required, utilizing information from line management when necessary. Line management shall provide information on work assignments as requested by Q&S in order to enable evaluations of required participation in an internal monitoring program. On occasion, line management will make this determination for their own personnel, utilizing criteria supplied by Q&S.

All FMPC employees, visitors and subcontractors are responsible for reporting for in vivo examinations when scheduled, and for leaving excreta samples for in vitro analysis when requested. Failure to comply is considered a serious offense under the WMCO Rules of Conduct and may result in disciplinary action or restriction from radiologically controlled areas. R

3.2.1 Urinalysis

Most urine samples collected at the FMPC for internal radiation monitoring are grab samples from single voidings.

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Aliquots of these samples are analyzed for total uranium, and the results are reported as concentration of uranium in the sample (mg U/L). These samples are screening samples, intended to identify potential intakes of uranium which can then be further evaluated by additional bioassay measurements. The schedule for collecting routine samples and the criteria for collecting non-routine (i.e., incident or special samples are established by Q&S.

Special urine samples are collected as required by Q&S. Reasons for collecting special samples include, but are not limited to, analysis for uranium isotopes, analysis for radionuclides other than uranium, evaluation of daily excretion of radioactive material without relying on standard models for relating urinary concentration to daily output, and special studies.

3.2.2 Fecal Analysis

Fecal analysis is not performed routinely, but is performed when urine sampling is not adequate or appropriate for the radionuclide and chemical form of interest; or when it is helpful in determining the magnitude and nature of a suspected intake of radioactive material.

3.2.3 In Vivo Monitoring

In vivo monitoring is the detection and quantification of radioactive materials in a subject's body by means of measuring the photons emitted from the subject's body or certain organs within the body. In September, 1988, an In Vivo Examination Center (IVEC) was placed into service at the FMPC, with routine operation commencing in December 1988. This facility utilizes intrinsic germanium detectors inside a shielded counting chamber to provide sensitive, high resolution measurements of radioactive materials that emit low energy photons.

By June, 1989, a second in vivo monitoring device will be placed into service in the same facility. It is a whole body scanning device which utilizes a thick NaI(Tl) crystal to measure radioactive materials that emit higher energy photons, although with considerably poorer resolution than the germanium system.

Prior to September, 1988, routine in vivo monitoring was accomplished at the FMPC by using the Mobile In Vivo Radiation Monitoring Laboratory (MIVRML), which was rented from the Oak Ridge Y-12 Plant for limited periods of time each year, starting in 1986. A limited amount of special in vivo monitoring has also been performed, both before and after start-up of the FMPC IVEC, at other facilities as the need arose.

3.2.4 Internal Dose Assessments

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Starting with CY-1988, internal dose assessments are performed for identified intakes of radioactive material that are dosimetrically significant. Dose assessments are performed according to ICRP-30 methodology, except that Q&S may modify the approach if recent publications or actual bioassay data indicate that it is appropriate. In general dose assessments are based on bioassay data, rather than air sampling results. However in circumstances when bioassay data are not available or not appropriate, air sampling results can be used to estimate internal exposure at the discretion of Q&S. Dose assessments from exposure to radon and its decay products will generally be based on air sampling results.

Starting in CY-1989 results of dose assessments shall be included in personnel exposure records. The information that is retained in those records includes the following:

a. For each intake of radioactive material, the year the intake occurred;

b. Radionuclide(s) involved in each intake;

c. Annual effective dose equivalent received in each calendar year;

d. Annual dose equivalent to organs or tissues of interest in each calendar year;

e. Committed effective dose equivalent from intakes occurring during each calendar year;

f. Committed dose equivalent to organs or tissues of interest from intakes occurring during each calendar year.

3.2.5 Reports to Employees

Starting with CY-1986 results, annual external exposure totals for skin and whole body have been reported to individuals at the end of the calendar year. Starting with CY-1989 results, employees shall receive a summary of annual, cumulative, and committed effective dose equivalent at the end of each year. In addition, these results, along with more detailed information concerning a worker's exposure, are provided to employees upon their request.

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SECTION 4

ENGINEERING AND ADMINISTRATIVE CONTROLS FOR RADIOLOGICAL SAFETY

4.1 WMCO ALARA Programs

4.1.1 Statement of Policy

4.1.2 Responsibility

4.1.3 The Radiation Protection/ALARA Program

4.2 Engineering Controls for Facility Design/Modification

4.2.1 Ventilation Systems

4.2.2 Storage of Radioactive Material

4.3 Radiological Engineering Evaluation

4.4 Administrative Controls for Radiological Safety

4.4.1 Work Procedures

4.4.2 Radiation Work Permit

4.0 Engineering and Administrative Controls for Radiological Safety

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4.1 WMCO ALARA Programs

4.1.1 Statement of Policy

It is the policy of WMCO to keep radiation doses to employees, subcontractors, visitors, and the public as low as reasonably achievable based on sound cost-benefit analyses. The WMCO ALARA Program is accomplished through several aspects of the ALARA concept which are:

- To keep all radiation exposures to each WMCO employee ALARA.
- Maintain radiation doses to all subcontractors and visitors ALARA.
- Maintain the annual cumulative radiation dose to all personnel ALARA.
- Maintain the annual cumulative radiation dose to the general public ALARA.

Responsibilities for the implementation and effectiveness of WMCO's Radiation Protection/ALARA Program are shared by WMCO management, all departments, all other WMCO employees, and all subcontractor management and personnel.

4.1.2 Responsibilities

A. WMCO President, Vice Presidents and Managers

- Enforce rules, implement requirements and develop procedures necessary for an effective radiation protection and ALARA program.
- Elicit support for the WMCO Radiation Protection/ALARA Program from all WMCO employees.
- Support the department Managers in effective implementation of the Radiation Protection/ALARA Program.
- Identify locations, operations, and conditions that have the potential for causing exposure or environmental releases that are not ALARA.
- Specify and accomplish goals and objectives for WMCO operations which incorporate the WMCO ALARA philosophy and objectives.

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- o Review all process equipment and facility designs to ensure that the potential for significant radiation exposures and environmental releases are minimized.

- o Review all modifications of equipment or facilities to ensure that radiation exposures and environmental releases are ALARA.

- o Ensure ALARA considerations are engineered and incorporated into designs, installations, and retrofitting of equipment.

B. Manager, Quality and Safety (Q&S)

The Manager of Q&S is responsible for implementation and optimization of the Radiation Protection Program. He is also responsible for ensuring adequate radiation protection for all FMPC personnel. Other responsibilities include:

- o Ensure that all operations involving work with radioactive materials is supported by adequate radiation protection coverage.

- o Provide for employment of a qualified radiation protection staff.

- o Recommend a comprehensive radiation exposure control program for all FMPC personnel.

- o Review and recommend changes in procedures to maintain occupational exposures ALARA.

- o Promote the development of training programs related to work performed in radiation areas or with radioactive materials.

- o Support the collection, analysis, and evaluation of radiological data and information as it pertains to the Radiation Safety/ALARA Program.

C. Radiological Safety Section (RS)

The RS Section is responsible for the technical development and adequacy of the Radiation Protection/ALARA Program. RS also has the ongoing

responsibility for surveillance and supervisory action in the enforcement of the program. The section also has the responsibility to:

- o Identify locations, operations, and conditions which have the potential for causing significant personnel exposures to radiation.
- o Maintain a routine surveillance program including air sampling and surface contamination measurements in all nominally occupied areas.
- o Review and recommend changes in standard operating procedures to maintain exposures ALARA.
- o Participate in the development and implementation of training programs related to work in radiation areas or involving radioactive materials.
- o Conduct special investigations of radiation exposures which are near or exceed established administrative and regulatory guidelines or are outside of the expected norms.
- o Review all process equipment and facility designs to ensure that the potential for significant radiation exposures and environmental releases are minimized.
- o Review all modifications of current equipment or facilities to ensure that radiation exposures and environmental releases are ALARA.
- o Ensure ALARA considerations are engineered and incorporated into designs, installations, and retrofitting of equipment.

D. The WMCO ALARA Task Team

It is the philosophy of WMCO management that ALARA objectives and goals shall be derived and established by the departments incurring the exposure, with technical guidance provided by RS Section rather than goals being developed by the RS Section and imposed on operating groups. Each organization incurring exposure shall be accountable for the results of its ALARA program.

To coordinate the establishment and implementation of ALARA goals, a Task Team shall be formed. The Task Team shall consist of employees from each major department (three from at least the major areas of production) within the company who are experienced and knowledgeable of FMPC design features and operations. These individuals are assigned to develop the ALARA program. The department managers are responsible for appointment

of Task Team members and implementation of the ALARA program.

The ALARA Task Team shall:

- o Ensure the direction of the ALARA program through ALARA objectives and goals, and integrate management's ALARA philosophy and DOE regulatory requirements.
- o Ensure that ALARA objectives and goals are established by the operating departments incurring the exposure.
- o Act as a review and advisory group, whose primary functions are to review ALARA related topics (i.e., processes, operations, procedures, etc.) and major sources of radiation exposure with the intent of identifying means for their reduction.
- o Establish the direction of the WMCO ALARA Program by establishing and implementing fiscal year ALARA objectives and goals.
- o Ensure that the status of ALARA goals and objectives as well as the direction of the ALARA program are reviewed on a regular basis and inform management when attainment of ALARA objectives appears jeopardized.
- o Report to management and DOE on a regular basis concerning the status of ALARA goals and the direction of the ALARA program.
- o Make recommendations to top-level management on ALARA reviews made by the team.

E. <u>FMPC Employees</u>

The WMCO ALARA program is only as effective as each employee's ALARA performance, therefore all employees shall:

- o Comply with all radiological safety rules, procedures, and work permits, established by management and by the Q&S Department.
- o Report to management or the Q&S Department, process malfunctions or violations of rules, or procedures, that could result in an increased radiological hazard to an individual or to the environment.
- o Suggest improvements for the Radiation Protection/ALARA Program and for the radiologically safe operation of workplace processes and equipment.

- o Keep his/her radiation exposure using all ALARA principles and concepts when performing radiological work or when entering a radiation area.

4.1.3 The Radiation Protection/ALARA Program

An active Radiation Protection/ALARA Program can be very effective in lowering radiation doses or maintaining radiation doses at low levels.

The basis of the Radiation Protection/ALARA Program shall include a comprehensive set of procedures, job planning concepts, record keeping functions, and specialized equipment and radiological assessment. WMCO shall prepare for and preplan all radiological work. For routine work, operating procedures shall be developed. For nonroutine work special preplanning and work procedures or permits shall be developed. The ALARA concepts integrated into the Radiation Protection/ALARA Program and into the development of routine and nonroutine operating procedures shall be as follows:

- o Special radiological projects shall require radiation dose budgets and the incorporation of ALARA principles and concepts into work procedures prior to the initiation of work. Radiological work shall be planned and performed such that the total dose to all workers (person-rem) and to each individual is ALARA. A transient scope of operations is the principal characteristic of special radiological project.

- o Operating procedures shall be developed for routine performance of radiological work at the FMPC.

- o Job preplanning, work procedures, and worker briefings shall be conducted prior to nonroutine radiological work. Rehearsals of work to be performed in radiation areas shall be performed in low background areas prior to entry into the specific radiation work area when practical.

- o Radiological surveys and monitoring shall be conducted to obtain information with respect to radiation levels, contamination levels, and airborne radiation concentrations as appropriate. These surveys and monitoring will provide the data necessary to establish the radiation safety requirement to be incorporated into the radiological work procedure to keep exposure ALARA. Surveys and radiological monitoring shall continue during normal operations and prior to and during nonroutine operations as required by the RS Section.

- Radiation exposure rates shall be reduced either by decontamination, shielding or by removing radioactive sources from the work areas as appropriate in order to keep radiation doses to workers ALARA.

- Temporary/portable shielding shall be used to reduce radiation dose rates in the workplace whenever circumstances do not preclude its use.

- The ALARA concepts of minimizing time in a radiation area, maximizing distance from sources, and use of shielding shall be applied to all aspects of radiation work in order to keep exposures ALARA.

- Radiation Work Permits shall be used for specific jobs to document job requirements and to control radiation exposures. Supervisors requesting the work procedure shall review the prescribed protective features before the start of work.

- Temporary or portable exhaust ventilation systems shall be used where practical in order to keep radioactive air concentrations ALARA. Uses shall include jobs such as welding on contaminated surfaces etc.

- Protective equipment such as anti-contamination clothing, respirators, dosimetry devices, and monitoring equipment shall be used in the workplace as required by Q&S to keep radiation exposures ALARA.

- The Q&S Department and all other departments shall constantly search for and develop new ways to conduct both routine and nonroutine radiation work ALARA. All Radiation Work Permits shall be reviewed by the Radiological Safety Section to ensure proper documentation of radiological work and evaluate radiation exposure and work practices.

Facility and Equipment Design Features

The design of facilities, processes, and equipment necessary for the performance of work involved with radioactive materials provides one of the first and best opportunities for ensuring radiation exposures are kept ALARA.

When designing or modifying radiological facilities, processes, and equipment the following factors shall be considered:

- Radiation Shielding

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- o Access Control of Radiation Areas
- o Control of Airborne Contaminants (Ventilation)
- o Contamination Control (Isolation and Decontamination)
- o Need for Local Change Rooms
- o Radiation Monitoring Systems
- o Design shall limit exposure to one-fifth of the applicable DOE dose limits (i.e., 1 rem/year whole body) and take into account ALARA considerations.
- o Environmental Protection Systems:

  Gaseous - HEPA filtration, dust collectors, scrubbers, demisters, etc.

  Liquid - Water treatment systems.

All facility or process design/modification involving a radiological environment shall be reviewed and approved by the Radiological Safety Section.

4.2 Engineering Controls for Facility Design/Modification

The concept of maintaining ALARA radiation exposures shall be incorporated into the design of all facilities at FMPC (DOE Order 6430.1A, FMPC 2069). ALARA indicates that no level of exposure is acceptable if it can be reduced by some reasonable effort given the limitations of economics and practicality. Personnel exposure levels, under normal operating conditions, of less than 1/5 of the permissible dose equivalent limits shall be used as a design objective. Design factors to consider are: occupancy time, source terms, spacing processes, equipment, and shielding.

The following shall be considered in designing new equipment or modifying a facility:

- o Primary means for assuring personnel protection shall be through physical safeguards, e.g., remote handling equipment, shielding, ventilation, etc.
- o Protective coatings shall be used where appropriate to aid in decontamination, but shall comply with the ANSI standards.
- o Interior surfaces of components and facilities as well as layout of ducts and pipes, shall be designed to minimize buildup of contamination.
- o Equipment and components requiring frequent servicing shall be located in areas with the lowest practicable radiation fields and outside process enclosures if possible.

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- Ventilation systems shall be designed to assure proper control of airborne contaminants. Redundant equipment should be provided in all exhaust systems servicing contaminated and potentially contaminated areas. The system should permit easy and safe access for servicing.

- Decommissioning requirements shall be considered in the design of facilities and equipment.

- New equipment or modifications to existing equipment shall be designed in such a manner that a minimum of "hands on" contact with the product is required. Remote handling tools, robotics, etc., should be utilized. Appropriate training shall be given to employees in the use of these tools to minimize any negative impact on production. In many cases, an increased productivity should result along with significantly reduced exposures.

- Enclosures shall be designed with a negative pressure in respect to the surrounding environment. The exhaust from these enclosures shall be routed through a filtration media before being vented to the atmosphere.

4.2.1 Ventilation Systems

Plant ventilation equipment shall be designed and used to remove contamination from the work area. The optimum ventilation design causes contaminated air to be moved away from the work area and shall be equipped with a filtering system to prevent significant amounts of contamination from reaching the environment. The Industrial Ventilation Manual published by the American Conference of Governmental Industrial Hygienists shall be used as a design guide for air monitoring systems for both new and old systems. All booths and enclosures for radiological processes shall have controls on the outside and be provided with acceptable ventilation as determined by the Q&S Department. Visual flow indicators are located near the operating station of ventilated hoods and enclosures. These indicators give assurance to operators that proper ventilation is being maintained.

4.2.2 Storage of Radioactive Material

This criteria applies to all new and old warehousing facilities to ensure radioactive materials will be stored in an organized and controlled environment providing and that exposures are kept as low as reasonable achievable (ALARA).

Storage Definitions

- Interim Storage - Storage outside the work area for six months or less.

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- o Short Term Storage - Storage for more than six months but less than three years.
- o Long Term Storage - Storage for more than three years.
- o Temporary Storage - Work place storage within a plant.

Design Criteria Requirements

- o Stored radioactive material shall contribute less than 5 percent of the dose rate or less than 0.5 mrem/hr., whichever is less, (as measured at the work station) to the individual radiation workers whole body or skin dose.
- o The storage facility for radium and thorium shall be ventilated through a properly designed filter system which removes radon and thoron daughters and complies with DOE/EPA limits.
- o Dose rates at the warehouse exterior shall not exceed 0.5 mrem/hr.
- o Radioactive materials shall be stored in such a manner as to facilitate access (where access is necessary) and minimize exposure during storage, access, and retrieval.
- o Radioactive material storage facilities shall be designated as either long term, short term, interim or temporary storage facilities.
- o Uranium storage drums and facility alpha surface contamination shall be maintained at less than 1000 dpm/100 cm^2.
- o Alpha surface contamination on thorium storage containers and floors shall be maintained at less than 1000 dpm/100 cm^2 while the material is being stored.
- o Work area exposure rates from temporarily stored radioactive materials shall not exceed 0.5 mrem/hr.
- o The exposure rates within work area locations at interim storage facilities shall be maintained to less than 2.5 mrem/hr.
- o Short term and long term storage facilities with exposure rates in excess of 100 mrem/hour must be locked and will require a RWP for entry.
- o As necessary an appropriate type of shielding shall be provided to control exposure rates within nominally occupied warehouse facilities.

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- o Routine air samples shall be collected while any warehouse is being accessed in such a manner as to define the airborne contamination within the work area.

4.3 Radiological Engineering Evaluation

Radiological Safety Section evaluations are required on all projects involving changes in plant equipment or operations that involve radioactive material. The evaluation must be made to ensure that personnel are provided the maximum protection from exposure and that all radiation control regulations are followed.

To ensure that ALARA is practiced in the workplace the following guidelines shall be considered:

Preliminary Planning

Prior to preparation of the detailed work procedure for a specific job, the following items shall be considered to minimize exposure:

Plan in Advance: Many of the methods for reducing exposure to radiation require considerable planning, construction, and training prior to the start of work. Advance planning allows new ideas to be incorporated into the process.

Delete Unnecessary Work: Determine exactly what is to be accomplished. If secondary work can be accomplished in conjunction with the primary task, it should be planned and scheduled. An example would be to remove waste material either during or immediately after the task is completed. Do not allow the material to remain until a later time and require another work group to reenter the area for material removal.

Know Expected Radiation Levels: Radiation surveys shall be performed periodically in any facility utilizing radioactive materials. Reports of these surveys provide information on the general radiation levels encountered in most work. These radiation surveys provided in conjunction with inspections or other activities can define the nature of the radiation fields and identify favorable locations where personnel may take advantage of available shielding, distance, geometry, and other factors that affect the magnitude of the exposure rate or the portions of the body exposed to radiation.

Where sufficient advance notification of work is provided, it is possible to obtain more detailed surveys. Interpretation of surveys can often be improved if requests for detailed surveys are accompanied by photographs, drawings, or sketches on which RS Technicians can record or indicate the location of the radiation levels measured. In addition, a survey of work areas prior to starting the work will be necessary to determine any changes from earlier survey data.

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Consider Design Changes: If existing equipment needs replacing or facilities require modification, consideration shall be given to design changes which could be made to reduce exposure to radiation.

4.4 Administrative Controls for Radiological Safety

4.4.1 Work Procedures

Detailed written work procedures shall be used for routine jobs which might result in the spread of airborne radioactivity or surface contamination. Use of formal work procedures is essential in maintenance and repair work. Such detailed procedures shall include or reference information for minimizing exposure to radiation and limiting the spread of contamination. Each of the following items shall be incorporated, as applicable, into the work procedures.

Plan Access To and Exit From Work Area: In plans for access to and exit from the work area, include a convenient and large enough location for donning and removing anti-C clothing, for briefing personnel before entry and for surveying personnel for radioactive contamination. Where considerable work is to be done in a highly contaminated area, provide direct access from the work area to a change area. Plan the entrance and exit to radiological work areas to avoid having personnel waiting in areas where significant radiation levels exist; for example, locate the personnel monitoring station so that when several people are leaving a work area they do not have to wait inside a radiation area while the people ahead are self-monitoring.

Provide for Service Lines: Plan in advance for service lines, including lines for air, welding and ventilation, and specify, in the work procedure, methods to minimize exposure to radiation associated with their installation, maintenance and removal, and to control their interference with personnel access. Minimize the number of lines going into and inside a radiologically posted area. Minimize unnecessary accumulation of equipment. Use types of lines that can readily be decontaminated or use covers for the lines to prevent their being contaminated.

Provide Communication between workers inside areas with significant levels of radiation or contamination, and supervision and RS Technicians outside the area. Provision of communication devices, headsets, or speaker systems can reduce radiation exposure by reducing the time required to make decisions on matters not foreseen in written work procedures. Avoid the condition where headsets become contaminated with the potential of causing contamination of

subsequent users. Use of a communication system also allows supervising personnel to maintain effective control of a job even though continuous visual observation is impractical because of high radiation levels.

Remove Sources of Radiation: Significant reductions in radiation exposure can be obtained by eliminating some sources of radiation. The following are examples:

Unused plant components and hot spots which significantly contribute to the general area radiation levels may be reduced by cleaning and shielding. A hot spot is an area that normally has individual radiation levels greater than five times the general work area.

Perform as Much Work as Practicable Outside Radiation Posted Areas: Prefabrication shall be considered to minimize the work done in radiation posted areas; for example, prefabrication of temporary shielding to reduce installation time.

State Requirements for Standard Tools: By requiring supervisors to determine standard tools known to be needed for the job and requiring that they be available near the job location, radiation exposure of working personnel waiting for tools can be minimized.

Consider Special Tools: For certain jobs, special tools or jigs may allow major reductions in radiation exposure through simplification, reduction in time, or reduction of mistakes. These tools should be designed, built, and tested on full-scale models prior to their use in radiation areas if previous usage experience does not exist. In addition, individuals using these tools for the first time should be trained in the proper use, handling, and restrictions of the tool prior to use in the radiation area.

Estimate Dose: After planning the details of the work procedure where exposure to significant radiation levels will be experienced and prior to performing the work, an estimate of the dose to be expended on the job should be made. This estimate should be based upon radiation levels measured at the work location, and the estimated time it will take in radiation fields to complete each phase of the job. The estimate should reflect experience gained by others who have performed similar work.

Examination of dose estimates might cause an assessment of the details of the work procedure. For example, special tools might be developed to reduce working time. During and after the work, the actual dose received shall be compared with the estimates. Determining the reasons for discrepancies promptly and correcting them can reduce radiation dose.

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Consider Accident Situations: Potential accident situations and unusual occurrences (such as gross contamination, leakage, pressure surges, fires, personnel injury) should be considered during the preparation of the work plans. Contingency planning can reduce the potential for such occurrences and enhance the capability for expeditiously coping with the situation if they occur.

Inspection Requirements for Radiological Controls

It is necessary to include steps requiring radiological control inspections in detailed work procedures. Typical situations which may require verification of work area radiation levels prior to onset of work are 1) during removal of items from a system, 2) after flushing of a process system, and 3) after running a different process batch.

4.4.2 Radiation Work Permit (RWP)

Policy

Radiation Work Permits shall be issued for the performance of any task that involves exposure to radiation or radioactive material and for which there is not an approved work procedure. Radiation Work Permits are also required for tasks performed under approved work procedures if those tasks involve work in high radiation fields or in areas where radiation fields are variable or unknown. The RWP identifies the work activity, the associated radiological conditions and protective measures required to accomplish the work (see Figure 4-1).

The requesting supervisor initiates a RWP by describing on the RWP form the work to be performed, and arranges for a RS Technician to perform a radiation survey. It is the responsibility of the RS Technicians to complete the radiation survey, calculate the maximum time allowed by the work permit, specify work precautions, issue pocket dosimeters (if required), and read pocket dosimeters,

It is the responsibility of the worker(s) involved with the job to read the description of work on the RWP and understand the work restrictions. They will signify that they have been informed of the radiological protective requirements on the RWP by signing the form.

A Radiological Safety Technician shall be in attendance at any job where the following conditions are defined and until the condition no longer exists:

1. Whenever airborne radioactivity is greater than ten times the derived air concentration (DAC) limits (Appendix B).

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Figure 4-1

RADIATION WORK PERMIT FORM

RADIATION WORK PERMIT No.: _____

SECTION I: TO BE COMPLETED BY THE JOB SUPERVISOR

(1) JOB LOCATION — BUILDING: DATE: | (2) ISSUED DATE | (3) SHIFT: | (4) EXPIRATION DATE *

JOB DESCRIPTION

GRID LOCATION | REQUESTING SUPERVISOR'S SIGNATURE:

* Maximum 7 days from issuance

SECTION II: TO BE COMPLETED BY ERMT

(5) RADIATION LOCATION	INSTRUMENT READING (6) OW OPEN WINDOW mRad/hr	(7) CW CLOSED WINDOW mRad/hr	EXTREMITIES (8) OPEN WINDOW mRad/hr
1.			
2.			
3.			
4.			

(9) STAY TIME CALCULATIONS

BETA DOSE	SKIN DOSE	EXTREMITY
CORRECTION FACTOR (OW-CW)*F = mRem/hr	WHOLE BODY	TIME LIMIT
Side Window GM F = 8 mRem/hr		
CP Ion Chamber F = 3 mRem/hr		

INSTRUMENT TYPE	SERIAL NUMBER	CALIBRATION DATE

(10) AMBIENT BACKGROUND β/γ mrem/hr

(11) RADIOLOGICAL SURVEY FORM ATTACHED ☐ YES ☐ NO

(12) SURVEY MAP ATTACHED ☐ YES ☐ NO

(13) MONITORING REQUIREMENTS
- ☐ At start of job
- ☐ Intermittent
- ☐ Continuous
- ☐ On completion of job
- ☐ Not required
- ☐ Personnel survey at completion
- ☐ Air monitoring

(14) DOSIMETRY REQUIREMENTS**
- ☐ Direct reading dosimeter
- ☐ Wrist dosimeter
- ☐ Ring dosimeter
- ☐ Other _____

** TLD required for all radiation work

(15) PROTECTIVE EQUIPMENT

WHOLE BODY	BREATHING REQUIREMENTS	HEAD
☐ None	☐ Half face respirator	☐ Safety glasses
☐ Cloth coveralls	☐ Full face respirator	☐ Goggles
☐ Disposable coveralls	☐ Airline respirator	☐ Face shield
☐ Lab coat	☐ Airline hood	☐ Cap
☐ Tape openings	☐ Combination canister	☐ Hood
☐ Other _____	☐ SCBA	☐ Hard hat
	☐ Other _____	

HANDS (GLOVES)	SHIELDING	FEET AND LEGS
☐ Cotton	☐ Rubber Mat	☐ Latex shoe covers
☐ Rubberized	☐ Aluminum	☐ Disposable shoe covers
☐ Surgical	☐ Plywood	☐ Safety shoes
☐ Gauntlet	☐ Other _____	☐ Safety boots
☐ Other _____		☐ Other _____

(16) SPECIAL HEALTH PHYSICS INSTRUCTIONS AND REQUIREMENTS

ERMT SIGNATURE: DATE: TIME ISSUED:

SECTION III: APPROVAL SIGNATURES (as required)

NO	DISTRIBUTION OF COPIES
1	Posting
2	ERM Supervisor
3	Health Physics

SECTION IV: TO BE COMPLETED BY EMPLOYEES ***

(17) NAME(S) OF EMPLOYEE(S) (SIGNATURE)	(18) BADGE NUMBER	(19) RESPIRATOR FIT TEST	(20) RADIATION WORKER TRAINING
1.		☐ YES ☐ NO	☐ YES ☐ NO
2.		☐ YES ☐ NO	☐ YES ☐ NO
3.		☐ YES ☐ NO	☐ YES ☐ NO
4.		☐ YES ☐ NO	☐ YES ☐ NO
5.		☐ YES ☐ NO	☐ YES ☐ NO
6.		☐ YES ☐ NO	☐ YES ☐ NO

*** Signature indicates employee has read this RWP.

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2. Whenever the average removable surface contamination on accessible work surfaces is greater than 100,000 dpm/100 cm^2 beta/gamma or 10,000 dpm/100 cm^2 alpha.

3. Whenever penetrating whole body dose rates for the job exceed 100 mrem/hr or whole body skin doses exceed 1 rem/hr.

4. Whenever there is a high potential for radioactive environmental release.

5. Whenever work procedures could cause changes in the work environment such that any of the above criteria could be met.

Procedure

The requesting supervisor shall describe work on the RWP form in sufficient detail so as to leave no questions of what is to be done and then shall sign it.

Requesting supervisor notifies RS Technician of the work to be done.

The RS Technician determines if the area has been properly prepared for work. Loose contamination shall be cleaned/vacuumed from the immediate area by personnel designated by the requesting supervisor. The potential for external exposure from radioactive materials stored in the area or from nearby contaminated equipment shall be reduced by the use of rubber mats or other approved shielding.

If the sources of airborne contamination cannot be eliminated, respiratory protection shall be required.

Air supplied respiratory protection is required for all work inside enclosures where uranium is handled and which are not normally occupied.

Air supplied respiratory protection shall be required if significant amounts of radioactive material are airborne in the work area at the start of work or if there is a potential for the creation of airborne contaminants due to the nature of the work (see Section 8). Examples would be: welding on a contaminated surface, cleaning up spills of dry material, and changing dust collector bags.

Half-mask respirators may be worn on lower risk or more contained dust jobs. An example would be: removing pipes or ductwork where uranium bearing materials could be inside.

Determination of Time Limits - A time limit for work performed under the RWP will be established by one of the following methods:

Weekly Exposure Controls - Weekly dose control values that are used to establish work permit time limits are:

Whole Body Penetrating	150 mrem
Skin	300 mrem
Extremities	1500 mrem

Quarterly Dose Controls - Quarterly dose control values that are used to establish work permit time limits are:

Whole Body	2400 mrem
Skin	4000 mrem
Extremities	20,000 mrem

These are 80 percent of the occupational quarterly dose limits.

The Manager of Radiological Safety is responsible for determining when quarterly dose limits will be used for calculating the maximum time allowed on a work permit.

The time limit will be set by whichever dose rate is limiting, i.e., the one which allows the shortest time.

If the extremity dose is limiting, the RS Technician will issue the worker a pair of finger rings. The dosimeter pair the worker is issued can be kept the whole month. The worker should record the ring dosimeter numbers on the drawer used for storage.

After the work permit is completed, the requesting supervisor will review the precautions required for the job, have the person(s) doing the work read the permit and sign it, signifying that they have been informed of the radiological protection requirements. The RS Technician also signs, dates, and inserts the time of RWP issuance.

After all signatures are on the RWP form, the RS Technician will give the first copy to the requesting supervisor for posting at the work location. The second copy is retained for Radiological Safety Section records. The third copy of the RWP is forwarded to the cognizant Radiological Safety Engineer for review and evaluation of exposure control.

The work permit shall remain in force for the duration of the job, not to exceed seven calendar days, as long as conditions remain the same, i.e., all materials, equipment, shielding, and structures that were present when the survey was performed have not been adjusted or moved during the performance of work in such a way as to modify the conditions of the original permit. These control measures

may include requiring the use of a special tool, shielding, protective clothing, etc.

Time limits and extremity dosimeters shall also be required if exposure rates dictate their use. The environment of nominally occupied work locations where radioactive material is handled wll be sampled for airborne radioactive concentrations. This information may be used as a tool for determining the need for modifications of equipment to improve the work environment and reduce exposures.

Special instructions shall be given to employees prior to working on grossly contaminated items, such as bag filter changes, cleaning of large ventilation ducts, use of containment devices, etc.

SECTION 5

REQUIREMENTS FOR WORKING IN RADIOLOGICAL AREAS

5.1 Radiological Area Access Control Requirements

5.1.1 Radiological Area Designations

5.1.2 Radiation Safety Training

5.1.3 Dosimeters

5.1.4 Protective Clothing

5.1.5 Food, Beverage, Smoking

5.1.6 Open Wounds, Medical Tests with Radionuclides

5.2 Work in Radiological Areas

5.2.1 Contamination Control

5.3 Exiting from Radiological Areas

5.3.1 Protective Clothing

5.3.2 Contamination Monitoring

5.3.3 Release Criteria

5.0 Requirements for Working in Radiological Areas

Radioactive materials in several forms are present during operations at the FMPC. These materials must be handled carefully by all personnel to avoid unnecessary radiation exposure.

The presence of potential hazards from radiation exposure and radioactive contamination in otherwise normal jobs requires the establishment of protective controls. Requirements that assure satisfactory control are exercised to control exposure of personnel to radiation and radioactive contamination are defined in this section. These requirements are grouped into three parts; those that define access control to radiological areas, those that pertain to work in the area, and finally, those requirements applicable to exiting from the area.

5.1 Radiological Area Access Control Requirements

5.1.1 Radiological Area Designations

The area within the FMPC where radioactive materials or elevated radiation fields are present is defined as a Radiological Area. Access into this area is controlled to minimize personnel radiation exposure. The Radiological Area includes the production area, designated sections of the Technical Laboratories and Waste Storage Area. Within the Radiological Area, other areas may be defined depending on the level of radioactive contamination or radiation present. Each area is posted with signs that state the area designation and precautions or restrictions which apply. A summary of these area designations follows: R

Radiological Area: Those areas where radioactive materials are handled but the "actual" contamination or the potential for contamination on surfaces is low, provided that procedures are followed and equipment performs as designed. Monitoring of personnel and equipment shall be performed prior to movement from a Radiological Area. Monitoring equipment is provided and must be used by personnel prior to breaks, lunch, or exiting the plant site. Some operations performed in the Radiological Area may require personnel protective equipment. For specific work activities (e.g., maintenance involving opening of uranium process equipment) with the potential for creating significant contamination levels, a temporary contamination control zone may need to be established.

Radiation Area: The Radiation Area designation refers to those areas where the external exposure is greater than 2.5 mrem/hr but less than 100 mrem/hr. For areas of greater exposure High Radiation Area and Very High Radiation Area designations may be required. (See Section 6)

Contamination Area: Any area within a Radiological Area where a high potential for contamination exists, or where known levels of contamination exceed approved values. (See Section 7)

Airborne Radioactivity Area: - Any area where the routine potential exists for airborne radioactivity concentrations. (See Section 8)

Respirator Area: - Any area where respiratory protection is required. (See Section 8)

5.1.2 Radiation Safety Training

Radiological Area workers shall successfully complete the Radiation Worker Training Program before any unsupervised work assignment is made (see Section 13). All other employees will receive Radiation Safety Training commensurate with the employee's job assignment. This training shall be successfully completed every two years. WMCO's construction contractor, RUST Engineering Company shall provide radiation worker training for its employees and subcontractors. Vendors and personnel providing short term repairs on nonradiological equipment shall be provided a brief orientation of the FMPC operations and safety programs. All visitors entering the Radiological Areas of the FMPC shall be escorted by a qualified radiation worker unless the visitor has satisfactorily completed Radiation Worker Training. Drivers of delivery vehicles are exempted from training requirements. R R

5.1.3 Dosimeters

All contractor and subcontractor personnel except drivers of delivery vehicles shall wear a TLD to enter the Radiological Area. A radiation dosimeter will not be issued unless training qualifications are current. Visitor badges shall be issued for short-term visits of less than one month. TLD's shall be kept in designated storage racks when not being worn. R

5.1.4 Protective Clothing

Employees handling process materials or maintaining or renovating equipment or structures shall make a complete change of personal clothing to protective clothes and shoes. Personal articles shall not be stored in the Radiological Area. R

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Protective clothing, such as laboratory coats or smocks, and shoe covers may be required to enter Radiological Areas as determined by Radiological Safety. R

5.1.5 Food, Beverages, Smoking

Food, gum or chewing tobacco shall not be carried into the Radiological Area. Beverages or beverage ingredients in closed containers may be carried from nonradiological areas to break areas in the Radiological Area. Beverages are available and may be consumed in break areas and designated offices in addition to prescription medicine. Smoking is permitted only in designated areas. R R

5.1.6 Open Wounds, Medical Tests with Radionuclides

The existence of open wounds shall be reported to the Medical Services Section prior to work in Radiological Areas.

Personnel who are returning to work following tests or therapy with radioisotopes shall report to Medical Services. Generally, workers will be excluded from the Radiological Area until the radioactive material is eliminated from the body. This is because radiation from medical radioisotopes cannot be distinguished from contamination by radioactive materials in the Radiological Area which an individual could contact.

5.2 Work in Radiological Areas

Radiological controls at the FMPC are necessary in areas where radioactive materials are handled and in areas where potentially contaminated materials or personnel may be located. The major sources of radioactive contamination and radiation exposure are in the production and inspection areas of the facility. Additional sources of radiation and radioactive contamination are encountered in the handling and processing of waste materials generated during the production cycle, the operation of radiation generating devices and the handling of radioactive samples. These operations can cause external radiation dose to involved personnel and could cause internal deposition of radionuclides if proper controls to prevent the generation and spread of contamination are not followed. The following rules shall be followed by individuals to control or minimize radiological hazards:

- o Obey promptly, "stop work" and "evacuate" orders of Radiological Safety personnel. R
- o Obey posted, written and verbal radiological control instructions. R
- o Wear personal dosimetry devices and air samplers as required by signs, procedures, labels, or by Radiological Safety personnel. R

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- Maintain an awareness of personal radiation dose status to avoid exceeding limits. Report prior or concurrent occupational radiation dose to the Dosimetry Section. R

- Remain in as low a radiation exposure area as practicable.

- Loitering in radiation areas is prohibited.

- Eat, drink, chew, or smoke only in designated areas.

- Wear Anti-C clothing and respiratory protection equipment properly when they are required in order to minimize spread of contamination to the skin and internal deposition of contamination. Anti-C clothing shall be removed as directed by Radiological Safety personnel. R

- Monitor for contamination with hand and foot monitors or friskers when entering break area or leaving any Radiological Area that requires the use of personnel monitors. Follow posted requirements for entering break areas or using designated smoking areas.

- Follow good "housekeeping" practices to minimize the spread of contamination and the amount of material that has to be decontaminated or disposed of as radioactive waste. Work areas should be returned to "as found" or better radiological conditions to the maximum extent practicable.

- Avoid contact with contaminated surfaces or allowing clothing, tools, or other equipment to do so.

- Place all contaminated equipment, such as tools and sampling bottles, on disposable surfaces (e.g., sheet plastic) when not in use and inside plastic bags when work is finished. Have contents of bags surveyed for contamination before transporting.

- For a known or possible spill of radioactive material, minimize its spread and immediately notify supervision and the Radiological Safety Section. R

- Report the presence of open wounds to the Medical Services Section and Radiological Safety Section personnel prior to work in areas where radioactive contamination exists. If a wound occurs while in the work area, report immediately to Radiological Safety personnel, and Medical Services Section.

- Know the emergency alarm signals and the required work area response actions.

- Submit bioassay samples and undergo whole body counts or other special analyses when requested to assure that internal exposures are identified. Failure to comply is considered a serious offense under the WMCO Rules of Conduct and may result in disciplinary action or restriction from radiologically controlled areas. R

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5.2.1 Contamination Control

An ongoing program of contamination control shall be part of the ALARA commitment at FMPC. In order to reduce airborne activity within the work environment, surface contamination in occupied areas shall be removed as quickly as practical. Every effort shall be made to contain spills of radioactive material, and this includes preplanning of jobs that present a potential for significant contact with radioactive material. Surface contamination also adds to the general exposure rates within the work environment; therefore, work locations shall be kept clean and as contamination free as practical. Exposure rates and swipe surveys shall be conducted at a regular frequency by the Radiological Safety Technicians. The frequency of surveys in various areas are dependent upon the potential hazards of the areas. Results of the surveys shall be made available to the appropriate supervision who shall be responsible for initiating actions to correct radiological deficiencies noted on the surveys. Cleaning of the work locations shall be given priority consideration. Care shall be taken to limit exposure to personnel and control the spread of contamination in the work place.

General Requirements

Radioactive material shall be contained whenever practical. The containment may be in the form of plastic wrap, specially built plugs, covers or total containment devices. The containment shall have a radiation sticker attached with the date, exposure rate, contamination level, RS Technician's signature and any special instructions pertaining to handing of the item. Radioactive material shall be handled and stored in such a manner that the potential spread of contamination is minimized and exposures to all personnel are kept ALARA.

Ingots, derbies, cores, flats, etc., shall have loose surface contamination removed with a HEPA-filtered vacuum to reduce the spread of contamination and reduce the potential for elevated levels of airborne radioactivity within the work environment. The various items made of uranium metal shall be handled remotely whenever possible to reduce extremity exposure.

Physical Barriers

Physical barriers to control access into certain areas are a necessary part of the contamination control program at FMPC. Barriers shall be erected by Radiological Safety personnel in such a manner as to isolate hazards within the area but not impede emergency egress from it. Temporary barriers are normally made with yellow and magenta poly rope and yellow

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stanchions. Appropriate radiation signs shall be attached to the rope at least at 12 foot intervals. The signs posted at the entry to the area shall state the requirements for entry. Compliance with entry requirements is mandatory.

Protective Clothing

For entry in to designated contamination areas or where the potential for release of contamination exists, special disposable clothing (Anti-C clothing) shall be required as well as respiratory protective apparatus. Anti-C clothing shall be worn over issued work clothes and shoes and may include a zippered coverall, hood, gloves, and shoe covers. All Anti-C clothing shall be removed and bagged for disposal or laundering upon exiting from the work site control area.

Decontamination

The removal of contamination from surfaces may be accomplished by cleaning methods that prevent further spread of contamination. Decontamination is performed to prevent the spread of contamination and to reduce the accumulation of material on surfaces (which can lead to elevated exposure rates, especially beta).

Caution must be taken to avoid the spread of contamination to other surfaces or into the air. The integrity of equipment must also be protected against damage from abrasion and water.

Decontamination efforts sometimes involve work in areas having elevated radiation exposure rates. In such cases, the ALARA principles described in Section 4 and the radiation exposure guidelines in Section 6 should be consulted.

Cleaning

Cleaning of radiological contaminants shall be done using HEPA (High Efficiency Particulate Air) filtered vacuums, damp mopping (if use of water is not precluded by nuclear materials handling requirements for enriched material) or other methods which do not cause air suspension of dust. Surface contaminants must be removed to minimize the resuspension into the environment and potential inhalation by personnel in the area.

The frequency of cleaning shall be dependent on the amounts and types of surface contamination, the applicable limit, the recurrence of contamination, and nearby operations which may resuspend the contaminants. The WMCO surface contamination limits are shown in Table 5.1. When these limits are exceeded, prompt cleanup is required.

TABLE 5.1

REMOVABLE SURFACE CONTAMINATION LIMITS

Radiological Area	(dpm/100 cm^2) Alpha	Beta
Clean, drinking surfaces (Zone 1)	20	100
Other surfaces (Zone 2)	200	1000
Work surfaces (Zone 3)	5000	50000

Portable Vacuums

The spread of airborne radioactivity can be minimized by high velocity portable vacuums with a high efficiency particulate air (HEPA) filter. All proposed worksite vacuum systems shall be reviewed by the Q&S Department prior to their use (this includes wet and nonprocess vacuums). R

Portable vacuum units used for cleaning radioactive materials inside of production area buildings shall be equipped with a HEPA filter(s) or the exhaust must be routed to the building's filtered exhaust system. HEPA vacuums shall be leak tested by conducting a DOP challenge of the system immediately after installation or replacement of the HEPA filter and semi-annually thereafter. All HEPA vacuums shall be labeled with a sticker that states the unit has passed a leak test and the date when the vacuum must be retested. R

Only designated portable HEPA vacuums shall be used for cleanup of radioactive materials outside of production area buildings. Portable HEPA vacuum systems approved by Q&S for outside use shall be labeled with a sticker showing compliance with DOP testing. R

5.3 Exiting from Radiological Areas

5.3.1 Protective Clothing

All protective clothing and shoe covers shall be removed and left at the exit point from the Radiological Area for laundering. Shoes are kept in employee lockers. Dosimeters shall be stored in their designated storage area. Personnel changing from company issued work clothes, i.e., coveralls, shall shower before donning personal clothes.

Protective clothing which has fixed contamination exceeding 15,000 dpm/100 cm^2 beta-gamma shall not be issued. R

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5.3.2 Contamination Monitoring

All personnel exiting from the Radiological Area must monitor for contamination before entering the non-radiological area. Hand and foot monitors and friskers are provided with appropriate instructions for use at each exit point. All personal articles carried from the process area must likewise be monitored.

Contamination above an acceptable level, indicated by an instrument alarm, may generally be removed by repeated washing with soap. If contamination above acceptable limits remains, contact RS Technicians for assistance in decontamination and remain in place until the RS technician arrives to evaluate the reported contamination. R

Vehicles, equipment, and materials being taken from the Radiological Area are likewise subject to contamination monitoring. A pass card shall be issued to the vehicle operator as evidence of a contamination survey. Items with contamination greater than approved limits will not be permitted to leave the Radiological Area. R

5.3.3 Release Criteria

Release of trash and construction rubble from the Radiological Area is controlled by a contamination survey. Waste materials shall be surveyed for contamination before bagging. Construction rubble having levels of contamination greater than 35 pCi/gm for concrete and 30 pCi/gm for soil shall be stored in a remote part of the Radiological Area pending disposal. R

SECTION 6

REQUIREMENTS FOR WORKING IN RADIATION AREAS

6.1 Controlling Exposure in Radiation Areas

6.2 Exposure Limits for Radiation Areas

6.3 Requirements for Working in Radiation Areas

6.3.1 Posting Requirements

6.3.2 Access to High Radiation Areas

6.3.3 Authorization for Work in Radiation and High Radiation Areas

6.3.4 Shielding

6.4 Radiation Surveys

6.4.1 Requirements

6.4.2 Routine Surveys

6.4.3 Nonroutine Surveys

6.4.4 Survey Techniques

6.0 Requirements for Working in Radiation Areas

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6.1 Controlling Exposure in Radiation Areas

Radiation Exposure Control shall be maintained through the use of physical barriers, operating procedures, Radiation Work Permits, surveillance, training and engineered modifications to equipment. Work areas that produce high personnel exposures shall be identified and changes should be engineered to lower exposures. Functions that result in elevated exposures to personnel shall also be evaluated and appropriate changes made. These changes may include, but are not limited to, remote handling equipment, robotics, total enclosures, improved ventilation, and shielding.

All personnel have the responsibility of working in a safe manner and identifying potential hazards to supervision who shall investigate and recommend appropriate remedial actions. WMCO has the responsibility to provide a safe work environment and to investigate and resolve radiological safety concerns in a conscientious manner.

6.2 Exposure Limits for Radiation Areas

External exposure control is accomplished by identifying areas containing sources of radiation and controlling personnel access into these areas or by removing the radiation source. Radiation Areas are accessible areas where a major portion of the body could receive a dose equivalent greater than 2.5 mrem, but less than 100 mrem, in one hour.

High Radiation Areas are areas where a major portion of the body could receive a dose equivalent of 100 mrem or more in one hour. Major portions of the body are defined as the head, trunk, upper arms, thighs, and gonads.

6.3 Requirements for Working in Radiation Areas

6.3.1 Posting Requirements

Radiation and High Radiation Areas are defined by the following exposure rates:

Area	Effective Dose Rate Equivalent
Radiation Area	>2.5 <100 mrem/hr.
High Radiation Area	>100 mrem/hr.

Radiation Areas shall be conspicuously posted by the RS Technician with the standard magenta radiation symbol on a yellow background and the words "Radiation Area". The posting should display any additional information which may be appropriate in aiding individuals to minimize exposure to radiation.

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The boundaries of a Radiation Area or a High Radiation Area that are not formed by permanent structures (walls, doors, fences, etc.), shall be barricaded by radiation rope/ribbon installed at approximately waist height. Radiation posting signs must be attached.

High Radiation Areas shall be conspicuously posted by the RS Technicians with the standard magenta radiation symbol on a yellow background and the words "HIGH RADIATION AREA". The posting should include the maximum radiation level and location within the area. The information may be on the High Radiation Area sign or on a separate plant view or sketch. The posting at the entry shall contain special instructions and requirements which may be appropriate in minimizing exposure to radiation.

High Radiation Areas that have posted survey dates more than 90 days old must be resurveyed by the RS Technicians prior to allowing work in the area. If the conditions producing high radiation in an area are inherent to the facility or operation, and are relatively stable and not subject to change, permanent signs may be posted with the radiation symbol "HIGH RADIATION AREA" and appropriate information and instructions. The use of permanent signs shall be approved by the Manager, RS or his designate.

6.3.2 Access to High Radiation Areas

The boundaries of a High Radiation Area shall be evaluated by RS personnel for all possible means of access and those not formed by solid physical structures (walls, doors, fences, etc.), shall be barricaded to preclude unauthorized entry.

Access(es) to the High Radiation Area shall be locked or maintained under continuous surveillance. When locking systems are used, a key control system shall be established, the number of keys shall be minimized and the personnel authorized to sign out the keys shall be specifically designated in writing.

Positive controls shall be established for each individual entry such that no individual is prevented from leaving the area. Prior to locking an area, the area shall be inspected to ensure that no personnel remain inside.

No loitering or entry by unauthorized personnel shall be allowed in these areas.

Instances in which High Radiation Areas are not controlled as required by this paragraph shall be reported as Unusual Occurrences. These instances include the following:

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- Locking personnel in a High Radiation Area.
- Failing to post a High Radiation Area or failing to lock or guard a High Radiation Area. The Unusual Occurrence Report is not required if the area is properly controlled after its initial identification.

6.3.3 Authorization Work for in Radiation and High Radiation Areas

Radiation Work Permits are required for tasks performed under approved work procedures if those tasks involve work in high radiation fields or in areas where radiation fields are unknown or where large significant variations are possible in the radiation field. The RWP identifies the work activity, the associated radiological conditions and protective measures required to accomplish the work (See Section 4.4.2).

6.3.4 Shielding

Permanent shielding shall be designed and installed as part of construction of new facilities and during modifications to existing facilities where routine operations, materials or equipment produce or involve high radiation levels or where an unusual occurrence could result at such levels.

Changes in the use or operation of facilities which could affect radiation levels outside the shielding in excess of design levels, and changes in use of areas surrounding the shielding shall require prior review and approval by Q&S Management. Removal of permanent shielding shall not be permitted unless approval has been obtained from the Manager of Q&S. Radiation surveys are required any time shielding configurations are altered.

Temporary shielding shall be used in areas where its use is reasonably beneficial, for example where crucibles, derbies, and flats are being temporarily stored. Incorrect installation, unauthorized movement, or removal of temporary shielding can result in significant changes in work area radiation levels; therefore, control of temporary shielding is essential. Radiological Safety shall specify the locations where temporary shielding is required.

Rubber matting shall be routinely used on individual items such as a derby or an ingot. The rubber matting is very effective in reducing the beta exposure rate on individual components. The practice of covering the product will significantly reduce skin exposures.

Beta radiation can also be shielded with light metals, plywood, or heavy plastic. Aluminum and plywood are very good shielding materials. Heavy plastic shall not be used inside any building without approval of WMCO Safety and Fire

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Protection Engineering. Materials with a high atomic number (Z), i.e., lead, steel, should not be used as the primary shield against beta radiation since the X ray generated by beta absorption can contribute significantly to the penetrating radiation dose.

6.4 Radiation Surveys

The primary objective of radiation surveys is to identify existing and potential radiation levels. This is to assure that exposures are maintained as low as reasonably achievable (ALARA). Survey results are utilized to:

- o Evaluate jobs for ALARA considerations.
- o Set up procedures.
- o Provide a baseline for trend analysis, investigation and correction of unusual conditions.
- o Detect departures from operating procedures or failure of radiation controls.
- o Identify the origin of radiation exposures in the plant by location, system or component.

6.4.1 Requirements

Radiation surveys shall be performed by RS personnel to preclude the possibility of personnel being exposed to elevated levels of radiation and exceeding established radiation dose limits. They shall be used to meet the requirements for posting Radiation and High Radiation Areas. The surveys shall be performed to determine the magnitude and extent of radiation levels.

Radiation surveys are typically divided into routine and nonroutine classifications.

6.4.2 Routine Surveys

Routine surveys shall be performed by RS personnel on a regular basis (e.g., daily, weekly, monthly, etc.), while nonroutine surveys are performed as necessary to support plant processing modifications, work activities, and any nonroutine conditions.

Routine and nonroutine radiation surveys shall be performed for alpha, beta, and gamma radiation.

Surveys shall be performed with instruments calibrated for the type and energy range of radiation being monitored. The instrument range should be high enough to read the highest exposure rate expected. The instrument used shall have a current calibration label and its operability verified.

A sufficient number of survey points shall be taken in order to adequately assess the radiological status of the area being surveyed.

Surveys shall be accurately and legibly documented in ink on a standard form. These survey records shall be filed and maintained by area in chronological order so that previous radiological conditions can be readily reconstructed and background data for radiological engineering evaluation is readily available.

- o The data shall be in sufficient detail so that the meaning and intent of the record is clear.
- o Ditto marks and continuation lines are unacceptable for repeated data.
- o Any corrections to a survey record shall be made by drawing a single line through the incorrect entry (incorrect entry shall remain legible) and recording the correct entry. The person making the correction shall initial and date the entry. The use of erasures or correction tape/fluid is prohibited. Correction of each copy of a survey record shall be completed in the same manner.

6.4.3 Nonroutine Surveys

Nonroutine surveys shall be performed by RS personnel as necessary to support plant operations, maintenance and modification efforts. Examples of nonroutine surveys are as follows:

- o An initial radiation survey shall be performed before and after a new facility using radioactive materials becomes operational. The survey shall also be required after completion of any modifications or changes in existing facilities that the Manager of Q&S determines might lead to a substantial change in the radiation hazards associated with operation of the facility. The survey shall be thorough with specific requirements determined by Q&S Management.
- o Radiation surveys to verify the effectiveness of permanent or temporary shielding.
- o During removal of shielding so that personnel are not unexpectedly exposed to radiation.
- o After changes in use of operation of a shielded facility (may be part of the survey required by the first example above).

o After modifications to the shield or changes in shield materials.

Radiation surveys shall be performed at predetermined points in active work areas and adjacent areas whenever operations are performed that have the potential for significantly changing radiation levels. Examples of these are movement

of permanent or temporary shielding, radioactive waste processing, and relocation of highly radioactive materials. The survey may be done as part of a radiological inspection.

Radiation surveys shall be performed upon initial entry into tanks or enclosures that contain radioactive piping or components or high levels of loose contaminated material. Surveys shall be conducted when performing operations which could result in personnel being exposed to small intense beams of radiation. Examples of such operations include removing shielding at the boundaries of a High Radiation Area and opening containers of high activity radiation sources such as radiography sources.

6.4.4 Survey Techniques

When surveying areas or equipment where intense small beams of radiation can be present, the radiation detection instrument shall be used with audible response. An audible response is necessary due to the lag time in meter response. The probe shall be moved slowly enough so that the instrument has a chance to give an audible increase for a large radiation level increase. Particular attention shall be given to thoroughly scanning suspected areas, such as portable shield sections and areas which are or are likely to be occupied. Small intense beams have occurred in places such as outside shields surrounding sources containing many curies. For equipment with complex shield design, surveyors shall obtain briefings on the equipment design so that areas most likely to have small beams can be given special attention.

SECTION 7

REQUIREMENTS FOR WORKING IN CONTAMINATION AREAS

7.1 Controlling Contamination from Radioactive Material

7.2 Limits for Surface Contamination

7.3 Requirements for Working in Contamination Areas

7.3.1 Posting Requirements

7.3.2 Authorization for Work in Contamination Area

7.3.3 Anti-Contamination Clothing

7.3.4 Decontamination of Areas

7.3.5 Personnel Monitoring Requirements

7.3.6 Handling Radioactive Material

7.4 Contamination Surveillance

7.0 Requirements for Working in Contamination Areas

7.1 Controlling Contamination from Radioactive Material

A Contamination Area designation applies to those areas where radioactive material is handled and significant levels of contamination exist, or can be generated, even though procedures are followed and equipment performs as designed. Controls are established to prevent the removal and spread of contamination from the Contamination Areas via clothing, shoes, equipment, etc. Contamination monitoring of personnel and equipment prior to exit from the area is essential. Usually, special work practices will be required to limit potential employee exposure and to control the contamination generated. Anti-contamination (anti-C) apparel will be utilized and respiratory protection will often be required. Pre-job monitoring and evaluation by RS technicians will usually be required. The RWP (Radiation Work Permit) evaluation provides a summary of the contamination levels detected and the permit specifies any personnel protection requirements for the job must be posted at the work site. A Contamination Area may be either permanently or temporarily established; the operating requirements and controls would be the same in either case.

To achieve containment of contamination in the Contamination Area, all anti-Cs must be removed at a step-off pad prior to exit from the area. Additionally, personnel, tools, and equipment shall be monitored for contamination each time they exit the area. If the monitoring is to be performed by other than Radiological Safety personnel, specific exit guidelines shall be provided as "go", "no-go" criteria. Post-job contamination monitoring of a temporary Contamination Area is required with whatever decontamination activity is necessary to return the area to its previously designated status; at which time the barriers may be removed.

In all areas, the primary requirement is the control of contamination by two basic methods. First, positive contamination prevention through job planning that stresses the use of reasonable and innovative precautionary measures to eliminate, reduce, and/or contain contamination generated by the work activity. Second, an active decontamination program administered according to established contamination limits.

7.2 Limits for Surface Contamination

The values in Table 5.1 are those levels of contamination which provide an upper boundary condition for the particular area in question. Decontamination is required whenever the average contamination level in the area exceeds the Zone 2 and Zone 3 limits.

7.3 Requirements for Working in Contamination Areas

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7.3.1 Posting Requirements

Any area within a radiological area where high potential for contamination exists, or where known levels of surface contamination exceed the Zone 2 limits given in Table 5.1, shall be posted by RS personnel with "Contamination Area" signs.

Physical barriers to control access into certain areas are a necessary part of the contamination control program at FMPC. Barriers shall be erected by RS personnel in such a manner as to isolate hazards within the area. Temporary barriers are normally made with yellow and magenta rope and yellow stanchions. Appropriate signs shall be attached to the rope at least at 12 foot intervals. The signs shall have the standard magenta radiation symbol and the words "Contamination Area". Signs posted at the entry to the area shall contain special instructions and requirements.

The average removable nonwork surface contamination level in the area shall be specified on the sign. Personnel protection requirements shall also be specified on the sign.

Access control points for Contamination Areas must have the following: 1) a "Contamination Area" sign, 2) a step-off pad area, 3) a contamination-waste barrel or plastic bag (for disposal of gloves, shoe covers, tyvek coveralls, etc.), and 4) a shoe/shoe cover exchange area. There shall also be adequate provision of anti-contamination apparel stored on the clean side of the step-off pad.

Shoe covers or dedicated company-issued shoes, company-issued coveralls, and gloves shall be the minimum required for entry to Contamination Areas. Requirements for additional anti-contamination apparel and respiratory protection shall be specified by RS personnel on a case-by-case basis.

Portable contamination monitoring instruments shall be made available to workers in contamination areas, unless there is dedicated RS technician support for a particular job or operation. Workers shall be instructed by RS personnel in the use of these instruments.

7.3.2 Authorization for Work in Contamination Area

A Radiation Work Permit shall be required for the performance of any task that involves exposure to radioactive material for which there is not an approved work procedure. The RWP identifies the work activity, the associated radiological conditions and protective measures required to accomplish the work. (See Section 4)

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7.3.3 Anti-Contamination Clothing

For entry or work in designated Contamination Areas or where the potential for release of contamination exists, special disposable clothing (anti-C clothing) shall be required as well as respiratory protective apparatus. Anti-C clothing shall be worn over issued work clothes and shoes and may include a zippered coverall, hood, gloves and shoe covers. All anti-C clothing shall be removed and bagged for disposal upon exiting from the work site control area.

Personal property (exclusive of undergarments, jewelry, eye glasses, hearing aids and prosthetic devices) shall be prohibited in Contamination Areas.

7.3.4 Decontamination of Areas

If surface contamination levels in a Contamination Area which is accessible to personnel exceed the Zone 2 limits given in Table 5.1, the affected area or item must be decontaminated within 5 work days of the receipt of the survey results.

Cleaning of radiological contaminants shall be done using HEPA (High Efficiency Particulate Air) filtered vacuums or, damp mopping if water is not precluded by nuclear materials handling requirements for enriched material. Due to bulk properties (i.e., density, mass, diameter of particulate) surface contaminants must be removed to minimize the resuspension into the environment and inhalation by personnel in the area.

The frequency of cleaning shall be dependent on the amounts and types of surface contamination, the applicable limit, the recurrence of contamination, and nearby operations which may resuspend the contaminants.

When decontamination of any surface is required by Radiological Safety personnel, a post-decontamination survey shall be conducted in order to document the residual contamination levels.

All items requiring decontamination shall be tagged by RS personnel. The tag shall bear the words "Caution - Radioactive Contamination" or words of similar meaning. The tag shall specify:1) the maximum direct reading and removable contamination levels on the item, 2) the recommended action (wet decontamination, etc.), and 3) the personnel protection requirements necessary to carry out the recommended action.

7.3.5 Personnel Monitoring Requirements

Contamination monitoring instruments shall be deployed by RS personnel at all Contamination Area work sites. Alarm set-points and/or administrative action levels shall be set or posted.

7.3.6 Handling Radioactive Material

Radioactive material shall be contained or covered whenever practical. The containment may be in the form of plastic wrap, specially built plugs, covers or total containment devices. The containment shall have a radiation sticker attached with the date, exposure rate, contamination level, Radiological Safety technician's signature and any special instructions pertaining to handling of the item. Radioactive material shall be handled and stored in such a manner that the potential spread of contamination is minimized and exposures to all personnel are kept ALARA.

Ingots, derbies, cores, flats, etc., shall have loose contamination vacuumed from their surfaces before storage or transport to reduce the spread of contamination and reduce the potential for elevated levels of airborne radioactivity within the work environment. The various items made of uranium metal shall be handled remotely whenever possible to reduce extremity exposure.

7.4 Contamination Surveillance

In general, three basic types of surface contamination monitoring are performed by RS personnel:

1. Routine monitoring of facilities and equipment for contamination to specify decontamination requirements and/or to specify personnel protection or contamination control requirements for subsequent work activities.

2. Job specific monitoring of tasks that may involve the generation of significant contamination or that are performed in areas where significant levels of contamination may be present (e.g., Contamination Areas). This monitoring would include a pre-job hazard evaluation.

3. A routine contamination monitoring program of selected areas is required to determine the degree of general workplace contamination and to assess the effectiveness of contamination control practices.

A fourth type of monitoring is associated with an unusual occurrence. If contamination is found in an area that is normally contamination free, then surveys must be made to determine the extent of the problem. An investigation as to the cause should follow.

SECTION 8

REQUIREMENTS FOR WORKING IN AIRBORNE RADIOACTIVE AREAS

8.1 Controlling Airborne Radioactivity

8.2 Limits for Airborne Radioactivity

8.3 Requirements for Working in Airborne Radioactive Areas

8.3.1 Posting of Areas

8.3.2 Respiratory Protection

8.3.3 Authorization for Work in Airborne Radioactivity Areas

8.3.4 Containment of Airborne Radioactivity

8.4 Monitoring for Airborne Radioactivity

8.0 Requirements for Working in Airborne Radioactivity Areas

8.1 Controlling Airborne Radioactivity

Radioactivity can become airborne through such operations as burning, welding or grinding a contaminated component, decontamination, formation of particles from the products of process reactions, or disturbing deposited radioactivity on contaminated floors or other surfaces.

Airborne radioactivity at the FMPC is a combination of both particulate and gaseous radioactive material. Gaseous activity (e.g., radon, thoron) is experienced in very limited areas of the facility and does not normally represent a significant contribution to exposure.

Control of airborne radioactivity by the application of engineered controls is the primary means for minimizing inhalation of airborne radioactivity. In situations where engineered controls are not practicable such as in dust collector enclosures, respiratory protection shall be used.

Air samples shall be taken where significant concentrations of airborne radioactivity are probable or suspected within the work environment. Continuous air monitors (CAM's) are used to monitor selected nominally occupied areas. Continuous fixed-filter air samplers are used for monitoring the air exhausted in the plant stacks.

Other sampling equipment is available for specific applications. Portable, battery operated samplers are available for emergency sampling, such as at a fire. Working level monitors may be used for detecting the short-lived decay products of Rn-220 (Thoron) and Rn-222 (Radon). High volume samplers are required for quickly drawn samples which involve low DAC limit radionuclides, such as Th-232. Annular impactors may be used to eliminate radon and thoron decay products for early long-lived activity analyses.

8.2 Limits for Airborne Radioactivity

Limits for airborne radioactivity in occupied areas are listed in Appendix B to this manual. These limits are designated by the DOE as derived air concentrations (DAC) for airborne radioactivity and are limits for average concentrations of radionuclides of various solubility classes over a working year. The use of respiratory protection is prescribed on the basis of airborne concentrations present compared to the listed values. Measurement of air concentration is routinely reported at FMPC in units of uCi/cm^3.

8.3 Requirements for Working in Airborne Radioactive Areas

8.3.1 Posting of Areas

Any area within a Radiological Area where the potential exists for airborne radioactivity concentrations greater than 0.8 DAC hours per shift shall be posted by RS personnel as an Airborne Radioactivity Area.

Any area within a Radiological Area where actual airborne radioactivity concentrations exceed 2.0 DAC hours per shift when averaged over one calendar quarter or 8.0 DAC hours during any single shift shall be posted as a Respirator Area.

In addition, areas where surface contamination exceeds 50,000 alpha dpm/100 cm^2, or 100,000 beta-gamma dpm/100 cm^2 shall be posted as Airborne Radioactivity Areas due to the potential for resuspension of radioactivity until air sampling shows air activity to be less than the limits.

The posting shall have the standard magenta radiation symbol on a yellow background and the words "Airborne Radioactivity Area." Special instructions or requirements for entry to airborne areas shall be conspicuously posted at the entrance.

8.3.2 Respiratory Protection

If the sources of airborne contamination cannot be eliminated, respiratory protection shall be required. Respirators shall be used in accordance with the FMPC Respiratory Protection Manual (FMPC-2152).

Air supplied respiratory protection may be required if significant amounts of radioactive material are airborne in the work area at the start of work or if there is a potential for the creation of airborne contaminants due to the nature of the work. Examples would be: Welding on a contaminated surface, cleaning up spills of dry material, and changing dust collector bags.

Respiratory protection shall be considered whenever burning, grinding, or welding takes place on a contaminated surface.

A. Respirator Selection

Different brands of respiratory protective equipment are available at the FMPC. These respirators have been chosen to facilitate proper fitting and optimal user protection and comfort.

Several factors govern respirator selection. These include.

1. The nature and extent of the hazard.

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2. Work requirements and conditions.

3. Respiratory equipment protection limits.

4. Availability of approved equipment.

5. Facial characteristics (size, shape, etc.).

6. Skin reactions to the material from which the respirator is made.

B. Respirator Types

The types of respirators available for use are: Half-mask air-purifying respirators, full-face air-purifying respirators, air-supplied respirators with half- or full-face mask or hood and self-contained breathing apparatus (SCBAs). They are described in FMPC-2152.

C. Protection Factors

The overall protection provided by a respirator is defined as its protection factor (PF). Table 8.1 shows the protection factors for each type of respirator as listed in NRC Regulatory Guide 8.15.

The PF is defined as the ratio of the concentration of contaminants outside the respirator to that inside the respirator under conditions of use. For example, if the contaminant concentration inside a half mask respirator is less than 10 percent of that outside the respirator, it may be used for respiratory protection in atmospheres with a contaminant concentration up to 10 times the permissible exposure limit. When calculating the exposure of individuals wearing respiratory protection equipment from radioactive materials, the concentration of airborne radioactive contaminants is divided by the protection factor to determine actual intake. The PF is the lowest acceptable fit test factor (FTF) defined in FMPC-2152.

8.3.3 Authorization for Work in Airborne Radioactivity Areas

A Radiation Work Permit shall be required for the performance of any task that involves exposure to radioactive material for which there is not an approved work procedure. The RWP identifies the work activity, the associated radiological conditions and protective measures required to accomplish the work (See Section 4).

8.3.4 Containment of Airborne Radioactivity

The spread of airborne contamination should be minimized by employing a localized, high velocity, high efficiency particulate air (HEPA) filtered exhaust at the worksite. HEPA

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TABLE 8.1

RESPIRATORY PROTECTIVE EQUIPMENT

Type of Equipment	Condition Inside of Headpiece	Protection Factor [a]
1. Air-Purifying[b]		
(a) Half-Face	negative pressure	10
(b) Full-face Facepiece	negative pressure	50
2. Airline Respirator (Type "C" supplied air respirator)[c]		
(a) Half-mask	continuous air flow	1000
(b) Full-face facepiece with emergency supply of compressed air	continuous air flow	2000[d]
(c) Hood headpiece	continuous flow	2000
(d) Helmet headpiece	continuous flow	2000
3. Self-Contained Breathing Apparatus (SCBA)		
(a) Full-face facepiece - open circuit	pressure-demand	10,000[d]

NOTES:

[a] Protection factor is the multiplication constant used to determine the degree of protection from a properly used respirator (for example, the airborne limit for U-238 is 1×10^{-10} uCi/ml. A protection factor of 10 allows entrance into an environment with a concentration of 1×10^{-9} uCi/ml).

[b] An appropriate high efficiency radionuclide cartridge must be used in all cases.

[c] The equipment supplying breathing air and the air supplied shall meet the requirements in Compressed Gas Association (CGA) Standard G-7.1-1973 for Grade D air. The air in any breathing supply shall be tested initially and at least annually thereafter by Q&S.

[d] Approved for use in environments that are immediately dangerous to life and health.

filtered vacuum cleaners or portable air movers fitted with ducting and HEPA filters may be used for this application. Personnel are still required to use respiratory protection when the potential for airborne contamination exists. This requirement is not relaxed by the use of a localized HEPA filtered exhaust. Proposed worksite HEPA filtered exhaust systems shall be reviewed by the Q&S Department prior to their use.

To prevent cross contamination, designated vacuums shall be used in work areas. Hoses of vacuums used in contaminated work areas shall have the ends taped and tagged as radioactively contaminated after use.

Contamination containments shall be used to the maximum extent practicable to prevent personnel exposure to airborne radioactivity above the listed limits. This containment is required during radioactive work which has been known to cause or is expected to cause airborne radioactivity.

a. The exhaust from radiologically controlled containments shall be HEPA filtered whenever work is in progress in these containments to prevent the release of airborne contamination to the surrounding environment.

b. HEPA filters shall be installed in the exhaust from contamination containments to prevent personnel from being exposed to significant airborne radioactivity.

c. HEPA filters shall be installed and certified acceptable by Q&S in vacuum cleaners used for removing surface contamination.

8.4 Monitoring for Airborne Radioactivity

Air particulate surveys shall be performed by RS personnel. Records of the results of these surveys shall be reviewed by Radiological Safety personnel. The following air samples shall be the minimum performed:

a. During radioactive work which has been known to cause or is expected to cause airborne radioactivity, and in occupied surface contamination areas.

b. When opening a process system to the atmosphere for operation or maintenance. Air samples are not required during normal liquid sampling operations or when opening the system in a containment enclosure equipped with a high efficiency filter.

c. When initially entering tanks containing potential radioactive piping or material.

d. Whenever airborne radioactivity levels above the acceptable limit are suspected.

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The precise location for air samples cannot be specified for all situations. The primary objective is to obtain "breathing zone" (BZ) air samples or general area air samples. BZ air samples are collected using a portable, battery powered air pump with a small filter located as close to the worker's immediate breathing zone as possible. General area sampling shall be performed continuously in normal work or process areas. The locations for air samples shall be based on the following: 1) the breathing zone of the worker, 2) the position of the sampler relative to the work zone and other operations which might contribute to elevated levels of radioactivity in the breathing zone, 3) the type of work being performed (for example, grinding), and 4) the containment enclosure arrangement used. The volume of air sampled depends on the equipment used and the radionuclides of concern.

Radionuclides and Their Chemical Forms at FMPC

The potential airborne radionuclides of limiting concern in the various plants and areas of FMPC are shown in Table 8.1. Solubility classes are listed based on conservative assumptions. The process activity or condition producing the chemical form is also listed.

When it is determined by Radiological Safety that an employee has been in an environment where the air concentration is equal to or greater than 40 DAC hours, without a respirator, he/she will leave a "special urine sample." This is based on requirements of DOE Order 5480.11, 9.g.2.

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TABLE 8.2

LOCATION AND SOLUBILITY CLASS OF POTENTIAL AIRBORNE RADIONUCLIDES AT FMPC

Plant/Location	Radionuclide/Form	Class	Source
Pilot Plant			
autoclave/reactor	UF_4	W (U-238)	UF_6/UF_4 conversion
	UF_6	D (U-238)	UF_6/UF_4 conversion
grit blaster and plasma spray unit	UO_2, U_3O_8	Y (U-238)	
	Th-234 and Pr-234	Y	U-238 decay products
wet area	Rn-220 (Thoron) and decay products	N/A	Th-232 embedded in floor/equipment
	Th-232	W	Th-232 embedded in floor/equipment
Plant 1	Th-232	W	Most conservative limit for sampling and processing.
Plant 2/3	UO_2, U_3O_8 UO_3	Y (U-238) D (U-238)	Start of process. End of process.
Plant 4	U-238 oxides	W	U oxide to UF_4.
Plant 5	U-238 oxides/metal	Y	Area B
	Th-234 and Pr-234	Y	U-238 decay products
	UF_4	W (U-238)	Area A
Plant 6	U-238 oxides/metal	Y	Machining/pickling.
	Sodium diuranate	W	Water treatment.
Plant 8	U-238	Y	Most conservative U limit for processing many U compounds.
Plant 9	U-238 oxides/metal	Y	

Solubility Class

D = very soluble
W = moderately soluble
Y = relatively insoluble

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SECTION 9

RESPONDING TO RADIATION INCIDENTS

9.1 Incident Repsonse

9.1.1 Basic Guidelines

9.1.2 Follow-up Actions

9.1.3 Radiological Safety Response to Incidents

9.2 High Radiation Alarm

9.3 Airborne Radioactive Alarm

9.4 Radioactive Material Spills

9.5 Radioactive Material Fires

9.0 Responding to Radiation Incidents

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9.1 Incident Response

An incident is a sudden unexpected event requiring immediate response to limit the impact on people, property or the environment. When radioactive material is involved, Radiological Safety plays a major role in evaluating, controlling, and recovering from the event. Examples of incidents involving radioactive materials are: nuclear criticality, fire or explosion involving radioactive material, spill of radioactive material and an unexpected radiation detection alarm.

Radiological Safety personnel shall respond to all radiological emergency incidents. The ability to assess and evaluate the situation and the immediate steps to minimize the effects of the event are crucial for controlling the emergency (see FMPC-503).

An emergency response may be initiated by personnel observing the event, alarms or the Emergency Operations Center (EOC). A rapid response is required; however, undue risks shall be avoided and employee safety shall not be compromised.

The type of emergency determines the level of planning for response. For example, a CAM alarm or a small radioactive spill requires little planning for the initial response. However, when an emergency causes a facility/plant evacuation, preplanning (e.g., stay time, route of entry, decontamination method, etc.) and the approval of the AEDO are necessary for re-entry.

9.1.1 Basic Guidelines

The basic guidelines for emergency response include the following:

- Radiation exposure considerations - These are not limiting factors for rescue of personnel.
- Rendering first aid to injured employees - This may be administered by members of the ERT, Medical Staff or other trained personnel.
- Attempt to stop the cause - Undue risks shall be avoided.
- Warn other personnel - Keep unnecessary personnel away from the event.
- Isolate the area - Install barriers as quickly as possible to establish a controlled area separating the affected area from the unaffected areas. In determining the size of the controlled area, the following should be considered: Gamma (penetrating) dose rates, possible spread of contamination, weather conditions, chemical hazards, nonradiological hazards, and security. Normal

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operations outside of the controlled area may continue.

- o Minimize Exposure - For initial response, unnecessary radiation exposure shall be avoided.

- o Survey - Define and assess the radiological problem and conditions. Interview people at the scene regarding the nature and extent of the incident. Perform radiological surveys; the type of survey is based on the event. Types of surveys include: personnel surveys, property and equipment surveys, dose rate estimates, air sampling, perimeter surveys, and re-entry surveys.

9.1.2 Follow-up Action

This includes, but is not limited to, decontamination, providing monitoring coverage, formal evaluations, restoration, and documentation. A planned operation is necessary to assure personnel exposures are minimized. Any planned exposure above the occupational dose limits requires the permission of the FMPC Site Manager and personnel who will be expected to receive the extra exposure.

Any employee involved in an incident which could have resulted in an intake of radioactive materials by inhalation, ingestion or absorption shall submit a urine sample at the end of employee's shift and again at the start of the next shift or as directed by Radiological Safety.

9.1.3 Radiological Safety Response to Incidents

The primary function of Radiological Safety is to provide the radiological data necessary to confirm and control the incident, determine the magnitude of the incident, minimize exposure to personnel, minimize contamination spread, and assist in the recovery actions. Radiological data is provided through surveys performed by Radiological Safety and by air sample monitors in or near the event area. Radiological surveys include radiation dose rates, radioactive contamination levels and air activity levels.

The primary purpose of all surveys is to assure personnel protection, to maintain exposure ALARA, and to minimize contamination of the area and personnel.

General Responsibilities of Radiological Safety Personnel

- o Respond to any potential emergency involving radioactive material.

- o Perform radiological surveys of personnel and the affected area.

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- Document survey results.
- Establish boundaries and access control.

Communication

- Normally, communication is made to the AEDO or EOC.
- The primary method of communication with the RS supervisor is the two-way radio No. 355, and telephone system Extension 6889.
- Contact the emergency representative as soon as possible after reaching the assigned area. Maintain frequent contact to provide radiological data.

Preparation

- Availability of emergency kits and instrumentation.
- Availability of equipment and supplies.
- Protective clothing.
- Respiratory protection.
- Dosimetry
- Emergency vehicle.
- Two-way radio.

Area Survey and Access Control

- Don protective clothing as necessary.
- Approach the affected area cautiously, with instruments operating.
- Survey area to determine incident size.
- Determine and establish boundaries based on dose rate, contamination spread, and air sampling.
- Establish entry/exit point of control.
- Determine radiation background in staging area.
- Survey personnel who have evacuated for contamination.
- If applicable, segregate personnel in protective clothing.

- o Set priority of survey. Injured personnel should be given first priority. Personnel in protective clothing, personnel who evacuated surface contamination area, and remaining personnel should follow.
- o Start air sampling.
- o Report survey results.
- o Survey all personnel and equipment leaving affected incident area.

Information to be Obtained

- o Time of incident.
- o Location of the incident.
- o Nature of the incident.
- o What radiological information is known.
  - Contamination (property and personnel).
  - Dose rate.
  - Isotopes involved and their solubility classes.
  - Air sampling data.
- o Availability of other personnel to support emergency activities.
- o Are nonradiological hazards involved (i.e., chemicals, explosive devices, fire, etc.)?
- o Plume tracking (if necessary).
- o Status of environmental protective actions (i.e., diverting storm drains, securing dust collectors, etc.).

9.2 High Radiation Alarm

Notification of a high radiation alarm will occur by means of the RDA system or a verbal warning from Q&S personnel or coworkers.

Immediate Action for High Radiation Alarm

- o Evacuate all personnel.
- o Stop any work or operation that may be causing the high radiation problem (for example, radiography).
- o Assure that personnel evacuated from contamination areas are surveyed for contamination.

- o Obtain information from evacuated personnel on the possible cause of the alarm.
- o If evacuated personnel are wearing direct self reading dosimeters, read the dosimeter and note any high reading.
- o Establish boundaries as necessary to control access until the source of the high dose rates have been identified, and eliminated or reduced to normal conditions.

9.3 Airborne Radioactivity Alarm

Notification of high airborne radioactivity may be either by means of a Constant Air Monitor (CAM) Alarm or a verbal warning from Q&S personnel or coworkers.

Immediate Actions for Airborne Radioactivity Alarm

- o Evacuate all unnecessary personnel from the area. If personnel must remain in the area due to operation considerations, they must don respiratory protection immediately.
- o Warn other personnel in the area.
- o Notify supervision and RS Technicians of the problem.
- o Request any work or operation that may be causing the airborne problem be suspended until further evaluation.
- o Turn off all unfiltered exhaust ventilation from the affected area.
- o Remain outside but adjacent to the affected area until released by RS personnel.

9.4 Radioactive Material Spills

Response actions are needed to minimize the spread of contamination if radioactive material is spilled. These apply to spilled radioactive material in dry or liquid form within or outside a facility/building.

CAUTION: If unfamiliar with the material or system, wait for qualified help. Do not move damaged containers. Evaluate potential for life threatening situations, such as toxic chemical fumes or criticality.

Immediate Actions for Radioactive Material Spill

- o Evacuate all unnecessary personnel in or near the spill area to a safe, central location. (Consider personal contamination surveys and nasal smears.)
- o Warn approaching personnel to remain outside of spill area.

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- o Evaluate the need for backup equipment and personnel. 360
- o Notify RS Supervisor.
- o Notify Operations Supervisor.
- o Notify AEDO if the spill is considered to contain more than one pound Uranium.
- o Notify appropriate Q&S personnel if spill is determined to have chemical or criticality concerns.

9.5 Radioactive Material Fires

Most of the facilities at the FMPC have been designed to prevent, detect, suppress, and confine fires and limit products of combustion. Most areas in the Production Plants have an automatic fire-suppression system (sprinkler system), which when activated will serve to extinguish the fire. In cases where the fire has been extinguished, and personnel have been evacuated to a safe distance, steps to isolate, control, and recover the area shall be performed by RS personnel.

Immediate Actions for Radioactive Material Fires

- o Notify Communications Center (call 6511) or activate fire pull box).
- o Evacuate all unnecessary personnel to a safe central location (consider personal contamination surveys and nasal smears).
- o SCBAs shall be worn by all personnel fighting the fire until airborne levels have been monitored and airborne concentrations permit other respiratory protection. Full-face respirators with purple cartridge shall be worn by all personnel required to enter an uncleared area or support fire fighting personnel.
- o Warn approaching personnel to stay clear of area, and away from smoke or fumes.

NOTE: The primary radiological danger during a radioactive fire is due to ingestion or inhalation of radioactive smoke, dust, vapors, or fumes. It is very important to keep personnel far enough away from the site of fire and smoke to prevent the inadvertent inhalation of possible airborne radioactivity. Whether inside or outside a building, personnel should remain upstream of air flow or plume.

- o Notify RS Supervisor
- o Notify operations supervisor
- o Notify appropriate Q&S section

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Section 10

SECTION 10

RADIATION CONTROL MANUAL

10.1 General Requirements

10.2 Transuranic Materials

10.3 Source Control Requirements

10.0 Radiation Source Control

10.1 General Requirements

For the purpose of defining requirements for control of sources, a radiation source is defined as a radiation generating device or a discrete amount of radioactive material used or designed for use in instrumentation (other than consumable standards) or radiography.

Radiation sources are used throughout the FMPC in various gages and as test standards. Inventories must be maintained and leak checks performed to maintain adequate control of sources.

10.2 Transuranic Materials

Materials controlled by Nuclear Materials inventory in accordance with DOE Order 5633.3 are not subject to the requirements of this manual. However, lesser quantities of transuranic materials not subject to the Nuclear Materials inventory shall be controlled in accordance with this manual.

Radiation sources falling in this category are as follows:

Elements or radionuclide	Amount
Plutonium	<1 gram
Americium-241 & 243	<1 gram
Curium	<1 gram
Berkelium	<1 microgram
Californium -252	<1 microgram
Neptunium -237	<1 gram

10.3 Source Control Requirements

- A permit for radiation sources shall be obtained from the Site Radiation Source Controller as required by Q&S. One permit shall be issued for each source custodian. The permit shall be updated as needed to reflect changing conditions of inventory or requirements.

- Radiation Source Permit forms are identified in Figures 10-1 and 10-2. Figure 10-1 shows the title page(s) of the permit. A form provided for specific data and requirements on each radiation source is presented in Figure 10-2.

- Source custodian(s) shall perform a quarterly inventory of all sources and provide notice of the inventory results to the Site Radiation Source Controller. Loss or damage to sources shall be reported to the Site Radiation Source Controller immediately.

- The source custodian(s) shall coordinate with Radiological

Safety to have leak checks of radiation sources and other functional checks performed as required in accordance with the Radiation Source permit.

- Prior to bringing a radiation source on site, a Radiation Source Permit must be obtained.

- Secure storage and use of radiation sources as identified by the Radiation Source Permit is the responsibility of the user. Users shall maintain their doses from radiation sources as low as reasonably achievable and maintain the integrity of the source container.

- Radiological Safety shall provide technical assistance upon request of the source user or custodian.

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FIGURE 10-1

RADIATION SOURCE PERMIT - TITLE PAGE

FMPC
OPERATIONS SAFETY & HEALTH - RADIOLOGICAL SAFETY
RADIATION SOURCE PERMIT

DEPARTMENT: | SECTION(S):

SOURCE CUSTODIAN

NAME: | BADGE NUMBER:

SOURCE			LEAK/FUNCTION CHECK	
I.D. NUMBER	PAGE	DESCRIPTION	TYPE	FREQUENCY

APPROVAL	DATE
Source Custodian	
Department Head	
Site Radiation Source Controller	

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FIGURE 10-2

RADIATION SOURCE PERMIT - DATA AND REQUIREMENTS

FMPC

OPERATIONS SAFETY & HEALTH - RADIOLOGICAL SAFETY

RADIATION SOURCE DATA AND REQUIREMENTS

SECTION 1 - *To be completed by Custodian*

SOURCE RADIONUCLIDE(S):

IDENTIFICATION NUMBER:	AMOUNT OF RADIOACTIVITY:	DATE OF ASSAY:

USE OF SOURCE:

USE LOCATION:

STORAGE LOCATION

DESCRIPTION OF EQUIPMENT/CONTAINER/ENCAPSULATION:

SECTION 2 - *To be completed by Site Radiation Source Controller*

LEAK CHECK REQUIREMENT:

FUNCTIONAL CHECK REQUIREMENT:

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Section 11

SECTION 11

RADIOACTIVE MATERIAL SHIPPING AND RECEIVING

11.1 General Requirements

11.2 Transportation Standards

11.3 Surveying of Shipments

11.4 Radiation and Contamination Limits

11.5 Marking, Labeling and Placarding

11.0 Radioactive Material Shipping and Receiving

11.1 General Requirements

Radioactive materials received onto or shipped from the FMPC shall conform to U.S. Department of Transportation (DOT) and U.S. Department of Energy (DOE) rules and regulations. These rules and regulations apply to vehicles and packages used for the shipments as well as the materials themselves.

These rules and regulations shall apply to all radioactive materials received or shipped, to vehicles used to ship exclusive use shipments, and to vehicles which deliver exclusive use shipments, regardless of intent to reuse for an exclusive use shipment. It does not apply to materials transported exclusively on site. Requirements for on site transportation of radioactive materials are specified in FMPC-2089.

Personnel responsible for shipping radioactive material are responsible for packaging it in compliance with applicable rules and regulations.

The Transportation and Materials Management Department shall notify RS Technicians when vehicles carrying radioactive material arrive on site, are empty, are loaded and ready for dispatch, and for preparation of required shipping papers.

The Radiological Safety Section shall survey packages, vehicles, etc., maintain records, and make required reports and notifications.

11.2 Transportation Standards

The Federal DOT, through Title 49 of the Code of Federal Regulations (49 CFR), sets standards for shipping radioactive materials. These regulations specify how the material is to be packaged, how it is loaded, exposure rates, removable surface contamination levels, and in some cases, how it is routed.

The U.S. Nuclear Regulatory Commission, through Title 10, Part 71 of the Code of Federal Regulations (10 CFR 71), supplements the DOT regulations for large quantities or high levels of byproduct materials and significant quantities of fissile materials.

The types of radioactive material shipments generally made to or from FMPC are:

LSA (Low Specific Activity) and Limited Quantity. LSA is for shipment of thorium and nonenriched compounds of uranium via exclusive use vehicles. Limited quantity is for solid forms of natural thorium or uranium (not to exceed 15 g of uranium-235). Limited quantity packages must have a surface dose rate of 0.5 mrem/hour or less.

11.3 Surveying of Shipments

Surveys of packages and vehicles shall be performed by Radiological Safety within the following time frames:

- Incoming packages nonexclusive use vehicle - As soon as practical but not more than three (3) hours after receipt during normal working hours.
- Incoming exclusive use vehicle - prior to opening.
- All Vehicles - after unloading.
- Vehicle to be used for exclusive use - within 24 hours of loading.
- Outgoing package nonexclusive use vehicle - within 24 hours of leaving.
- Outgoing exclusive use vehicles - within three (3) hours of leaving.

Removable contamination "Swipe" surveys are conducted using dry filter paper. A 300 square centimeter (cm^2) area of each package is to be swiped. Large smooth surfaces ("T" hoppers, UF_6 cylinder, vehicles, etc.) may be rough checked by swiping a large area with a tissue/towelette (e.g., Kimwipe). If there is detectable activity on the tissue/towelette, a formal 300 cm^2 swipe will be required. Exclusive use vehicles shall be surveyed prior to being loaded.

Packages shall be surveyed for exposure rate at the surface and at one (1) meter.

Vehicles shall be surveyed for exposure rate at the surface and at two (2) meters.

If the surface dose equivalent rate is 1.5 mrem/hour or less, packages separated by eight (8) feet or more may be considered in low background. Higher surface dose rates, larger packages --- or arrays of packages, or closer spacing shall use the "<" (less than) symbol when measured exposure rates are recorded due to unknown contributions from other packages.

NOTE: Because definitions of limited quantity and the requirements for Radioactive I, II, III labels are based on dose rate measurements, the errors resulting from packages being too close together could adversely affect shipping requirements, even though otherwise legal and proper.

11.4 Radiation and Contamination Limits

Limits are: Limited quantity packages:

Surface Dose Rate = 0.5 mrem/hr for non-exclusive shipments 2.0 mrem/hr for exclusive shipment.

Removable Contamination = 22 dpm/cm^2 averaged over 300 cm (2.2 dpm/cm^2 if alpha emitters other than uranium or thorium are present).

Package for other than exclusive use of vehicle shipment:

Surface Dose Rate: 200 mrem/hr

The Transport Index, i.e., the maximum radiation level in mrem/hr at one meter, is limited to not more than 10 units per package and not more than 50 units per shipment.

Exclusive use of vehicle package:

Surface Dose Rate:	200 mrem/hr
Any "Surface" of Vehicle:	200 mrem/hr
2 Meters (6.6 ft):	10 mrem/hr
Any normally occupied position in vehicle (truck Ca.):	2 mrem/hr
Contamination Limits:	Same as limited quantity packages.

Enclosed Exclusive use Vehicle:

Surface Dose Rate:	1000 mrem/hr
Surface of Vehicle:	200 mrem/hr
2 meters from surface of vehicle:	10 mrem/hr
Any normally occupied position in vehicle:	2 mrem/hr
Removable Contamination:	Same as limited quantity packages.

Empty exclusive use vehicles not marked "For Radioactive Materials Use Only", shall have an interior surface dose rate of 0.5 mrem/hour or less and the removable contamination must be less than 22 dpm/cm^2 (or 2.2 dpm/cm^2 if transuranic materials are present) averaged over 300 square centimeters.

11.5 Marking, Labeling and Placarding

Radioactive materials received onto, or shipped from, the FMPC shall conform to the marking, labeling, and placarding requirements of the DOT and DOE rules and regulations as they apply to packages and vehicles.

Personnel responsible for shipping radioactive material are responsible for properly packaging, marking and labeling in compliance with applicable rules and regulations.

The WMCO Transportation and Materials Management shall verify the labeling, marking and placarding of incoming materials, prior to acceptance, and to verify marking and labeling of outgoing packages, and to placard when placards are required on outgoing shipments.

The U.S. Department of Transportation (DOT) through Title 49 of the Code of Federal Regulations (49 CFR) establishes rules and regulations for labeling and placarding radioactive materials for shipment. The U.S. Department of Energy (DOE) establishes criteria for packaging and shipping radioactive materials through DOE Order 5480.3.

11.5.1 **Marking:** All packages except those shipped as either limited quantity or LSA/exclusive use of vehicle must be specification containers and shall be marked in accordance with the following sections of 49 CFR 172:

300	Applicability (what must be marked).
301	General requirements (information required in the marking).
304	Marking requirements, characteristics and location(s) of markings.
310	Radioactive materials - additional markings required for radioactive materials packages.
312	Liquid hazardous materials - "This side up" and prohibition on use of other arrows.
178	Specifies the requirements for the construction of specification containers and the required markings.

Tanks and portable tanks (49 CFR 171.8) have special marking requirements identified in the following sections of 49 CFR:

172.326	Portable tanks.
172.328	Cargo tanks.
172.332-336	Identification numbers (orange panels).

11.5.2 **Labels:** Packages of radioactive material shall be labeled in accordance with the following sections of 49 CFR unless they are LSA exclusive use or limited quantity shipments.

172.400	General labeling requirements.
172.402	Additional labeling requirements.
172.403	Radioactive materials additional labeling requirements.
172.406	Placement of required labels.
172.407	Label specifications (dimensions, colors, and wording).
173.29	"Empty" labels.
173.427	Specific requirements for use of "empty" labels on containers which have contained radioactive material.

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11.5.3 **Placards:** Any vehicles carrying a package which has a "Radioactive Yellow III" label and exclusive use vehicles carrying LSA must be placarded. The following sections of 49 CFR pertain to placarding.

172.500	Applicability of placarding requirements.
172.504	General placarding requirements (NOTE: UF_6 in Table 1 and exclusive use shipments of LSA in Footnote 5).
172.506	Placards for highway.
172.508	Placards for railroads.
172.574	Cargo tanks and portable tanks.
172.516	Visibility and display of placards.
172.519	Specifications (construction, materials, shape) for placards.
172.556	"Radioactive" placard.

11.5.4 **Miscellaneous:** Transportation indexes for fissile material are given in Table 2 of 49 CFR 173.417.

Limited quantities of radioactive materials are defined by 49 CFR 173.421, 173.421-1, and 173.423.

LSA exemptions and marking, labeling, and placarding requirements are given in 49 CFR 173.425.

49 CFR 173.444 lists the sections which proved <u>exceptions</u> to labeling requirements.

Section 12

SECTION 12

RECORDKEEPING

12.1 Radiological Monitoring Records

12.2 Work Place Monitoring

12.3 Personnel Exposure

12.0 Recordkeeping

12.1 Radiological Monitoring Records

All original radiological sampling data including maps, surveys and original sample worksheets shall be filed by Radiological Safety and kept indefinitely.

Laboratories (including offsite laboratories) shall maintain records of instrument serial numbers, calibration, calibration source identification along with documentation of a complete quality control program in accordance with NRC Regulatory Guide 4.15. This information shall also be maintained indefinitely.

12.2 Work Place Monitoring

Records of surveys, data sheets, maps, radiation work permits, health physics calculations, investigations, air sample results, worksheets and any other documentation directly related to work place monitoring shall be filed by Radiological Safety according to location (i.e., plant, building, project or location) and maintained for an indefinite length of time.

Data compiled on computer disks shall be trackable to original survey results and shall be controlled through the use of backup disks.

Documentation of work conditions affecting the results of work area monitoring shall be listed on the appropriate record with sufficient detail to allow understanding at an undefined future date. Data stored on disk shall not be construed as sufficient reason to destroy original information.

12.3 Personnel Exposure

Completed monthly dosimetry reports shall be retained. Each plant supervisor and the subcontractor shall receive a copy of his/her personnel's monthly dose.

A summary of annual, cumulative and committed effective dose equivalent shall be provided to each employee and subcontractor radiation worker on an annual basis. Dose records shall be kept indefinitely by Dosimetry and Instrumentation.

All raw data, corrected data and employee external radiation reports shall be retained in a folder labeled with the particular month.

An extremity dosimetry report is generated quarterly by Dosimetry and Instrumentation with extremity dose totals for each month, e.g., a March report will contain results for January, February, and March of that year.

Section 13

SECTION 13

RADIATION SAFETY TRAINING

13.1 Radiation Safety Training

13.2 Training Records

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13.0 Radiation Safety Training

13.1 Radiation Safety Training

Radiation safety training shall be provided to all WMCO employees and subcontractors by Q&S and all RUST subcontractor employees by RUST Engineering Company. The scope and depth of training is a function of the employee's work assignment. R

13.1.1 Employee Orientation

All employees shall receive an orientation in radiation safety within one month of their initial employment. Retraining shall be provided when there are significant changes to radiation protection policies and procedures which effect general plant employees, but at a sufficient frequency not to exceed two years. The initial orientation should include, but is not limited to:

- o the risk of low-level occupational radiation exposure, including cancer and genetic effects
- o the risk of prenatal radiation exposure
- o basic radiation protection concepts
- o DOE and WMCO radiation protection policies and procedures
- o employee and management responsibilities for radiation safety
- o emergency procedures

13.1.2 Radiation Worker Training

Radiation worker training programs shall be established and conducted at a sufficient frequency (not to exceed two years) to familiarize the worker with the fundamentals of radiation protection and the proper procedures for maintaining exposures ALARA. Training should include both classroom and applied training. Training shall precede or be concurrent with assignment as a radiation worker while under the supervision of a trained individual. The knowledge of radiation safety fundamentals possessed by radiation workers shall be certified by examination prior to an unsupervised assignment. Radiation dosimeters will not be issued unless this training has been satisfactorily completed. The level of training in the following topics shall be commensurate with each worker's assignment: R

- o radioactivity and radioactive decay
- o characteristics of ionizing radiation
- o man-made radiation sources

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- acute effects of exposure to radiation
- risks associated with occupational radiation exposures
- special considerations in the exposure of women of reproductive age
- dose equivalent limits
- mode of exposure--internal and external
- dose equivalent determinations
- basic protective measures--time, distance, shielding
- specific plant procedures for maintaining exposure as low as reasonably achievable (ALARA)
- radiation survey instrumentation--calibration and limitations
- radiation monitoring programs and procedures
- contamination control, including protective clothing and equipment and workplace design
- self-monitoring instruments for detection of contamination bioassay and in vivo measurements
- personnel decontamination
- emergency procedures
- warning signs and alarms
- responsibilities of employees and management
- interaction with radiation protection staff

13.1.3 RS Technician Training

Radiation protection technician training programs shall be established and conducted at a sufficient frequency, not to exceed two years, to familiarize technicians with the fundamentals of radiation protection and the proper procedures for maintaining exposures ALARA. This program shall include both classroom and applied training and shall precede or be concurrent with assignment as a radiation protection technician while under the supervision of a trained individual. The knowledge of radiation safety fundamentals possessed by radiation protection technicians shall be certified by examination prior to an unsupervised work assignment. The training program should include the R

topics listed in the paragraph above and should emphasize procedures specific to the facility where the technician is assigned. The level of training in each topic shall be commensurate with the technician's assignment.

13.2 Training Records

Training records of plant employees, radiation workers, and radiation safety personnel shall be retained by Human Resources Department to document the level of understanding and proficiency of personnel who work with radioactive materials. Certification of successful completion of training programs and performance records shall also be retained.

SECTION 14

RADIATION EFFECTS

14.1 Exposure Effects

14.2 Control of Collective Dose

14.3 Radiation Risk

Section 14

14.0 Radiation Effects

14.1 Exposure Effects

It is generally accepted by the scientific community that exposure to ionizing radiation can cause biological effects that are harmful to the exposed organism. These effects are classified into three categories:

Somatic Effects: Effects occurring in the exposed person that, in turn, may be divided into two classes:

Prompt effects that are observable soon after a large or acute dose (e.g., 100 rems or more to the whole body in a few hours), and

Delayed effects such as cancer that may occur years after exposure to radiation.

Genetic Effects: Abnormalities that may occur in the future children of exposed individuals and in subsequent generations. Genetic effects exceeding normal incidence have not been observed in any of the studies of exposed humans.

Teratogenic Effects: Effects that may be observed in children who were exposed during the fetal and embryonic stages of development.

14.2 Control of Collective Dose

Concerns about these biological effects have resulted in controls on dose to individual workers and in efforts to control the collective dose (person-rems) to the worker population.

Nuclear activities result in a significant fraction of the total occupational radiation exposure in the United States. Regulatory action has recently focused more attention on maintaining occupational radiation exposure at levels that are as low as reasonably achievable (ALARA). Radiation protection training for all workers who could be exposed to ionizing radiation is an essential component of any program designed to maintain exposure levels ALARA. A clear understanding of what is presently known about the biological risks associated with exposure to radiation will result in more effective radiation protection and should generate more interest on the part of the worker in minimizing both individual and collective doses. In addition, radiation workers have the right to whatever information on radiation risk is available to enable them to make informed decisions regarding the acceptance of these risks. It is intended that workers develop an understanding of the risks involved rather than excessive fear or indifference.

14.3 Radiation Risk

At the low dose limits set for occupational radiation exposure in the United States, it is difficult to demonstrate a relationship between exposure and effect. There is considerable uncertainty and controversy regarding estimates of radiation risk. In Appendix C, a range of risk estimates is provided (see Table 1) as well as a discussion of the health risks due to radiation exposure. Information on radiation risk has been included from such sources as the 1980 National Academy of Sciences' Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR-80), the International Commission on Radiological Protection (ICRP) Publication 27 entitled "Problems in Developing an Index of Harm," the 1979 report of the science work group of the Interagency Task Force on the Health Effects of Ionizing Radiation, the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR report), and numerous published articles (see the bibliography to Appendix C).

APPENDIX A

Radiation Safety Terminology

These are terms commonly used in nuclear industry.

(From NUREG-0770, Glossary of Terms: Nuclear Power and Radiation, June 1981. U.S. Nuclear Regulatory Commission.)

RADIATION SAFETY TERMINOLOGY

TERM	DEFINITIONS
absorber	Any material that absorbs or lessens the intensity of ionizing radiation. A thin sheet of paper will absorb alpha particles and a thin piece of aluminum will absorb all except the most energetic beta particles. Concrete and steel absorb gamma rays. Neutron absorbers (like boron, hafnium, and cadmium) are used in control rods for reactors. (See shielding.)
absorption	The process by which the number of particles or photons entering a body of matter is reduced or attenuated by interaction with the matter. (See neutron capture.
activation	The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear radiation. (See induced radioactivity.)
air sampling	The collection and analysis of samples of air to measure its radioactivity or to detect the presence of radioactive substances, particulate matter or chemical pollutants.
ALARA	Acronym for "As Low As Reasonably Achievable," a basic concept of radiation protection that specifies that radioactive discharges from nuclear plants and radiation exposure to personnel be kept as far below regulatory limits as practical.
alpha particle	A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus that has a mass number of 4 and an electrostatic charge of +2. It has low-penetrating power and short range. The most energetic alpha particle will generally fail to penetrate the skin. Alphas are hazardous when an alpha-emitting radioisotope is introduced into the body.
anion	Negatively charged ion. (See ionization)
atom	The smallest particle of an element that cannot be divided or broken up by chemical means. It consists of a central core called the nucleus, which contains protons and neutrons. Electrons orbit in the region surrounding the nucleus.
atomic number	The number of positively charged protons in the nucleus of an atom and the number of electrons on an electrically neutral atom.

atomic weight	See mass number.
attenuation	The process by which a beam of radiation is reduced in intensity when passing through some material. It is a combination of absorption and scattering processes.
background radiation	The natural radiation in man's environment, including cosmic rays and radiation from the naturally occurring radioactive elements, both outside and inside the bodies of humans and animals. An average individual exposure from background radiation is 125 millirem per year in mid latitudes at sea level.
beta particle	A charged particle emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal or plastic.
becquerel	A unit, in the International System of Units (SI), for the measurement of radioactivity equal to one transformation or atomic disintegration per second.
bioassay	The collection and analysis of human hair, tissue, nasal smears, urine or fecal samples to determine the amount of radioactive material that might have been deposited in the body. Routes of possible entry are inhalation, ingestion or injection.
biological half-life	The time required for a biological system, such as that of a human, to eliminate by natural processes half the amount of a substance (such as a radioactive material) that is present within it.
biological shield	A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level safe for humans.
body burden	The amount of radioactive material which if deposited in the total body will produce the maximum permissible dose rate to the body organ considered the critical organ.
bone seeker	A radioisotope that tends to accumulate in the bones when it is introduced into the body. An example is strontium-90, which behaves chemically like calcium.
Bremsstrahlung	Secondary photon radiation produced by deceleration of charged particles passing through matter.
calibration	The check or correction of the accuracy of a measuring instrument to assure proper operational characteristics. (See counter.)

cask	A heavily shielded container used to store and/or ship radioactive materials. Lead and steel are common materials used in the manufacture of casks.
charged particle	An ion. An elementary particle carrying a positive or negative electric charge.
chronic exposure	See exposure.
committed dose equivalent	Predicted total dose equivalent to a given organ or tissue over a 50 year period after an intake of a radionuclide into the body.
compound	A chemical combination of two or more elements combined in a fixed and definite proportion by weight.
contamination, radioactive	The deposition of uncontained or unwanted radioactive material on the surfaces of structure, areas, objects, or personnel.
controlled area	A defined area in which the occupational exposure of personnel to radiation or radioactive material is under the control of an individual in charge of radiation protection.
control room (building)	An area in a plant from which most of the plant power production and emergency safety equipment can be operated by remote control.
cosmic radiation	Penetrating ionizing radiation, both particulate and electromagnetic, originating in space. Secondary cosmic rays, formed by interactions in the earth's atmosphere, account for about 45 to 50 millirem of the 125 millirem background radiation that an average individual receives a year.
counter	A general designation applied to radiation detection instruments or survey meters that detect and measure radiation. The signal that announces an ionization event is called a count. (See Geiger-Mueller counter.)
critical organ	The body organ receiving a radionuclide or radiation dose that results in the greatest overall risk.
criticality	A term used in radiation physics to describe the state when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed (by the fuel and poisons) and escaping the pile. A reaction is said to be "critical" when it achieves a self-sustaining nuclear chain reaction.
crud	A colloquial term for corrosion and wear products (rust particles, etc.) that become radioactive under a radiation flux. (See induced radioactivity.)

cumulative dose	The total dose resulting from repeated exposures of radiation to the same region, or to the whole body, over a period of time.
curie (Ci)	The basic unit used to describe the quantity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is the rate of decay of 1 gram of radium. A curie is also a quanitity of any radionuclide that decays at a rate of 37 billion disintegrations per second. Named for Marie and Pierre Curie, who discovered radium in 1898.
daughter products	Isotopes that are formed by the radioactive decay of some other radioisotope. In the case of radium-226, for example, there are 10 successive daughter products, ending in the stable isotope lead-206.
decay, radioactive	The decrease in the amount of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation. (See half-life; radioactive.)
decontamination	The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination; (2) letting the material stand so that the radioactivity is decreased as a result of natural decay.
depleted uranium	Uranium having a percentage of uranium-235 smaller than the 0.72 percent found in natural uranium. (See mill tailings.)
design-basis phenomena	Earthquakes, tornados, hurricanes, floods, etc., that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to assure public health and safety.
detector	A material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument. (See counter.)
differential pressure (DP)	The difference in pressure between two points of a system, such as between the inlet and outlet of a pump.
disintegration	See decay, radioactive.
dose	A quantity (total or accumulated) of ionizing radiation received. The term "dose" is often used in the sense of the exposure, expressed in roentgens,

which is a measure of the total amount of ionization that the quantity of X ray or gamma radiation could produce in air. This should be distinguished from the absorbed dose, given in rads, that represents the energy absorbed from any radiation in a gram of any material. Furthermore, the biological dose, given in rem, is a measure of the biological damage to living tissue from the radiation exposure.

dose equivalent	A term used to express the amount of biologically effective radiation when modifying factors have been considered. The product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. It is expressed numerically in rem.
dosimeter	A portable instrument for measuring and registering the total accumulated exposure to ionizing radiation. (See dosimetry.)
dosimetry	The theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made. (See film badge; survey meter.)
dose rate	The radiation dose delivered per unit of time. Measured, for example, in rem per hour.
effective half-life	The time required for the amount of a radioactive element present in a living organism to be diminished 50 percent as a result of the combined action of radioactive decay and biological elimination. (See biological half-life.)
electromagnetic (radiation)	A traveling wave motion resulting from changing electric and magnetic fields. Familiar electromagnetic radiations range from X rays (and gamma rays) of short wavelength, through the ultra-violet, visible, and infrared regions, to radar and radio waves of relatively long wavelength. All electromagnetic radiations travel in a vacuum with the velocity of light (See photon.)
electron	An elementary particle with a unit negative charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom. (See beta particle.)
element	One of the 103 known chemical substances that cannot be broken down further without changing its chemical properties. Some examples include hydrogen, nitrogen, gold, lead, and uranium.
enrichment	See isotopic enrichment.

erythema	An abnormal redness of the skin due to distension of the capillaries with blood. It can be caused by many different agents -- heat, drugs, ultraviolet rays and ionizing radiation.
exposure	The act or condition of being subject to the effect or risk of a field of radiation or dispersion of radioactive material. Acute exposure is generally accepted to be a large exposure received over a short period of time. Chronic exposure is exposure received during a lifetime. (See dose.)
external radiation	Exposure to ionizing radiation when the radiation source is located outside the body.
extremities	The hands and forearms and the feet and ankles. (Permissible radiation exposures in these regions are generally greater than for the whole body because they contain less blood-forming material.)
fissile material	Although sometimes used as a synonym for fissionable material, this term has acquired a more restricted meaning; namely, any material fissionable by thermal (slow) neutrons. The three primarily fissile materials are uranium-233, uranium-235 and plutonium-239.
fission	The splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation.
gamma ray (gamma radiation)	High-energy, short wavelength electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or uranium. Gamma rays are identical to X rays of the same energy.
gases	Normally formless fluids that completely fill the space and take the shape of their container.
gaseous diffusion (plant)	A method of isotopic separation based on the fact that gas atoms or molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. This method is used to separate uranium-235 from uranium-238; it requires large gaseous diffusion plants and enormous amounts of electric power.

Geiger-Mueller counter	A radiation detection and measuring instrument. It consists of a gas-filled chamber, such as a tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation interacts in the chamber, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation. It was named for Hans Geiger and W. Mueller who invented it in the 1920s. It is sometimes called simply a Geiger counter, or a G-M counter.
graphite	A form of carbon, similar to the lead used in pencils, used as a moderator in some nuclear reactors also for molds in high temperature furnaces.
gray (Gy)	A unit, in the International System of Units (SI), of absorbed dose which is equal to 1 joule per kilogram. 1 Gy = 100 rad
half-life	The time in which half the atoms of a particular radioactive substance disintegrates to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical half-life.
half-life, biological	The time required for the body to eliminate by physiologic processes half of the material present in it.
half-life, effective	The time required for a radionuclide present in a biological system to be reduced by half as a combined result of radioactive decay and biological elimination.
half-thickness	The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value. This value varies with radiation energy and beam size and location of shielding. (See attenuation; shielding.)
health physics	The science concerned with recognition, evaluation and control of health hazards from ionizing and non-ionizing radiation.
heat exchanger	Any device that transfers heat from one fluid (liquid or gas) to another fluid or to the environment.
heat sink	Anything that absorbs heat; usually part of the environment, such as the air, a river or outer space.
high radiation area	Any area accessible to personnel, in which a major portion of the body could receive a radiation dose of 100 millirem (0.1 rem) in one hour. These areas must

be posted as "high radiation areas" and access into these areas is maintained under strict control.

hot	A colloquial term meaning highly radioactive.
hot spot	The region in a radiation/contamination area in which the level of radiation/contamination is noticeably greater than in neighboring regions in the area.
induced radioactivity	See activation.
ion	An atom or group of atoms that carries a positive or negative charge as a result of having lost or gained electrons; an electron that is not associated with a nucleus. (See ionization.)
ionization	The process of adding one or more electrons to or removing one or more electrons from atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or ionizing radiations can cause ionization.
ionization chamber	An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of electricity. (See counter.)
ionizing radiation	Any radiation with sufficient energy to displace electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma, X rays, neutrons and ultraviolet light. High doses of ionizing radiation may produce severe skin or tissue damage.
irradiation	Exposure to radiation.
isotope	One of two or more atoms with the same number of protons, but different number of neutrons in their nuclei. Thus, carbon-12, carbon-13 and carbon-14 are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes have the same chemical properties, but often different physical properties (for example, carbon-12 and carbon-13 are stable, carbon-14 is radioactive.
isotope separation	The process of separating isotopes from one another, or changing their relative abundances, as by gaseous diffusion or electromagnetic separation. Isotope separation is a step in the isotopic enrichment process.
isotopic enrichment	A process by which the relative abundances of the isotopes of a given element are altered, thus producing a form of the element that has been enriched in one particular isotope and depleted in its other isotopic forms.

kilo-	A prefix that multiplies a basic unit by 1000. Example: 1 kilometer = 1000 meters.
kilovolt (kV)	The unit of electrical potential equal to 1000 volts.
LD 50/30	The acute dose of radiation expected to cause death within 30 days to 50 percent of those exposed without medical intervention. Generally accepted to range from 400 to 450 rem for humans when received over a short period of time.
low population zone (LPZ)	An area of low population density often required around a nuclear installation. The number and density of residents is of concern in emergency planning so that certain protective measures (such as notification and instructions to residents) can be accomplished in a timely manner.
lung counter	An instrument system used to identify and measure radioactivity in the lungs of human begins; it uses heavy shielding to keep background radiation interference low and ultra sensitive radiation detectors and electronic counting equipment.
mass-energy equation	The equation developed by Albert Einstein which is usually given as $E = mc^2$, showing that, the energy of a body, E (no matter what form the energy takes), varies with the product of the mass, m, of the body and a factor, c^2. The factor c^2, the square of the speed of light in a vacuum, may be regarded as the conversion factor relating units of mass and energy. The equation predicted the possibility of releasing enormous amounts of energy by the conversion of mass to energy. It is also called the Einstein equation.
mass number	The number of nucleons (neutrons and protons) in the nucleus of an atom. Also known as the atomic weight of an atom.
mega- (M)	A prefix that multiplies a basic unit by 1,000,000.
megacurie (MCi)	One million curies. (See curie.)
micro-	A prefix that divides a basic unit into one million parts.
microcurie (uCi)	A one-millionth part of a curie. (See curie.)
microsecond (us)	A one-millionth part of a second.
mill tailings	Naturally radioactive residue from the processing of uranium ore into yellowcake in a mill. Although the milling process recovers about 93 percent of the uranium, the residues, or tailings, contain several radioactive elements, including uranium, thorium, radium, polonium and radon.

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milli- (m)	A prefix that divides a basic unit by 1000.
millirem (mrem)	A one-thousandth part of a rem. (See rem.)
milliroentgen (mR)	A one-thousandth part of a roentgen. (See roentgen.)
molecule	A group of atoms held together by valence (electron) forces. A molecule is the smallest unit of a compound that can exist by itself and retain all its chemical properties.
monitoring	Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, as a safety measure, for purposes of health protection or contamination control. (See radiological survey.)
nano- (n)	A prefix that divides a basic unit by one billion.
nanocurie (nCi)	One billionth part of a curie.
natural radiation	See background radiation.
natural uranium	Uranium as found in nature. It contains 0.7 percent uranium-235, 99.3 percent uranium-238 and a trace of uranium-234.
neutron	An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen and in two isotopes of hydrogen.
neutron capture	The process in which an atomic nucleus absorbs a neutron.
neutron chain reaction	A process in which some of the neutrons released in one fission event cause other fissions to occur. There are three types of chain reactions: (1) Nonsustaining chain reaction - An average of less than one fission is produced by the neutrons released by each previous fission (reactor subcriticality.) (2) Sustaining chain reaction - An average of exactly one fission is produced by the neutrons released by each previous fission (reactor criticality.) (3) Multiplying chain reaction - An average of more than one fission is produced by the neutrons released by previous fission (reactor supercriticality.)
noble gas	A gaseous chemical element that does not readily enter into chemical combination with other elements. An inert gas. (See fission gases.)

nuclear disintegration	See decay, radioactive.
nuclear energy	The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.
nuclear fission	See fission.
nuclear force	A powerful short-ranged attractive force that holds together the particles inside an atomic nucleus.
nuclear radiation	See radiation, nuclear.
nuclear reaction	The process of inducing a disintegration of the nucleus of an atom.
nucleon	Common name for a constituent particle of the atomic nucleus. At present, applied to protons and neutrons but may include any other particles found to exist in the nucleus.
nucleus (or atomic nucleus); nuclei (plural)	The small, central, positively charged region of an atom that carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which has a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number. (See isotope.)
nuclide	A general term referring to all known isotopes, both stable (279) and unstable (about 5000), of the chemical elements.
occasional radiation worker	An individual who does not routinely work with or in the proximity of radiation generating devices or radioactive materials but whose duties may occasionally bring him/her into areas where radiation exposure may occur.
parent	A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter).
parts per million (ppm)	Parts (molecules) of a substance contained in a million parts of air (or water) by volume.

periodic table	An arrangement of chemical elements in order of increasing atomic number. Elements of similar properties are placed one under the other, yielding groups or families of elements. Within each group, there is a variation of chemical and physical properties, but in general there is a similarity of chemical behavior within each group.
personnel monitoring	The determination of the degree of radioactive contamination on individuals using survey meters, or the determination of radiation exposure received by means of dosimetry devices.
photon	A quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and X rays are examples of photons.
pico- (p)	A prefix that divides a basic unit by one trillion.
picocurie (pCi)	One trillionth part of a curie.
pig	A container (usually lead) used to ship or store radioactive materials. The thick walls protect the person handling the container from radiation. Large containers are commonly called casks.
plutonium (Pu)	A heavy, radioactive, manmade metallic element with atomic number 94. Its most important isotope is fissile plutonium-239, which is produced by neutron irradiation of uranium-238.
pocket dosimeter	A small ionization detection instrument that indicates radiation exposure directly or indirectly. An auxiliary charging device is usually necessary.
positron	Particle equal in mass, but opposite in charge, to the electron; a positive electron.
proportional counter	An instrument in which an electronic detection system receives pulses that are proportional to the number of ions formed in a gas-filled chamber by ionizing radiation.
protection factor	The degree of protection provided by the proper fit and use of respiratory protective equipment.
proton	An elementary nuclear particle with a positive electric charge located in the nucleus of an atom. (See atomic number.)

quality factor	The principal factor by which the absorbed dose is to be multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiations, the biological damage to exposed persons. It is used because some types of radiation, such as alpha particles, are more biologically damaging than other types.
rad	Acronym for radiation absorbed dose. The basic unit of absorbed dose of radiation. A dose of one rad means the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing material.
radiac	An acronym derived from "radioactivity detection indication and computation," a generic term applying to radiological instruments or equipment.
radiation area	Any area, accessible to personnel, in which the level of radiation is such that a major portion of an individual's body could receive in any one hour a dose in excess of 5 millirem, or in any five consecutive days a dose in excess of 100 millirem.
radiation detection instrument	A device that detects and registers the characteristics of ionizing radiation. (See counter.)
radiation monitoring	See monitoring.
radiation, nuclear	Particles (alpha, beta, neutrons) or photons (gamma) emitted from the nucleus of an unstable (radioactive) atom as a result of radioactive decay.
radiation shielding	Reduction of radiation field by interposing a shield of absorbing material between any radiation source and a person's work area or radiation-sensitive device.
radiation source	Usually a man-made sealed source of radioactive material used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators, X-ray units and radioisotope generators and natural radionuclides may be considered sources.
radiation standards	Exposure standards, radioactivity concentration guide, rules for safe handling, regulations for transportation, regulations for industrial control of radiation and control of radioactive material by legislative means.
radiation syndrome	See radiation sickness (syndrome).
radiation warning symbol	An officially prescribed symbol (a magenta trefoil) on a yellow background that must be displayed where certain quantities of radioactive materials are

present or where certain doses of radiation could be received. Its uses are prescribed by law.

radioactive	Exhibiting radioactivity or pertaining to radioactivity.
radioactive contamination	Deposition of radioactive material in any place where it is not contained or wanted.
radioactive isotope	A radioisotope.
radioactive series	A succession of nuclides, each of which tranforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.
radioactive waste	See waste, radioactive.
radioactivity	The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope.
radiobiology	The study of the effects of ionizing radiations upon living tissue or organisms.
radiography	The making of shadow images on photographic film by the action of ionizing radiation.
radioisotope	An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. Approximately 5000 natural and artificial radioisotopes have been identified.
radiological survey	The evaluation of the radiation hazards accompanying the production, use, or existence of radioactive materials under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that my be involved, and a sufficient knowledge or processes affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.
radiology	That branch of medicine dealing with the diagnostic and therapeutic applications of radiant energy, including X rays and radioisotopes.
radionuclide	A radioisotope.
radiosensitivity	The relative susceptability of cells, tissues, organs, organisms, or other substances to the injurious action of ionizing radiation.

radium (Ra)	A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has a mass number of 226. It occurs in minute quantities associated with uranium in pitchblend, carnotite and other minerals.
radon (Rn)	A radioactive element that is one of the heaviest gases known. Its atomic number is 86, and its mass number is 222. It is a daughter of radium.
reaction	Any process involving a chemical or nuclear change.
recycling	The reuse of fissionable material after it has been recovered by chemical processing from spent or depleted reactor fuel, re-enriched and refabricated into new fuel elements.
rem	Acronym of roentgen equivalent man. The unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary X rays. (See quality factor.)
restricted area	Any area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.
roentgen (R)	A unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, a German scientist who discovered X rays in 1895.
roentgen equivalent man (or mammal)	See rem.
scattered radiation	Radiation that, during its interaction with a substance, has been changed in direction. It may also have been modified by a decrease in energy. It is one form of secondary radiation.
scintillation detector or counter	The combination of phosphor, photomultiplier tube, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation. (See counter.)
secondary radiation	Radiation originating as the result of absorption of other radiation in matter. It may be either electromagnetic or particulate in nature.
shielding	Any material or obstruction that absorbs radiation and thus tends to protect personnel or material from the effects of ionizing radiation.
sievert (Sv)	A unit, in the International system of Units (SI), of dose equivalent. 1 Sv = 100 rem

soluble	Readily dissolved in body fluids.
somatic effects of radiation	Effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.
special nuclear material	Includes plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235.
spent (depleted) fuel	Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction.
source material	Any physical or chemical form of uranium or thorium or ores which contain by weight 0.05% or more of uranium or thorium.
stable isotope	An isotope that does not undergo radioactive decay.
stay time	The period during which personnel may remain in a restricted area before accumulating some permissible exposure.
subcritical mass	An amount of fissionable material insufficient in quantity or of improper geometry to sustain a fission chain reaction.
survey	A study to (1) find the radiation or contamination level of specific objects or locations within an area of interest; (2) locate regions of higher-than-average intensity; i.e., hot spots. (See personnel monitoring.)
survey meter	Any portable radiation detection instrument especially adapted to establish the existence and amount of ionizing radiation present. (See counter.)
tailings, tails	See mill tailings.
tenth thickness	The thickness of a given material that will decrease the amount (or dose) of radiation to one-tenth of the amount incident upon it. Two-tenth thicknesses will reduce the dose received by a factor of 10 x 10; i.e., 100, and so on. (See shielding.)
terrestrial radiation	The portion of natural radiation (background that is emitted by naturally occurring radioactive materials in the earth.
thermalization	The process undergone by high-energy (fast) neutrons as they lose energy by collision. (See neutron, thermal.)
toxicology	Is the study of the adverse effects of chemicals on living organisms.

tritium (^3H)	A radioactive isotope of hydrogen (one proton, two neutrons). Because it is chemically identical to natural hydrogen, tritium can easily be taken into the body by any inhalation, ingestion or absorption path. Decays by beta emission. Its radioactive half-life is about 12 1/2 years.
ultraviolet	Electromagnetic radiation of a wavelength between the shortest visible violet and low-energy X rays.
unrestricted area	The area outside the owner-controlled portion of a nuclear facility (usually the site boundary).
unstable isotope	A radioisotope.
uranium (U)	A radioactive element with the atomic number 92, and as found in natural ores, has an atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natural uranium), which is fissle, and uranium-238 (99.3 percent of natural uranium), which is fissionable by fast neutrons and is fertile. Natural uranium also includes a minute amount of uranium-234.
uranium enrichment	See isotopic enrichment.
uranium millings (tails)	See mill tailings.
vapor	The gaseous form of substances that are normally in liquid or solid form.
waste, radioactive	Solid, liquid and gaseous materials from nuclear operations that are radioactive or become radioactive and for which there is no further use. Wastes are generally classified as high level (having radioactivity concentrations of hundreds of thousands of curies per gallon or cubic foot), low level (in the range of less than 1 microcurie per gallon or cubic foot), or intermediate level (between these extremes).
whole-body counter	A device used to identify and measure the radiation in the body (body burden) of human beings and animals; it uses heavy shielding to minimize the interference of background radiation on ultrasensitive radiation detectors and electronic counting equipment.
whole-body exposure	An exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated. Where a radioisotope is uniformly distributed throughout the body tissues, rather than being concentrated in certain parts, the irradiation can be considered as a whole-body exposure.
wipe sample (swipe or smear)	A sample made for the purpose of determining the presence of removable radioactive contamination on a

surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. It is also known as a "swipe sample." May also be called "smears" at some facilities.

X rays — Penetrating electromagnetic radiation (photon) having a wavelength that is much shorter than that of visible light. These rays are usually produced by excitation of the electron field around certain nuclei. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays, and to those originating in the electron field of the atom as X rays. These rays are sometimes called roentgen rays after their discoverer, W. K. Roentgen.

yellowcake — A product of the uranium milling process, yellowcake is a solid uranium compound that takes its name from the color and texture. Yellowcake is the initial feed material to the fuel cycle.

APPENDIX B

Derived Air Concentrations (DAC)

for

Controlling Radiation Exposure to Workers at DOE Facilities

(From DOE Order 5480.11, Radiation Protection for Occupational Workers, (12/21/88), U.S. Department of Energy.)

DERIVED AIR CONCENTRATIONS FOR CONTROLLING RADIATION EXPOSURE TO WORKERS AT DOE FACILITIES

The derived air concentrations (DAC) for limiting radiation exposures through inhalation of radionuclides by workers are listed in Table 1, Page B-3. The values are based on either a stochastic (committed effective dose equivalent) dose limit of 5 rem (0.05 Sv) or a nonstochastic (organ) dose limit of 50 rem (0.5 Sv) per year, whichever is more limiting. (Note: the 15 rem [0.15 Sv] dose limit for the lens of the eye does not appear as a critical organ dose limit.)

Table 1 contains five columns of information: (1) radionuclide; (2) inhaled air DAC for lung retention class D (uCi/mL); (3) inhaled air DAC for lung retention class W (uCi/mL); (4) inhaled air DAC for lung retention class Y (uC/mL); and (5) an indication of whether or not the DAC for each class is controlled by the stochastic (effective dose equivalent) or nonstochastic (tissue) dose. The classes D, W, and Y have been established by the International Commission on Radiological Protection (ICRP) to describe the clearance of inhaled radionuclides from the lung. This classification refers to the approximate length of retention in the pulmonary region. Thus, the range of half-times is less than 10 days for class D (days), from 10 to 100 days for class W (weeks), and greater than 100 days for class Y (years). The DACs in Table 1 are listed by radionuclide, in order of increasing atomic mass, and are based on the assumption that the particle size distribution of the inhaled material is unknown. For this situation, the ICRP recommends that an assumed particle size distribution of 1 um be used. For situations where the particle size distribution is known to differ significantly from 1 um, appropriate corrections (as described in the DOE report Internal Dose Conversion Factors for Calculation of Dose to the Public)[1/] can be made to both the estimated dose to workers and the DACs.

The following assumptions and procedures were used in calculating these DAC values for inhalation by workers:

(1) The worker is assumed to inhale 2,400 m^3 of air during a 2000-hour work year, as defined by the ICRP in its Publication No. 23.[2/]

(2) The internal dose factors used in calculating the DAC values were taken from the report Internal Dose Conversion Factors for Calculation of Dose to the Public.[1/] These factors are based on the metabolic data and dosimetry models recommended by the ICRP in its Publication No. 30.[3/]

1/ U.S. Department of Energy (DOE). 1988. Internal Dose Conversion Factors for Calculation of Dose to the Public. Washington, D.C.

2/ International Commission on Radiological Protection (ICRP). 1975. ICRP Publication 23: Report of the Task Group on Reference Man. Pergamon Press, New York, New York.

3/ International Commission on Radiological Protection (ICRP). 1979-1982. ICRP Publication 30: Limits for Intakes of Radionuclides by Workers. Parts 1 to 3 and Supplements 2(3/4) through 8(4), Pergamon Press, New York, New York.

The DAC values are given for individual radionuclides. For known mixtures of radionuclides, the sum of the ratio of the observed concentration of a particular radionuclide and its corresponding DAC for all radionuclides in the mixture must not exceed 1.0.

Table 1

Derived Air Concentrations (DAC) for Controlling Radiation Exposures to Workers at DOE Facilities

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
H-3 (Water)2/	2.E-05	2.E-05	2.E-05	St/St/St
H-3 (Elemental)2/	5.E-01	5.E-01	5.E-01	St/St/St
Be-7	-3/	9.E-06	8.E-06	/St/St
Be-10	-	6.E-08	6.E-09	/St/St
C-11 (Org)2/	2.E-04	2.E-04	2.E-04	St/St/St
C-11 (CO)2/	5.E-04	5.E-04	5.E-04	St/St/St
C-11 (CO_2)2/	3.E-04	3.E-04	3.E-04	St/St/St
C-14 (Org)2/	1.E-06	1.E-06	1.E-06	St/St/St
C-14 (CO)2/	7.E-04	7.E-04	7.E-04	St/St/St
C-14 (CO_2)2/	9.E-05	9.E-05	9.E-05	St/St/St
F-18	3.E-05	4.E-05	3.E-05	St/St/St
Na-22	3.E-07	-	-	St/ /
Na-24	2.E-06	-	-	St/ /
Mg-28	7.E-07	5.E-07	-	St/St/
Al-26	3.E-08	3.E-08	-	St/St/
Si-31	1.E-05	1.E-05	1.E-05	St/St/St
Si-32	1.E-07	5.E-08	2.E-09	St/St/St
P-32	4.E-07	2.E-07	-	St/St/
P-33	3.E-06	1.E-06	-	St/St/
S-35	7.E-06	9.E-07	-	St/St/
S-35 (Gas)	-	6.E-06	-	/St/
Cl-36	1.E-06	1.E-07	-	St/St/
Cl-38	2.E-05	2.E-05	-	St/St/
Cl-39	2.E-05	2.E-05	-	St/St/
K-40	2.E-07	-	-	St/ /
K-42	2.E-06	-	-	St/ /
K-43	4.E-06	-	-	St/ /
K-44	3.E-05	-	-	St/ /
K-45	5.E-05	-	-	St/ /

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Ca-41	-	2.E-06	-	/E /
Ca-45	-	3.E-07	-	/St/
Ca-47	-	4.E-07	-	/St/
Sc-43	-	-	1.E-05	/ /St
Sc-44m	-	-	3.E-07	/ /St
Sc-44	-	-	5.E-06	/ /St
Sc-46	-	-	1.E-07	/ /St
Sc-47	-	-	1.E-06	/ /St
Sc-48	-	-	6.E-07	/ /St
Sc-49	-	-	2.E-05	/ /St
Ti-44	5.E-09	1.E-08	2.E-09	St/St/St
Ti-45	1.E-05	1.E-05	1.E-05	St/St/St
V-47	4.E-05	4.E-05	-	St/St/
V-48	4.E-07	3.E-07	-	St/St/
V-49	1.E-05	7.E-06	-	BS/St/
Cr-48	5.E-06	3.E-06	3.E-06	St/St/St
Cr-49	3.E-05	4.E-05	4.E-05	St/St/St
Cr-51	2.E-05	1.E-05	8.E-06	St/St/St
Mn-51	2.E-05	2.E-05	-	St/St/
Mn-52m	4.E-05	4.E-05	-	St/St/
Mn-52	5.E-07	4.E-07	-	St/St/
Mn-53	5.E-06	5.E-06	-	BS/St/
Mn-54	4.E-07	3.E-07	-	St/St/
Mn-56	6.E-06	9.E-06	-	St/St/
Fe-52	1.E-06	1.E-06	-	St/St/
Fe-55	8.E-07	2.E-06	-	St/St/
Fe-59	1.E-07	2.E-07	-	St/St/
Fe-60	3.E-09	8.E-09	-	St/St/
Co-55	-	1.E-06	1.E-06	/St/St
Co-56	-	1.E-07	8.E-08	/St/St
Co-57	-	1.E-06	3.E-07	/St/St
Co-58m	-	4.E-05	3.E-05	/St/St
Co-58	-	5.E-07	3.E-07	/St/St
Co-60m	-	2.E-03	1.E-03	/St/St
Co-60	-	7.E-08	1.E-08	/St/St
Co-61	-	3.E-05	2.E-05	/St/St
Co-62m	-	7.E-05	7.E-05	/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Ni-56 (Inorg)	8.E-07	5.E-07	-	St/St/
Ni-56 (Vapor)	-	5.E-07	-	/St/
Ni-57 (Inorg)	2.E-06	1.E-06	-	St/St/
Ni-57 (Vapor)	-	3.E-06	-	/St/
Ni-59 (Inorg)	2.E-06	3.E-06	-	St/St/
Ni-59 (Vapor)	-	8.E-07	-	/St/
Ni-63 (Inorg)	7.E-07	1.E-06	-	St/St/
Ni-63 (Vapor)	-	3.E-07	-	/St/
Ni-65 (Inorg)	1.E-05	1.E-05	-	St/St/
Ni-65 (Vapor)	-	7.E-06	-	/St/
Ni-66 (Inorg)	7.E-07	3.E-07	-	St/St/
Ni-66 (Vapor)	-	1.E-06	-	/St/
Cu-60	4.E-05	5.E-05	4.E-05	St/St/St
Cu-61	1.E-05	2.E-05	1.E-05	St/St/St
Cu-64	1.E-05	1.E-05	9.E-06	St/St/St
Cu-67	3.E-06	2.E-06	2.E-06	St/St/St
Zn-62	-	-	1.E-06	/ /St
Zn-63	-	-	3.E-05	/ /St
Zn-65	-	-	1.E-07	/ /St
Zn-69m	-	-	3.E-06	/ /St
Zn-69	-	-	6.E-05	/ /St
Zn-71m	-	-	7.E-06	/ /St
Zn-72	-	-	5.E-07	/ /St
Ga-65	7.E-05	8.E-05	-	St/St/
Ga-66	1.E-06	-	1.E-06	St/ /St
Ga-67	6.E-06	4.E-06	-	St/St/
Ga-68	2.E-05	2.E-05	-	St/St/
Ga-70	7.E-05	8.E-05	-	St/St/
Ga-72	2.E-06	1.E-06	-	St/St/
Ga-73	6.E-06	6.E-06	-	St/St/
Ge-66	1.E-05	8.E-06	-	St/St/
Ge-67	4.E-05	4.E-05	-	St/St/
Ge-68	2.E-06	4.E-08	-	St/St/
Ge-69	6.E-06	3.E-06	-	St/St/
Ge-71	2.E-04	2.E-05	-	St/St/
Ge-75	3.E-05	3.E-05	-	St/St/
Ge-77	4.E-06	2.E-06	-	St/St/
Ge-78	9.E-06	9.E-06	-	St/St/
As-69	-	5.E-05	-	/St/

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
As-70	-	2.E-05	-	/St/
As-71	-	2.E-06	-	/St/
As-72	-	6.E-07	-	/St/
As-73	-	7.E-07	-	/St/
As-74	-	3.E-07	-	/St/
As-76	-	6.E-07	-	/St/
As-77	-	2.E-06	-	/St/
As-78	-	9.E-06	-	/St/
Se-70	1.E-05	2.E-05	-	St/St/
Se-73m	6.E-05	6.E-05	-	St/St/
Se-73	6.E-06	7.E-06	-	St/St/
Se-75	3.E-07	3.E-07	-	St/St/
Se-79	3.E-07	2.E-07	-	St/St/
Se-81m	3.E-05	3.E-05	-	St/St/
Se-81	9.E-05	1.E-04	-	St/St/
Se-83	5.E-05	5.E-05	-	St/St/
Br-74m	1.E-05	2.E-05	-	St/St/
Br-74	3.E-05	3.E-05	-	St/St/
Br-75	2.E-05	2.E-05	-	St/St/
Br-76	2.E-06	2.E-06	-	St/St/
Br-77	1.E-05	8.E-06	-	St/St/
Br-80m	7.E-06	6.E-06	-	St/St/
Br-80	8.E-05	9.E-05	-	St/St/
Br-82	2.E-06	2.E-06	-	St/St/
Br-83	3.E-05	3.E-05	-	St/St/
Br-84	2.E-05	3.E-05	-	St/St/
Rb-79	5.E-05	-	-	St/ /
Rb-81m	1.E-04	-	-	St/ /
Rb-81	2.E-05	-	-	St/ /
Rb-82m	7.E-06	-	-	St/ /
Rb-83	4.E-07	-	-	St/ /
Rb-84	3.E-07	-	-	St/ /
Rb-86	3.E-07	-	-	St/ /
Rb-87	6.E-07	-	-	St/ /
Rb-88	3.E-05	-	-	St/ /
Rb-89	6.E-05	-	-	St/ /
Sr-80	9.E-04	-	1.E-03	St/ /St
Sr-81	3.E-05	-	3.E-05	St/ /St
Sr-83	3.E-06	-	2.E-06	St/ /St
Sr-85m	3.E-04	-	3.E-04	St/ /St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Sr-85	1.E-06	-	7.E-07	St/ /St
Sr-87m	5.E-05	-	6.E-05	St/ /St
Sr-89	3.E-07	-	6.E-08	St/ /St
Sr-90	8.E-09	-	2.E-09	BS/ /St
Sr-91	2.E-06	-	1.E-06	St/ /St
Sr-92	4.E-06	-	3.E-06	St/ /St
Y-86m	-	2.E-05	2.E-05	/St/St
Y-86	-	1.E-06	1.E-06	/St/St
Y-87	-	1.E-06	1.E-06	/St/St
Y-88	-	1.E-07	1.E-07	/St/St
Y-90m	-	5.E-06	5.E-06	/St/St
Y-90	-	3.E-07	3.E-07	/St/St
Y-91m	-	1.E-04	7.E-05	/St/St
Y-91	-	7.E-08	5.E-08	/St/St
Y-92	-	3.E-06	3.E-06	/St/St
Y-93	-	1.E-06	1.E-06	/St/St
Y-94	-	3.E-05	3.E-05	/St/St
Y-95	-	6.E-05	6.E-05	/St/St
Zr-86	2.E-06	1.E-06	1.E-08	St/St/St
Zr-88	9.E-08	2.E-07	1.E-07	St/St/St
Zr-89	2.E-06	1.E-06	1.E-06	St/St/St
Zr-93	3.E-09	1.E-08	2.E-08	BS/BS/BS
Zr-95	6.E-08	2.E-07	1.E-07	BS/St/St
Zr-97	8.E-07	6.E-07	5.E-07	St/St/St
Nb-88	-	1.E-04	9.E-05	/St/St
Nb-89 (66 min)	-	2.E-05	2.E-05	/St/St
Nb-89 (122 min)	-	8.E-06	7.E-06	/St/St
Nb-90	-	1.E-06	1.E-06	/St/St
Nb-93m	-	5.E-07	7.E-08	/St/St
Nb-94	-	8.E-08	6.E-09	/St/St
Nb-95m	-	1.E-06	9.E-07	/St/St
Nb-95	-	5.E-07	5.E-07	/St/St
Nb-96	-	1.E-06	1.E-06	/St/St
Nb-97	-	3.E-05	3.E-05	/St/St
Nb-98	-	2.E-05	2.E-05	/St/St
Mo-90	3.E-06	-	2.E-06	St/ /St
Mo-93m	7.E-06	-	6.E-06	St/ /St
Mo-93	2.E-06	-	7.E-08	St/ /St
Mo-99	1.E-06	-	6.E-07	St/ /St
Mo-101	6.E-05	-	6.E-05	St/ /St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Tc-93m	7.E-05	1.E-04	-	St/St/
Tc-93	3.E-05	4.E-05	-	St/St/
Tc-94m	2.E-05	2.E-05	-	St/St/
Tc-94	8.E-06	1.E-05	-	St/St/
Tc-96m	1.E-04	1.E-04	-	St/St/
Tc-96	1.E-06	9.E-07	-	St/St/
Tc-97m	3.E-06	5.E-07	-	SW/St/
Tc-97	2.E-05	2.E-06	-	St/St/
Tc-98	7.E-07	1.E-07	-	St/St/
Tc-99m	6.E-05	1.E-04	-	St/St/
Tc-99	2.E-06	3.E-07	-	SW/St/
Tc-101	1.E-04	2.E-04	-	St/St/
Tc-104	3.E-05	4.E-05	-	St/St/
Ru-94	2.E-05	3.E-05	2.E-05	St/St/St
Ru-97	8.E-06	5.E-06	5.E-06	St/St/St
Ru-103	7.E-07	4.E-07	3.E-07	St/St/St
Ru-105	6.E-06	6.E-06	5.E-06	St/St/St
Ru-106	4.E-08	2.E-08	5.E-09	St/St/St
Rh-99m	2.E-05	3.E-05	3.E-05	St/St/St
Rh-99	1.E-06	9.E-07	8.E-07	St/St/St
Rh-100	2.E-06	2.E-06	2.E-06	St/St/St
Rh-101m	5.E-06	3.E-06	3.E-06	St/St/St
Rh-101	2.E-07	3.E-07	7.E-08	St/St/St
Rh-102m	2.E-07	2.E-07	5.E-08	St/St/St
Rh-102	4.E-08	7.E-08	2.E-08	St/St/St
Rh-103m	4.E-04	5.E-04	5.E-04	St/St/St
Rh-105	5.E-06	3.E-06	2.E-06	St/St/St
Rh-106m	1.E-05	1.E-05	1.E-05	St/St/St
Rh-107	1.E-04	1.E-04	1.E-04	St/St/St
Pd-100	6.E-07	5.E-07	6.E-07	St/St/St
Pd-101	1.E-05	1.E-05	1.E-05	St/St/St
Pd-103	3.E-06	2.E-06	1.E-06	St/St/St
Pd-107	9.E-06	3.E-06	2.E-07	K /St/St
Pd-109	3.E-06	2.E-06	2.E-06	St/St/St
Ag-102	8.E-05	9.E-05	8.E-05	St/St/St
Ag-103	4.E-05	6.E-05	5.E-05	St/St/St
Ag-104m	4.E-05	5.E-05	5.E-05	St/St/St
Ag-104	3.E-05	6.E-05	6.E-05	St/St/St
Ag-105	4.E-07	7.E-07	7.E-07	St/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Ag-106m	3.E-07	4.E-07	4.E-07	St/St/St
Ag-106	7.E-05	9.E-05	8.E-05	St/St/St
Ag-108m	8.E-08	1.E-07	1.E-08	St/St/St
Ag-110m	6.E-08	8.E-08	4.E-08	St/St/St
Ag-111	7.E-07	4.E-07	4.E-07	L /St/St
Ag-112	3.E-06	4.E-06	4.E-06	St/St/St
Ag-115	4.E-05	4.E-05	3.E-05	St/St/St
Cd-104	3.E-05	5.E-05	5.E-05	St/St/St
Cd-107	2.E-05	2.E-05	2.E-05	St/St/St
Cd-109	1.E-08	5.E-08	5.E-08	K /K /St
Cd-113m	1.E-09	4.E-09	5.E-09	K /K /St
Cd-113	9.E-10	3.E-09	6.E-09	K /K /St
Cd-115m	2.E-08	5.E-08	6.E-08	K /St/St
Cd-115	6.E-07	5.E-07	6.E-07	St/St/St
Cd-117m	5.E-06	7.E-06	6.E-06	St/St/St
Cd-117	5.E-06	7.E-06	6.E-06	St/St/St
In-109	2.E-05	3.E-05	-	St/St/
In-110 (69 min)	2.E-05	2.E-05	-	St/St/
In-110 (5 h)	7.E-06	8.E-06	-	St/St/
In-111	3.E-06	3.E-06	-	St/St/
In-112	3.E-04	3.E-04	-	St/St/
In-113m	6.E-05	8.E-05	-	St/St/
In-114m	3.E-08	4.E-08	-	St/St/
In-115m	2.E-05	2.E-05	-	St/St/
In-115	6.E-10	2.E-09	-	St/St/
In-116m	3.E-05	5.E-05	-	St/St/
In-117m	1.E-05	2.E-05	-	St/St/
In-117	7.E-05	9.E-05	-	St/St/
In-119m	5.E-05	6.E-05	-	St/St/
Sn-110	5.E-06	5.E-06	-	St/St/
Sn-111	9.E-05	1.E-04	-	St/St/
Sn-113	5.E-07	2.E-07	-	St/St/
Sn-117m	5.E-07	6.E-07	-	BS/St/
Sn-119m	1.E-06	4.E-07	-	St/St/
Sn-121m	4.E-07	2.E-07	-	St/St/
Sn-121	6.E-06	5.E-06	-	St/St/
Sn-123m	5.E-05	6.E-05	-	St/St/
Sn-123	3.E-07	7.E-08	-	St/St/
Sn-125	4.E-07	2.E-07	-	St/St/
Sn-126	2.E-08	3.E-08	-	St/St/
Sn-127	8.E-06	8.E-06	-	St/St/

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Sn-128	1.E-05	1.E-05	-	St/St/
Sb-115	1.E-04	1.E-04	-	St/St/
Sb-116m	3.E-05	6.E-05	-	St/St/
Sb-116	1.E-04	1.E-04	-	St/St/
Sb-117	9.E-05	1.E-04	-	St/St/
Sb-118m	8.E-06	9.E-06	-	St/St/
Sb-119	2.E-05	1.E-05	-	St/St/
Sb-120 (16 min)	2.E-04	2.E-04	-	St/St/
Sb-120 (6 d)	9.E-07	6.E-07	-	St/St/
Sb-122	1.E-06	4.E-07	-	St/St/
Sb-124m	3.E-04	3.E-04	-	St/St/
Sb-124	4.E-07	1.E-07	-	St/St/
Sb-125	1.E-06	2.E-07	-	St/St/
Sb-126m	8.E-05	8.E-05	-	St/St/
Sb-126	4.E-07	2.E-07	-	St/St/
Sb-127	9.E-07	4.E-07	-	St/St/
Sb-128 (9 h)	2.E-06	1.E-06	-	St/St/
Sb-128 (10 min)	2.E-04	2.E-04	-	St/St/
Sb-129	4.E-06	4.E-06	-	St/St/
Sb-130	3.E-05	3.E-05	-	St/St/
Sb-131	1.E-05	1.E-05	-	T /T /
Te-116	9.E-06	1.E-05	-	St/St/
Te-121m	8.E-08	2.E-07	-	BS/St/
Te-121	2.E-06	1.E-06	-	St/St/
Te-123m	9.E-08	2.E-07	-	BS/St/
Te-123	8.E-08	2.E-07	-	BS/BS/
Te-125m	2.E-07	3.E-07	-	BS/St/
Te-127m	1.E-07	1.E-07	-	BS/St/
Te-127	9.E-06	7.E-06	-	St/St/
Te-129m	3.E-07	1.E-07	-	St/St/
Te-129	3.E-05	3.E-05	-	St/St/
Te-131m	2.E-07	2.E-07	-	T /T /
Te-131	2.E-06	2.E-06	-	T /T /
Te-132	9.E-08	9.E-08	-	T /T /
Te-133m	2.E-06	2.E-06	-	T /T /
Te-133	9.E-06	9.E-06	-	T /T /
Te-134	1.E-05	1.E-05	-	T /T /
I-120m	9.E-06	-	-	St/ /
I-120	4.E-06	-	-	T / /
I-121	7.E-06	-	-	T / /
I-123	3.E-06	-	-	T / /

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
I-124	3.E-08	-	-	T / /
I-125	3.E-08	-	-	T / /
I-126	1.E-08	-	-	T / /
I-128	5.E-05	-	-	St/ /
I-129	4.E-09	-	-	T / /
I-130	3.E-07	-	-	T / /
I-131	2.E-08	-	-	T / /
I-132m	4.E-06	-	-	T / /
I-132	3.E-06	-	-	T / /
I-133	1.E-07	-	-	T / /
I-134	2.E-05	-	-	E / /
I-135	7.E-07	-	-	T / /
Cs-125	6.E-05	-	-	St/ /
Cs-127	4.E-05	-	-	St/ /
Cs-129	1.E-05	-	-	St/ /
Cs-130	8.E-05	-	-	St/ /
Cs-131	1.E-05	-	-	St/ /
Cs-132	2.E-06	-	-	St/ /
Cs-134m	6.E-05	-	-	St/ /
CS-134	4.E-08	-	-	St/ /
Cs-135m	8.E-05	-	-	St/ /
Cs-135	5.E-07	-	-	St/ /
Cs-136	3.E-07	-	-	St/ /
Cs-137	7.E-08	-	-	St/ /
Cs-138	2.E-05	-	-	St/ /
Ba-126	6.E-06	-	-	St/ /
Ba-128	7.E-07	-	-	St/ /
Ba-131m	6.E-04	-	-	St/ /
Ba-131	3.E-06	-	-	St/ /
Ba-133m	4.E-06	-	-	St/ /
Ba-133	3.E-07	-	-	St/ /
Ba-135m	5.E-06	-	-	St/ /
Ba-139	1.E-05	-	-	St/ /
Ba-140	6.E-07	-	-	St/ /
Ba-141	3.E-05	-	-	St/ /
Ba-142	6.E-05	-	-	St/ /
La-131	5.E-05	7.E-05	-	St/St/
La-132	4.E-06	5.E-06	-	St/St/
La-135	4.E-05	4.E-05	-	St/St/
La-137	3.E-08	1.E-07	-	L /E /
La-138	2.E-09	6.E-09	-	St/St/

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
La-140	6.E-07	5.E-07	-	St/St/
La-141	4.E-06	5.E-06	-	St/St/
La-142	9.E-06	1.E-05	-	St/St/
La-143	4.E-05	4.E-05	-	St/St/
Ce-134	-	3.E-07	3.E-07	/St/St
Ce-135	-	2.E-06	2.E-06	/St/St
Ce-137m	-	2.E-06	2.E-06	/St/St
Ce-137	-	6.E-05	5.E-05	/St/St
Ce-139	-	3.E-07	3.E-07	/St/St
Ce-141	-	3.E-07	3.E-07	/St/St
Ce-143	-	8.E-07	7.E-07	/St/St
Ce-144	-	1.E-08	6.E-09	/St/St
Pr-136	-	1.E-04	9.E-05	/St/St
Pr-137	-	6.E-05	6.E-05	/St/St
Pr-138m	-	2.E-05	2.E-05	/St/St
Pr-139	-	5.E-05	5.E-05	/St/St
Pr-142m	-	7.E-05	6.E-05	/St/St
Pr-142	-	8.E-07	8.E-07	/St/St
Pr-143	-	3.E-07	3.E-07	/St/St
Pr-144	-	5.E-05	5.E-05	/St/St
Pr-145	-	4.E-06	3.E-06	/St/St
Pr-147	-	8.E-05	8.E-05	/St/St
Nd-136	-	2.E-05	2.E-05	/St/St
Nd-138	-	3.E-06	2.E-06	/St/St
Nd-139m	-	7.E-06	6.E-06	/St/St
Nd-139	-	1.E-04	1.E-04	/St/St
Nd-141	-	3.E-04	3.E-04	/St/St
Nd-147	-	4.E-07	3.E-07	/St/St
Nd-149	-	1.E-05	1.E-05	/St/St
Nd-151	-	8.E-05	8.E-05	/St/St
Pm-141	-	8.E-05	7.E-05	/St/St
Pm-143	-	3.E-07	3.E-07	/St/St
Pm-144	-	5.E-08	5.E-08	/St/St
Pm-145	-	7.E-08	8.E-08	/BS/St
Pm-146	-	2.E-08	2.E-08	/St/St
Pm-147	-	6.E-08	6.E-08	/BS/St
Pm-148m	-	1.E-07	1.E-07	/St/St
Pm-148	-	2.E-07	2.E-07	/St/St
Pm-149	-	8.E-07	8.E-07	/St/St
Pm-150	-	8.E-06	7.E-06	/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Pm-151	-	2.E-06	1.E-06	/St/St
Sm-141m	-	4.E-05	-	/St/
Sm-141	-	7.E-05	-	/St/
Sm-142	-	1.E-05	-	/St/
Sm-145	-	2.E-07	-	/St/
Sm-146	-	1.E-11	-	/BS/
Sm-147	-	2.E-11	-	/BS/
Sm-151	-	4.E-08	-	/BS/
Sm-153	-	1.E-06	-	/St/
Sm-155	-	9.E-05	-	/St/
Sm-156	-	4.E-06	-	/St/
Eu-145	-	8.E-07	-	/St/
Eu-146	-	5.E-07	-	/St/
Eu-147	-	7.E-07	-	/St/
Eu-148	-	2.E-07	-	/St/
Eu-149	-	1.E-06	-	/St/
Eu-150 (12 h)	-	3.E-06	-	/St/
Eu-150 (34 yr)	-	8.E-09	-	/St/
Eu-152m	-	3.E-06	-	/St/
Eu-152	-	1.E-08	-	/St/
Eu-154	-	8.E-09	-	/St/
Eu-155	-	4.E-08	-	/BS/
Eu-156	-	2.E-07	-	/St/
Eu-157	-	2.E-06	-	/St/
Eu-158	-	2.E-05	-	/St/
Gd-145	7.E-05	7.E-05	-	St/St/
Gd-146	5.E-08	1.E-07	-	St/St/
Gd-147	2.E-06	2.E-06	-	St/St/
Gd-148	3.E-12	1.E-11	-	BS/BS/
Gd-149	9.E-07	1.E-06	-	St/St/
Gd-151	2.E-07	5.E-07	-	BS/St/
Gd-152	4.E-12	2.E-11	-	BS/BS/
Gd-153	6.E-08	3.E-07	-	BS/St/
Gd-159	3.E-06	2.E-06	-	St/St/
Tb-147	-	1.E-05	-	/St/
Tb-149	-	3.E-07	-	/St/
Tb-150	-	9.E-06	-	/St/
Tb-151	-	4.E-06	-	/St/
Tb-153	-	3.E-06	-	/St/
Tb-154	-	2.E-06	-	/St/

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Tb-153	-	3.E-06	-	/St/
Tb-156m (24 h)	-	3.E-06	-	/St/
Tb-156m (5 h)	-	1.E-05	-	/St/
Tb-156	-	6.E-07	-	/St/
Tb-157	-	1.E-07	-	/BS/
Tb-158	-	8.E-09	-	/St/
Tb-160	-	1.E-07	-	/St/
Tb-161	-	7.E-07	-	/St/
Dy-155	-	1.E-05	-	/St/
Dy-157	-	3.E-05	-	/St/
Dy-159	-	1.E-06	-	/St/
Dy-165	-	2.E-05	-	/St/
Dy-166	-	3.E-07	-	/St/
Ho-155	-	7.E-05	-	/St/
Ho-157	-	6.E-04	-	/St/
Ho-159	-	4.E-04	-	/St/
Ho-161	-	2.E-04	-	/St/
Ho-162m	-	1.E-04	-	/St/
Ho-162	-	1.E-03	-	/St/
Ho-164m	-	1.E-04	-	/St/
Ho-164	-	3.E-04	-	/St/
Ho-166m	-	3.E-09	-	/St/
Ho-166	-	7.E-07	-	/St/
Ho-167	-	2.E-05	-	/St/
Er-161	-	3.E-05	-	/St/
Er-165	-	8.E-05	-	/St/
Er-169	-	1.E-06	-	/St/
Er-171	-	4.E-06	-	/St/
Er-172	-	6.E-07	-	/St/
Tm-162	-	1.E-04	-	/St/
Tm-166	-	6.E-06	-	/St/
Tm-167	-	8.E-07	-	/St/
Tm-170	-	9.E-08	-	/St/
Tm-171	-	1.E-07	-	/BS/
Tm-172	-	5.E-07	-	/St/
Tm-173	-	5.E-06	-	/St/
Tm-175	-	1.E-04	-	/St/
Yb-162	-	1.E-04	1.E-04	/St/St
Yb-166	-	8.E-07	8.E-07	/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Yb-167	-	3.E-04	3.E-04	/St/St
Yb-169	-	3.E-07	3.E-07	/St/St
Yb-175	-	1.E-06	1.E-06	/St/St
Yb-177	-	2.E-05	2.E-05	/St/St
Yb-178	-	2.E-05	1.E-05	/St/St
Lu-169	-	2.E-06	2.E-06	/St/St
Lu-170	-	9.E-07	8.E-07	/St/St
Lu-171	-	8.E-07	8.E-07	/St/St
Lu-172	-	5.E-07	5.E-07	/St/St
Lu-173	-	1.E-07	1.E-07	/BS/St
Lu-174m	-	1.E-07	9.E-08	/BS/St
Lu-174	-	5.E-08	7.E-08	/BS/St
Lu-176m	-	1.E-05	1.E-05	/St/St
Lu-176	-	2.E-09	3.E-09	/BS/St
Lu-177m	-	5.E-08	3.E-08	/BS/St
Lu-177	-	9.E-07	9.E-07	/St/St
Lu-178m	-	8.E-05	7.E-05	/St/St
Lu-178	-	5.E-05	5.E-05	/St/St
Lu-179	-	8.E-06	6.E-06	/St/St
Hf-170	2.E-06	2.E-06	-	St/St/
Hf-172	4.E-09	2.E-08	-	BS/BS/
Hf-173	5.E-06	5.E-06	-	St/St/
Hf-175	4.E-07	5.E-07	-	BS/St/
Hf-177m	2.E-05	4.E-05	-	St/St/
Hf-178m	6.E-10	2.E-09	-	BS/BS/
Hf-179m	1.E-07	3.E-07	-	BS/St/
Hf-180m	9.E-06	1.E-05	-	St/St/
Hf-181	7.E-08	2.E-07	-	BS/St/
Hf-182m	4.E-05	6.E-05	-	St/St/
Hf-182	3.E-10	1.E-09	-	BS/BS/
Hf-183	2.E-05	2.E-05	-	St/St/
Hf-184	3.E-06	3.E-06	-	St/St/
Ta-172	-	5.E-05	4.E-05	/St/St
Ta-173	-	8.E-06	7.E-06	/St/St
Ta-174	-	4.E-05	4.E-05	/St/St
Ta-175	-	7.E-06	6.E-06	/St/St
Ta-176	-	5.E-06	5.E-06	/St/St
Ta-177	-	8.E-06	7.E-06	/St/St
Ta-178	-	4.E-05	3.E-05	/St/St
Ta-179	-	2.E-06	4.E-07	/St/St
Ta-180m	-	3.E-05	2.E-05	/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Ta-180	-	2.E-07	1.E-08	/St/St
Ta-182m	-	2.E-04	2.E-04	/St/St
Ta-182	-	1.E-07	6.E-08	/St/St
Ta-183	-	5.E-07	4.E-07	/St/St
Ta-184	-	2.E-06	2.E-06	/St/St
Ta-185	-	3.E-05	3.E-05	/St/St
Ta-186	-	1.E-04	9.E-05	/St/St
W-176	2.E-05	-	-	St/ /
W-177	4.E-05	-	-	St/ /
W-178	8.E-06	-	-	St/ /
W-179	7.E-04	-	-	St/ /
W-181	1.E-05	-	-	St/ /
W-185	3.E-06	-	-	St/ /
W-187	4.E-06	-	-	St/ /
W-188	5.E-07	-	-	St/ /
Re-177	1.E-04	2.E-04	-	St/St/
Re-178	1.E-04	1.E-04	-	St/St/
Re-181	4.E-06	4.E-06	-	St/St/
Re-182 (64 h)	1.E-06	9.E-07	-	St/St/
Re-182 (12 h)	5.E-06	6.E-06	-	St/St/
Re-184m	1.E-06	2.E-07	-	St/St/
Re-184	2.E-06	6.E-07	-	St/St/
Re-186m	7.E-07	6.E-08	-	SW/St/
Re-186	1.E-06	7.E-07	-	St/St/
Re-187	3.E-04	4.E-05	-	SW/St/
Re-188m	6.E-05	6.E-05	-	St/St/
Re-188	1.E-06	1.E-06	-	St/St/
Re-189	2.E-06	2.E-06	-	St/St/
Os-180	2.E-04	2.E-04	2.E-04	St/St/St
Os-181	2.E-05	2.E-05	2.E-05	St/St/St
Os-182	2.E-06	2.E-06	2.E-06	St/St/St
Os-185	2.E-07	3.E-07	3.E-07	St/St/St
Os-189m	1.E-04	9.E-05	7.E-05	St/St/St
Os-191m	1.E-05	9.E-06	7.E-06	St/St/St
Os-191	9.E-07	7.E-07	6.E-07	St/St/St
Os-193	2.E-06	1.E-06	1.E-06	St/St/St
Os-194	2.E-08	2.E-08	3.E-09	St/St/St
Ir-182	6.E-05	6.E-05	5.E-05	St/St/St
Ir-184	1.E-05	1.E-05	1.E-05	St/St/St
Ir-185	5.E-06	5.E-06	4.E-06	St/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Ir-186	3.E-06	3.E-06	2.E-06	St/St/St
Ir-187	1.E-05	1.E-05	1.E-05	St/St/St
Ir-188	2.E-06	2.E-06	1.E-06	St/St/St
Ir-189	2.E-06	2.E-06	2.E-06	St/St/St
Ir-190m	8.E-05	9.E-05	8.E-05	St/St/St
Ir-190	4.E-07	4.E-07	4.E-07	St/St/St
Ir-192m	4.E-08	9.E-08	6.E-09	St/St/St
Ir-192	1.E-07	2.E-07	9.E-08	St/St/St
Ir-194m	4.E-08	7.E-08	4.E-08	St/St/St
Ir-194	1.E-06	8.E-07	8.E-07	St/St/St
Ir-195m	1.E-05	1.E-05	9.E-06	St/St/St
Ir-195	2.E-05	2.E-05	2.E-05	St/St/St
Pt-186	2.E-05	-	-	St/ /
Pt-188	7.E-07	-	-	St/ /
Pt-189	1.E-05	-	-	St/ /
Pt-191	3.E-06	-	-	St/ /
Pt-193m	2.E-06	-	-	St/ /
Pt-193	1.E-05	-	-	St/ /
Pt-195m	2.E-06	-	-	St/ /
Pt-197m	2.E-05	-	-	St/ /
Pt-197	4.E-06	-	-	St/ /
Pt-199	6.E-05	-	-	St/ /
Pt-200	1.E-06	-	-	St/ /
Au-193	6.E-06	7.E-06	7.E-06	St/St/St
Au-194	2.E-06	2.E-06	2.E-06	St/St/St
Au-195	1.E-06	6.E-07	2.E-07	St/St/St
Au-198m	3.E-07	4.E-07	4.E-07	St/St/St
Au-198	5.E-07	1.E-06	1.E-06	St/St/St
Au-199	1.E-06	1.E-06	1.E-06	St/St/St
Au-200m	8.E-07	1.E-06	1.E-06	St/St/St
Au-200	2.E-05	3.E-05	3.E-05	St/St/St
Au-201	6.E-05	9.E-05	9.E-05	St/St/St
Hg-193m (Org)	6.E-06	-	-	St/ /
Hg-193m (Inorg)	4.E-06	3.E-06	-	St/St/
Hg-193m (Vapor)	-	4.E-06	-	/St/
Hg-193 (Org)	3.E-05	-	-	St/ /
Hg-193 (Inorg)	2.E-05	2.E-05	-	St/St/
Hg-193 (Vapor)	-	1.E-05	-	/St/
Hg-194 (Org)	1.E-08	-	-	St/ /
Hg-194 (Inorg)	2.E-08	5.E-08	-	St/St/
Hg-194 (Vapor)	-	1.E-08	-	/St/

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Hg-195m (Org)	3.E-06	-	-	St/ /
Hg-195m (Inorg)	2.E-06	2.E-06	-	St/St/
Hg-195m (Vapor)	-	2.E-06	-	/St/
Hg-195 (Org)	2.E-05	-	-	St/ /
Hg-195 (Inorg)	1.E-05	1.E-05	-	St/St/
Hg-195 (Vapor)	-	1.E-05	-	/St/
Hg-197m (Org)	4.E-06	-	-	St/ /
Hg-197m (Inorg)	3.E-06	2.E-06	-	St/St/
Hg-197m (Vapor)	-	2.E-06	-	/St/
Hg-197 (Org)	6.E-06	-	-	St/ /
Hg-197 (Inorg)	5.E-06	4.E-06	-	St/St/
Hg-197 (Vapor)	-	3.E-05	-	/St/
Hg-199m (Org)	7.E-05	-	-	St/ /
Hg-199m (Inorg)	6.E-05	7.E-05	-	St/St/
Hg-199m (Vapor)	-	3.E-05	-	/St/
Hg-203 (Org)	3.E-07	-	-	St/ /
Hg-203 (Inorg)	5.E-07	5.E-07	-	St/St/
Hg-203 (Vapor)	-	3.E-07	-	/St/
Tl-194m	6.E-05	-	-	St/ /
Tl-194	3.E-04	-	-	St/ /
Tl-195	5.E-05	-	-	St/ /
Tl-197	5.E-05	-	-	St/ /
Tl-198m	2.E-05	-	-	St/ /
Tl-198	1.E-05	-	-	St/ /
Tl-199	3.E-05	-	-	St/ /
Tl-200	5.E-06	-	-	St/ /
Tl-201	9.E-06	-	-	St/ /
Tl-202	2.E-06	-	-	St/ /
Tl-204	9.E-07	-	-	St/ /
Pb-195m	8.E-05	-	-	St/ /
Pb-198	3.E-05	-	-	St/ /
Pb-199	3.E-05	-	-	St/ /
Pb-200	3.E-06	-	-	St/ /
Pb-201	9.E-06	-	-	St/ /
Pb-202m	1.E-05	-	-	St/ /
Pb-202	2.E-08	-	-	St/ /
Pb-203	4.E-06	-	-	St/ /
Pb-205	6.E-07	-	-	St/ /
Pb-209	2.E-05	-	-	St/ /
Pb-210	1.E-10	-	-	BS/ /
Pb-211	3.E-07	-	-	St/ /
Pb-212	1.E-08	-	-	St/ /

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organl/ (D / W / Y)
Pb-214	3.E-07	-	-	St/ /
Bi-200	3.E-05	4.E-05	-	St/St/
Bi-201	1.E-05	2.E-05	-	St/St/
Bi-202	2.E-05	3.E-05	-	St/St/
Bi-203	3.E-06	2.E-06	-	St/St/
Bi-205	1.E-06	5.E-07	-	St/St/
Bi-206	6.E-07	4.E-07	-	St/St/
Bi-207	7.E-07	2.E-07	-	St/St/
Bi-210m	2.E-09	3.E-10	-	K /St/
Bi-210	1.E-07	1.E-08	-	K /St/
Bi-212	1.E-07	1.E-07	-	St/St/
Bi-213	1.E-07	2.E-07	-	St/St/
Bi-214	3.E-07	4.E-07	-	St/St/
Po-203	3.E-05	4.E-05	-	St/St/
Po-205	2.E-05	3.E-05	-	St/St/
Po-207	1.E-05	1.E-05	-	St/St/
Po-210	3.E-10	3.E-10	-	E /St/
At-207	1.E-06	9.E-07	-	St/St/
At-211	3.E-08	2.E-08	-	St/St/
Rn-220	8.E-09 4/	-4/	-4/	-4/
Rn-222	3.E-08 4/	-4/	-4/	-4/
Fr-222	2.E-07	-	-	St/ /
Fr-223	3.E-07	-	-	St/ /
Ra-223	-	3.E-10	-	/St/
Ra-224	-	7.E-10	-	/St/
Ra-225	-	3.E-10	-	/St/
Ra-226	-	3.E-10	-	/St/
Ra-227	-	6.E-06	-	/BS/
Ra-228	-	5.E-10	-	/St/
Ac-224	1.E-08	2.E-08	2.E-08	BS/St/St
Ac-225	1.E-10	3.E-10	3.E-10	BS/St/St
Ac-226	1.E-09	2.E-09	2.E-09	BS/St/St
Ac-227	2.E-13	7.E-13	2.E-12	BS/BS/St
Ac-228	4.E-09	2.E-08	2.E-08	BS/BS/St
Th-226	-	7.E-08	6.E-08	/St/St
Th-227	-	1.E-10	1.E-10	/St/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Th-228	-	4.E-12	7.E-12	/BS/St
Th-229	-	4.E-13	1.E-12	/BS/BS
Th-230	-	3.E-12	7.E-12	/BS/BS
Th-231	-	3.E-06	3.E-06	/St/St
Th-232	-	5.E-13	1.E-12	/BS/BS
Th-234	-	9.E-08	6.E-08	/St/St
Pa-227	-	5.E-08	4.E-08	/St/St
Pa-228	-	5.E-09	5.E-09	/BS/St
Pa-230	-	2.E-09	1.E-09	/St/St
Pa-231	-	7.E-13	2.E-12	/BS/BS
Pa-232	-	9.E-09	2.E-08	/BS/BS
Pa-233	-	3.E-07	2.E-07	/St/St
Pa-234	-	3.E-06	3.E-06	/St/St
U-230	2.E-10	1.E-10	1.E-10	BS/St/St
U-231	3.E-06	2.E-06	2.E-06	St/St/St
U-232	9.E-11	2.E-10	3.E-12	BS/St/St
U-233	5.E-10	3.E-10	2.E-11	BS/St/St
U-234	5.E-10	3.E-10	2.E-11	BS/St/St
U-235	6.E-10	3.E-10	2.E-11	BS/St/St
U-236	6.E-10	3.E-10	2.E-11	BS/St/St
U-237	1.E-06	7.E-07	6.E-07	St/St/St
U-238	6.E-10	3.E-10	2.E-11	BS/St/St
U-239	8.E-05	7.E-05	6.E-05	St/St/St
U-240	2.E-06	1.E-06	1.E-06	St/St/St
Np-232	-	1.E-06 5/	-	/BS/
Np-233	-	1.E-03 5/	-	/St/
Np-234	-	1.E-06 5/	-	/St/
Np-235	-	5.E-07 5/	-	/BS/
Np-236 (1.E+05 yr)	-	1.E-11 5/	-	/BS/
Np-236 (22 h)	-	2.E-08 5/	-	/BS/
Np-237	-	2.E-12 5/	-	/BS/
Np-238	-	4.E-08 5/	-	/BS/
Np-239	-	1.E-06 5/	-	/St/
Np-240	-	3.E-05 5/	-	/St/
Pu-234	-	9.E-08 5/	8.E-08 5/	/St/St
Pu-235	-	1.E-03 5/	1.E-03 5/	/St/St
Pu-236	-	7.E-12 5/	1.E-11 5/	/BS/St
Pu-237	-	1.E-06 5/	1.E-06 5/	/St/St
Pu-238	-	3.E-12 5/	7.E-12 5/	/BS/BS
Pu-239	-	2.E-12 5/	6.E-12 5/	/BS/BS

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Pu-240	-	2.E-12 5/	6.E-12 5/	/BS/BS
Pu-241	-	1.E-10 5/	3.E-10 5/	/BS/BS
Pu-242	-	2.E-12 5/	6.E-12 5/	/BS/BS
Pu-243	-	1.E-05 5/	1.E-05 5/	/St/St
Pu-244	-	2.E-12 5/	6.E-12 5/	/BS/BS
Pu-245	-	2.E-06 5/	2.E-06 5/	/St/St
Am-237	-	1.E-04 5/	-	/St/
Am-238	-	1.E-06 5/	-	/BS/
Am-239	-	5.E-06 5/	-	/St/
Am-240	-	1.E-06 5/	-	/St/
Am-241	-	2.E-12 5/	-	/BS/
Am-242m	-	2.E-12 5/	-	/BS/
Am-242	-	3.E-08 5/	-	/BS/
Am-243	-	2.E-12 5/	-	/BS/
Am-244m	-	2.E-06 5/	-	/BS/
Am-244	-	7.E-08 5/	-	/BS/
Am-245	-	3.E-05 5/	-	/St/
Am-246m	-	7.E-05 5/	-	/St/
Am-246	-	4.E-05 5/	-	/St/
[illegible]-238	-	4.E-07 5/	-	/St/
[illegible]m-240	-	2.E-10 5/	-	/BS/
Cm-241	-	9.E-09 5/	-	/BS/
Cm-242	-	1.E-10 5/	-	/BS/
Cm-243	-	3.E-12 5/	-	/BS/
Cm-244	-	4.E-12 5/	-	/BS/
Cm-245	-	2.E-12 5/	-	/BS/
Cm-246	-	2.E-12 5/	-	/BS/
Cm-247	-	2.E-12 5/	-	/BS/
Cm-248	-	6.E-13 5/	-	/BS/
Cm-249	-	6.E-06 5/	-	/BS/
Bk-245	-	5.E-07	-	/St/
Bk-246	-	1.E-06	-	/St/
Bk-247	-	2.E-12	-	/BS/
Bk-249	-	9.E-10	-	/BS/
Bk-250	-	2.E-07	-	/BS/
Cf-244	-	2.E-07 5/	2.E-07 5/	/St/St
Cf-246	-	4.E-09 5/	4.E-09 5/	/St/St
Cf-248	-	4.E-11 5/	5.E-11 5/	/BS/St
Cf-249	-	2.E-12 5/	6.E-12 5/	/BS/BS
Cf-250	-	5.E-12 5/	1.E-11 5/	/BS/St

Radionuclide	Inhaled Air - Lung Retention Class D (µCi/mL)	W (µCi/mL)	Y (µCi/mL)	Stochastic or Organ1/ (D / W / Y)
Cf-251	-	2.E-12 3/	5.E-12 3/	/BS/BS
Cf-252	-	1.E-11 3/	2.E-11 3/	/BS/St
Cf-253	-	8.E-10 3/	7.E-10 3/	/St/St
Cf-254	-	9.E-12 3/	7.E-12 3/	/St/St
Es-250	-	3.E-07	-	/BS/
Es-251	-	4.E-07	-	/BS/
Es-253	-	6.E-10	-	/St/
Es-254m	-	4.E-09	-	/St/
Es-254	-	4.E-11	-	/BS/
Fm-252	-	6.E-09	-	/St/
Fm-253	-	4.E-09	-	/St/
Fm-254	-	4.E-08	-	/St/
Fm-255	-	9.E-09	-	/St/
Fm-257	-	1.E-10	-	/E /
Md-257	-	4.E-08	-	/St/
Md-258	-	1.E-10	-	/BS/

1/ A determination of whether the DACs are controlled by stochastic (St) or nonstochastic (organ) dose, or if they both give the same result (E) for each lung retention class is given in this column. The key to the organ notation for nonstochastic dose is: BS = Bone surface, K = Kidney, L = Liver, SW = Stomach wall, and T = Thyroid. A blank indicates that no calculations are performed for the lung retention class shown.

2/ The ICRP identifies tritiated water and carbon as having immediate uptake and distribution; therefore no solubility classes are designated. For purposes of this table, the DAC values are shown as being constant, independent of solubility class. For tritiated water, the inhalation DAC values allow for an additional 50% absorption through the skin, as described in ICRP Publication No. 30: Limits for Intakes of Radionuclides by Workers. For elemental tritium, the DAC values are based solely on consideration of the dose-equivalent rate to the tissues of the lung from inhaled tritium gas contained within the lung, without absorption in the tissues.

3/ A dash indicates no values given for this data category.

4/ These values are appropriate for protection from radon combined with its short-lived daughters and are based on information given in ICRP Publication 32: Limits for Inhalation of Radon Daughters by Workers and Federal Guidance Report No. 11: Limiting Values of Radionuclide Intake and Air Concentrations, and Dose Conversion Factors for Inhalation, Submersion, and Ingestion (EPA 520/1-88-020). The values given are for 100% equilibrium concentration conditions of the radon daughters with the parent. To allow for an actual measured equilibrium concentration or a demonstrated equilibrium concentration, the values given in this table should be multiplied by the ratio (100%/actual %) or (100%/demonstrated %), respectively. Alternatively, the DAC values for Rn-220 and Rn-222 may be replaced by 1 WL* and 1/3 WL,* respectively, for appropriate limiting of daughter concentrations. Because of the dosimetric considerations for radon, no f_1 or lung clearance values are listed.

* A "Working Level" (WL) is any combination of short-lived radon daughters, in one liter of air without regard to the degree of equilibrium, that will result in the ultimate emission of 1.3 E+05 MeV of alpha energy.

5/ For the calculations, f_1 values were obtained from ICRP Publication 48: The Metabolism of Plutonium and Related Elements. It is assumed that the effective dose equivalents for inhalation are unchanged even though the f_1 values have changed. This is because the contribution to organ dose from inhalation is dependent mainly on transfer from lung to blood when f_1 values are small. Also, the gastrointestinal tract dose would be unchanged because the fraction of activity passing through the tract is $(1.0 - f_1)$.

APPENDIX C

CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

(From NUREG 8.29, Instruction Concerning Risks From Occupational Radiation Exposure, July 1981. U.S. Nuclear Regulatory Commission.)

APPENDIX C

CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

This instructional material is intended to provide the best available information concerning what is currently known about the health risks from exposure to ionizing radiation. A question and answer format has been used. The questions were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training. Risk estimates have been compiled from numberous sources generally recognized as reliable. A bibliography is included for the user interested in further study.

The biological effects that are known to occur after exposure to high doses (hundreds of rems[2]) of radiation are discussed early in the document; discussions of the estimated risks from the low occupational dose (<5 rems per year) follow. It is intended that this information will help develop an attitude of healthy respect for the risks associated with radiation, rather than unnecessary fear or lack of concern. Additional guidance is being or will be developed concerning other topics in radiation protection training.

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1. What is meant by risk?

Risk can be defined in general as the probability (chance) of injury, illness, or death resulting from some activity. However, the perception of risk is affected by how the individual views its probability and its severity. The intent of this document is to provide estimates of and explain the basis for possible risk of injury, illness, or death resulting from occupational radiation exposure. (See Questions 9 and 10 for estimates of radiation risk and comparisons with other types of risk.)

2. What are the possible health effects of exposure to radiation?

Some of the health effects that exposure to radiation may cause are cancer (including leukemia), birth defects in the future children of exposed parents, and cataracts.[3] These effects (with the exception of genetic effects) have been observed in studies of medical radiologists, uranium miners, radium workers, and radiotherapy patients who have received large doses of radiation. Studies of people exposed to radiation from atomic weapons have also provided data on radiation effects. In addition, radiation effects studies with laboratory animals have provided a large body of data on radiation-induced health effects, including genetic effects.

The observations and studies mentioned above, however, involve levels of radiation exposure that are much higher (hundreds of rems) than those permitted occupationally today (<5 rems per year). Although studies have not shown a cause-effect relationship between health effects and current levels of occupational radiation exposure, it is prudent to assume that some health effects do occur at the lower exposure levels.

3. What is meant by prompt effects, delayed effects, and genetic effects?

a. Prompt effects are observable shortly after receiving a very large dose in a short period of time. For example, a whole-body[4] dose of 450 rems (90 times the annual dose limit for routine occupational exposure) in an hour to an average adult will cause vomiting and diarrhea within a few hours; loss of hair, fever, and weight loss within a few weeks; and about a 50 percent chance of death within 60 days without medical treatment.

b. Delayed effects such as cancer may occur years after exposure to radiation.

c. Genetic effects can occur when there is radiation damage to the genetic material. These effects may show up as birth defects or other conditions in the future children of the exposed individual and succeeding generations, as demonstrated in animal experiments. However, excess genetic effects clearly caused by radiation have not been observed in human populations exposed to radiation. It has been observed, however, that radiation can change the genes in cells of the human body. Thus, the possibility exists that genetic effects can be caused in humans by low doses even though no direct evidence exists as yet.

4. In worker protection, which effects are of most concern to the NRC?

The main concern to the NRC is the delayed incidence of cancer. The chance of delayed cancer is believed to depend

[1] Ionizing radiation consists of energy or small particles such as gamma, beta, or alpha radiation emitted from radioactive materials which, when absorbed by living tissue, can cause chemical and physical damage.

[3] Cataracts differ from other radiation effects in that a certain level of dose to the lens of the eye (~300 rems) is required before they are observed.

on how much radiation exposure a person gets; therefore, every reasonable effort should be made to keep exposures low.

Immediate or prompt effects are very unlikely since large exposures would normally occur only if there were a serious radiation accident. Accident rates in the radiation industry have been low, and only a few accidents have resulted in exposures exceeding the legal limits. The probability of serious genetic effects in the future children of workers is estimated in the BEIR[5] report, based on animal studies, at less than one-third that of delayed cancer (5-65 genetic effects per million rems compared to 160-450 cancer cases). A clearer understanding of the cause-effect relationship between radiation and human genetic effects will not be possible until additional research studies are completed.

5. What is the difference between acute and chronic exposure?

Acute radiation exposure, which causes prompt effects and may also cause delayed effects, usually refers to a large dose of radiation received in a short period of time; for example, 450 rems received within a few hours or less. The effects of acute exposures are well known from studies of radiotherapy patients, some of whom received whole-body doses; atomic bomb victims; and the few accidents that have occurred in the early days of atomic weapons and reactor development, industrial radiography, and nuclear fuel processing. There have been few occupational incidents that have resulted in large exposures. NRC data indicate that, on the average, 1 accidental overexposure in which any acute symptoms are observed occurs each year. Most of these occur in industrial radiography and involve exposures of the hands rather than the whole body.

Chronic exposure, which may cause delayed effects but not prompt effects, refers to small doses received repeatedly over long time periods; for example, 20-100 mrem (a mrem is one-thousandth of a rem) per week every week for several years. Concern with occupational radiation risk is primarily focused on chronic exposure to low levels of radiation over long time periods.

6. How does radiation cause cancer?

How radiation causes cancer is not well understood. It is impossible to tell whether a given cancer was caused by radiation or by some other of the many apparent causes. However, most diseases are caused by the interaction of several factors. General physical condition, inherited traits, age, sex, and exposure to other cancer-causing agents such as cigarette smoke are a few possible contributing factors. One theory is that radiation can damage chromosomes in a cell, and the cell is then directed along abnormal growth patterns. Another is that radiation reduces the body's normal resistance to existing viruses which can then multiply and damage cells. A third is that radiation activates an existing virus in the body which then attacks normal cells causing them to grow rapidly.

What is known is that, in groups of highly exposed people, a higher than normal incidence of cancer is observed. Higher than normal rates of cancer can also be produced in laboratory animals by high levels of radiation. An increased incidence of cancer has not been demonstrated at radiation levels below the NRC limits.

7. If I receive a radiation dose, does that mean I am certain to get cancer?

Not at all. Everyone gets a radiation dose every day (see Question 25), but most people do not get cancer. Even with doses of radiation far above legal limits, most individuals will experience no delayed consequences. There is evidence that some radiation damage can be repaired. The danger from radiation is much like the danger from cigarette smoke. Only a fraction of the people who breathe cigarette smoke get lung cancer, but there is good evidence that smoking increases a person's chances of getting lung cancer. Similarly, there is evidence that the larger the radiation dose, the larger the increase in a person's chances of getting cancer.

Radiation is like most substances that cause cancer in that the effects can be seen clearly only at high doses. Estimates of the risks of cancer at low levels of exposure are derived from data available for exposures at high dose levels and high dose rates. Generally, for radiation protection purposes these estimates are made using the linear model (Curve 1 in Figure 1). We have data on health effects at high doses as shown by the solid line in Figure 1. Below about 100 rems, studies have not been able to accurately measure the risk, primarily because of the small numbers of exposed people and because the effect is small compared to differences in the normal incidence from year to year and place to place. Most scientists believe that there is some degree of risk no matter how small the dose (Curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (Curve 3), the threshold effect. A few believe that risk levels off so that even very small doses imply a significant risk (Curve 4). The majority of scientists today endorse either the linear model (Curve 1) or the linear-quadratic model (Curve 2). The NRC endorses the linear model (Curve 1), which shows the number of effects decreasing as the dose decreases, for radiation protection purposes.

It is prudent to assume that smaller doses have some chance of causing cancer. This is as true for natural cancer-causers such as sunlight and natural radiation as it is for those that are man made such as cigarette smoke, smog, and man-made radiation. As even very small doses may entail some small risk, it follows that no dose should be taken without a reason. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory

[5] The National Academy of Sciences established a committee on the Biological Effects of Ionizing Radiation (BEIR) whose 1980 report on the effects on populations of exposure to low levels of ionizing radiation provides much of the background for this guide.

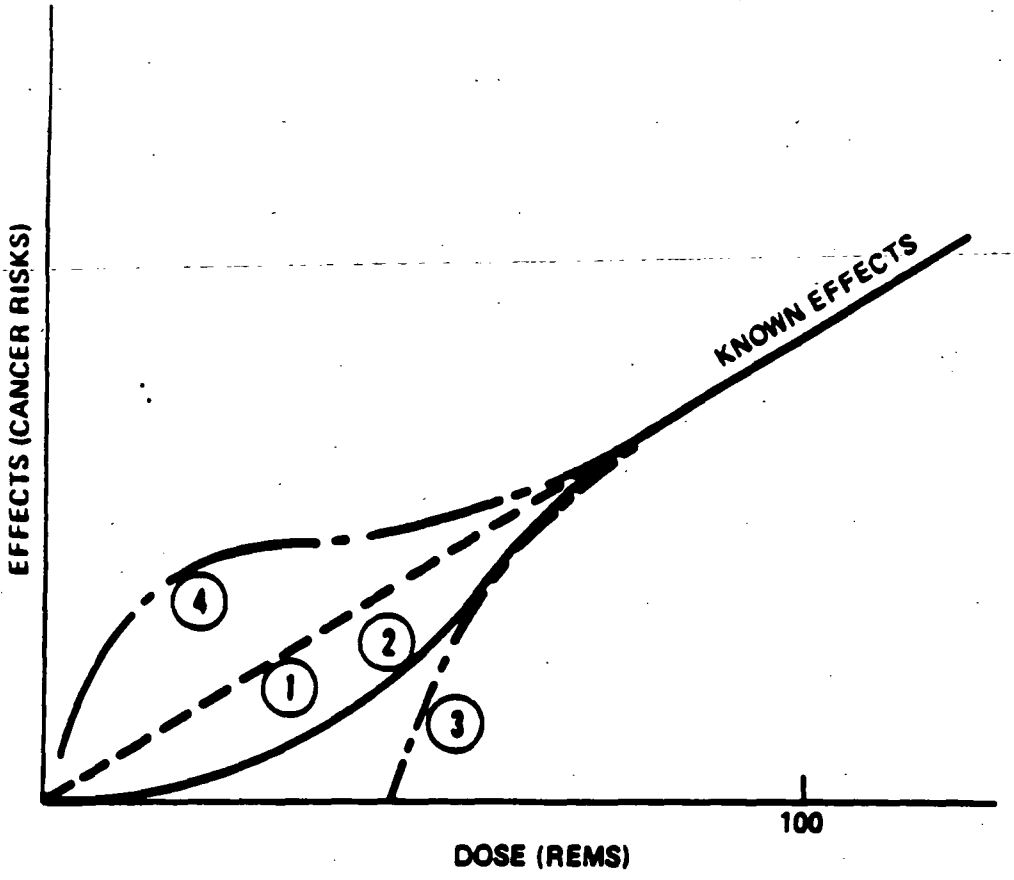

Figure 1. Some proposed models for how the effects of radiation vary with doses at low levels.

limits; doses should be kept as low as is reasonably achievable (ALARA).

We don't know exactly what the chances are of getting cancer from a low-level radiation dose, but we can make estimates based on extensive scientific knowledge. The estimates of radiation risks are at least as reliable as estimates for the effects from any chemical hazard. Being exposed to typical occupational radiation doses is taking a chance, but that chance is reasonably well understood.

It is important to understand the probability factors here. A similar question would be: If you select one card from a full deck, will you get the ace of spades? This question cannot be answered with a simple yes or no. The best answer is that your chances are 1 in 52. However, if 1000 people each select one card from full decks, we can predict that about 20 of them will get an ace of spades. Each person will have 1 chance in 52 of drawing the ace of spades, but there is no way that we can predict which persons will get the right card. The issue is further complicated by the fact that in 1 drawing by 1000 people, we might get only 15 successes and in another perhaps 25 correct cards in 1000 draws. We can say that if you receive a radiation dose, you will have increased your chances of eventually developing cancer. It is assumed that the more radiation exposure you get, the more you increase your chances of cancer.

Not all workers incur the same level of risk. The radiation risk incurred by a worker depends on the amount of dose received. Under the linear model explained above, a worker who receives 5 rems in a year incurs 10 times as much risk as another worker (the same age) who receives only 0.5 rem. The risk depends not only on the amount of dose, but also on the age of the worker at the time the dose is received. This age difference is due, in part, to the fact that a young worker has more time to live than an older worker, and the risk is believed to depend on the number of years of life following the dose. The more years left, the larger the risk. It should be clear that, even within the regulatory dose limits, the risk may vary a great deal from one worker to another. Fortunately, only a very few workers receive doses near 5 rems per year; as pointed out in the answer to Question 19, the average annual dose for all radiation workers is less than 0.5 rem.

A reasonable comparison involves exposure to the sun's rays. Frequent short exposures provide time for the skin to repair. An acute exposure to the sun can result in painful burning, and excessive exposure has been shown to cause skin cancer. However, whether exposure to the sun's rays is short term or spread over time, some of the injury is not repaired and may eventually result in skin cancer.

The effect upon a group of workers occupationally exposed to radiation may be an increased incidence of cancer over and above the number of cancers that would normally be expected in that group. Each exposed individual has an increased probability of incurring subsequent cancer. We can say that if 10,000 workers each receive an additional 1 rem in a year, that group is more likely to have a larger incidence of cancer than 10,000 people who do not receive the additional radiation. An estimate of the increased probability of cancer from low radiation doses delivered to large groups is one measure of occupational risk and is discussed in Question 9.

8. What groups of expert scientists have studied the risk from exposure to radiation?

In 1956, the National Academy of Sciences established advisory committees to consider radiation risks. The first of these was the Advisory Committee on the Biological Effects of Atomic Radiations (BEAR) and more recently it was renamed the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR). These committees have periodically reviewed the extensive research being done on the health effects of ionizing radiation and have published estimates of the risk of cancer from exposure to radiation (1972 and 1980 BEIR reports). The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) are two other groups of scientists who have studied radiation effects and published risk estimates (ICRP Publication 26, 1977). These two groups have no government affiliation. In addition, the United Nations established an independent study group that published an extensive report in 1977, including estimates of cancer risk from ionizing radiation (UNSCEAR, 1977).

Several individual research groups or scientists such as Alice Stewart, E.S. Gilbert, T.F. Mancuso, T.W. Anderson, to name a few, have published studies concerning low-level radiation effects. The bibliography to this appendix includes several articles for the reader who wishes to do further study. The BEIR-80 report includes analysis of the work of many independent researchers.

9. What are the estimates of the risk of cancer from radiation exposure?

The cancer risk estimates (developed by the organizations identified in Question 8) are presented in Table 1.

In an effort to explain the significance of these estimates, we will use an approximate average of 300 excess cancer cases per million people, each exposed to 1 rem of ionizing radiation. If in a group of 10,000 workers each receives 1 rem, we could estimate that three would develop cancer because of that exposure, although the actual number could be more or less than three.

TABLE 1

Estimates of Excess Cancer Incidence from Exposure to Low-Level Radiation

Source	Number of Additional[a] Cancers Estimated to Occur in 1 Million People After Exposure of Each to 1 Rem of Radiation
BEIR, 1980	160-450[b]
ICRP, 1977	200
UNSCEAR, 1977	150-350

[a] Additional means above the normal incidence of cancer.

[b] All three groups estimated premature deaths from radiation-induced cancers. The American Cancer Society has recently stated that only about one-half of all cancer cases are fatal. Thus, to estimate incidence of cancer, the published numbers were multiplied by 2. Note that the three groups are in close agreement on the risk of radiation-induced cancer.

The American Cancer Society has reported that approximately 25 percent of all adults in the 20- to 65-year age bracket will develop cancer at some time from all possible causes such as smoking, food, alcohol, drugs, air pollutants, and natural background radiation. Thus in any group of 10,000 workers not exposed to radiation on the job, we can expect about 2,500 to develop cancer. If this entire group of 10,000 workers were to receive an occupational radiation dose of 1 rem each, we could estimate that three additional cases might occur which would give a total of about 2,503. This means that a 1-rem dose to each of 10,000 workers might increase the cancer rate from 25 percent to 25.03 percent, an increase of about 3 hundredths of one percent.

As an individual, if your cumulative occupational radiation dose is 1 rem, your chances of eventually developing cancer during your entire lifetime may have increased from 25 percent to 25.03 percent. If your lifetime occupational dose is 10 rems, we could estimate a 25.3 percent chance of developing cancer. Using a simple linear model, a lifetime dose of 100 rems may have increased your chances of cancer from 25 to 28 percent.

The normal chance of developing cancer if you receive no occupational radiation dose is about equal to your chance of getting any spade on a single draw from a full deck of playing cards, which is one chance out of four. The additional chance of developing cancer from an occupational exposure of 1 rem is less than your chances of drawing an ace from a full deck of cards three times in a row.

Since cancer resulting from exposure to radiation usually occurs 5 to 25 years after the exposure and since not all cancers are fatal, another useful measure of risk is years of

life expectancy lost on the average from a radiation-induced cancer. It has been estimated in several studies that the average loss of life expectancy from exposure to radiation is about 1 day per rem of exposure. In other words, a person exposed to 1 rem of radiation may, on the average, lose 1 day of life. The words "on the average" are important, however, because the person who gets cancer from radiation may lose several years of life expectancy while his coworkers suffer no loss. The ICRP estimated that the average number of years of life lost from fatal industrial accidents is 30 while the average number of years of life lost from a fatal radiation-induced cancer is 10. The shorter loss of life expectancy is due to the delayed onset of cancer.

It is important to realize that these risk numbers are only estimates. Many difficulties are involved in designing research studies that can accurately measure the small increases in cancer cases due to low exposures to radiation as compared to the normal rate of cancer. There is still uncertainty and a great deal of controversy with regard to estimates of radiation risk. The numbers used here result from studies involving high doses and high dose rates, and they may not apply to doses at the lower occupational levels of exposure. The NRC and other agencies both in the United States and abroad are continuing extensive long-range research programs on radiation risk.

Some members of the National Academy of Sciences BEIR Advisory Committee and others feel that risk estimates in Table 1 are higher than would actually occur and represent an upper limit on the risk. Other scientists believe that the estimates are low and that the risk could be higher. However, these estimates are considered by the NRC staff to be the best available that the worker can use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should make every effort to keep exposure to radiation ALARA to avoid unnecessary risk. The worker, after all, has the first line responsibility for protecting himself from radiation hazards.

10. How can we compare radiation risk to other kinds of health risks?

Perhaps the most useful unit for comparison among health risks is the average number of days of life expectancy lost per unit of exposure to each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from apparent causes, and estimating the number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total group observed.

Several studies have compared the projected loss of life expectancy resulting from exposure to radiation with other health risks. Some representative numbers are presented in Table 2.

These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.

TABLE 2

Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Natural background radiation, calculated	8
Medical diagnostic x-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose, calculated (industry average for the higher-dose job categories is 0.65 rem/yr)	1
1 rem/yr for 30 years, calculated	30

[a]Adapted from Cohen and Lee, "A Catalogue of Risks," *Health Physics*, Vol. 36, June 1979.

A second useful comparison is to look at estimates of the average number of days of life expectancy lost from exposure to radiation and from common industrial accidents at radiation-related facilities and to compare this number with days lost from other occupational accidents. Table 3 shows average days of life expectancy lost as a result of fatal work-related accidents. Note that the data for occupations other than radiation related do not include death risks from other possible hazards such as exposure to toxic chemicals, dusts, or unusual temperatures. Note also that the unlikely occupational exposure at 5 rems per year for 50 years, the maximum allowable risk level, may result in a risk comparable to the average risks in mining and heavy construction.

Industrial accident rates in the nuclear industry and related occupational areas have been relatively low during the entire history of the industry (see Table 4). This is believed to be due to the early and continuing emphasis on tight safety controls. The relative safety of various occupational areas can be seen by comparing the probability of death by accident per 10,000 workers over a 40-year working lifetime. These figures do not include death from possible causes such as exposure to toxic chemicals or radiation.

11. Can a worker become sterile or impotent from occupational radiation exposure?

Observation of radiation therapy patients who receive localized exposures, usually spread over a few weeks, has

TABLE 3

Estimated Loss of Life Expectancy from Industrial Hazards[5]

Industry Type	Estimates of Days of Life Expectancy Lost, Average
All industry	74
Trade	30
Manufacturing	43
Service	47
Government	55
Transportation and utilities	164
Agriculture	277
Construction	302
Mining and quarrying	328
Radiation accidents, death from exposure	<1
Radiation dose of 0.65 rem/yr (industry average) for 30 years, calculated	20
Radiation dose of 5 rems/yr for 50 years	250
Industrial accidents at nuclear facilities (nonradiation)	58

[5]Adapted from Cohen and Lee, "A Catalogue of Risk," *Health Physics*, Vol. 36, June 1979; and World Health Organization, *Health Implications of Nuclear Power Production*, December 1975.

TABLE 4

Probability of Accidental Death by Type of Occupation[6]

Occupation	Number of Accidental Deaths for 10,000 Workers for 40 Years
Mining	252
Construction	228
Agriculture	216
Transportation and public utilities	116
All industries	56
Government	44
Nuclear industry (1975 data excluding construction)	40
Manufacturing	36
Services	28
Wholesale and trade	24

[6]Adapted from National Safety Council, *Accident Facts*, 1979; and Atomic Energy Commission, *Operational Accidents and Radiation Exposure Experience*, WASH-1192, 1975.

shown that a dose of 500-800 rems to the gonads can produce permanent sterility in males or females (an acute whole-body dose of this magnitude would probably result in death within 60 days). An acute dose of 20 rems to the testes can result in a measurable but temporary reduction in sperm count. Such high exposures on the job could result only from serious and unlikely radiation accidents. Although high doses of radiation can affect fertility, they have no effect on the ability to function sexually. Likewise, exposure to permitted occupational levels of radiation has no observed effect on fertility and also has no effect on the ability to function sexually.

12. What are the NRC external radiation dose limits?

Federal regulations currently limit occupational external whole-body radiation dose to 1¼ rems in any calendar quarter or specified 3-month period. However, when there is documented evidence that a worker's previous occupational dose is low enough, a licensee may permit a dose of up to 3 rems per quarter or 12 rems per year. The accumulated dose may not exceed 5(N - 18) rems[6] where N is the person's age in years, i.e., the lifetime occupational dose may not exceed an average of 5 rems for each year above the age of 18.

An additional whole-body dose of approximately 5 rems per year is permitted from internal exposure. (See Question 28.)

13. What is meant by ALARA?

In addition to providing an upper limit on a person's permissible radiation exposure, the NRC also requires that its licensees maintain occupational exposures as far below the limit as is reasonably achievable (ALARA). This means that every activity at a nuclear facility involving exposure to radiation should be planned so as to minimize unnecessary exposure to individual workers and also to the worker population. A job that involves exposure to radiation should be scheduled only when it is clear that the benefit justifies the risks assumed. All design, construction, and operating procedures should be reviewed with the objective of reducing unnecessary exposures.

14. Has the ALARA concept been applied if, instead of reaching dose limits during the first week of a quarter, the worker's dose is spread out over the whole quarter?

No. For radiation protection purposes, the risk of cancer from low doses is assumed to be proportional to the amount of exposure, not the rate at which it is received. Thus it is assumed that spreading the dose out over time or over larger numbers of people does not reduce the overall risk. The ALARA concept has been followed only when the individual and collective doses are reduced by reducing the time of exposure or decreasing radiation levels in the

[6]The NRC has published a proposed rule change for public comment that would eliminate the 5(N-18) formula. This proposal is currently under consideration by a task force reviewing all of 10 CFR Part 20. Recent EPA guidance recommends eliminating the 5(N-18) formula. If adopted, the maximum allowed annual dose will be 5 rems rather than 12.

individual and collective doses are reduced by reducing the time of exposure or decreasing radiation levels in the working environment.

15. What is meant by collective dose and why should it be maintained ALARA?

Nuclear industry activities expose an increasing number of people to occupational radiation in addition to the radiation doses they receive from natural background radiation and medical radiation exposures. The collective occupational dose (person-rems) is the sum of all occupational radiation exposure received by all the workers in an entire worker population. For example, if 100 workers each receive 2 rems, the individual dose is 2 rems and the collective dose is 200 person-rems. The total additional risk of cancer and genetic effects in an exposed population is assumed to depend on the collective dose.

It should be noted that, from the viewpoint of risk to a total population, it is the collective dose that must be controlled. For a given collective dose, the number of health effects is assumed to be the same even if a larger number of people share the dose. Therefore, spreading the dose out may reduce the individual risk, but not that of the population.

Efforts should be made to maintain the collective dose ALARA so as not to unnecessarily increase the overall population incidence of cancer and genetic effects.

16. Is the use of extra workers a good way to reduce risks?

There is a "yes" answer to this question and a "no" answer. For a given job involving exposure to radiation, the more people who share the work, the lower the average dose to an individual. The lower the dose, the lower the risk. So, for you as an individual, the answer is "yes."

But how about the risk to the entire group of workers? Under assumptions used by the NRC for purposes of protection, the risk of cancer depends on the total amount of radiation energy absorbed by human tissue, not on the number of people to whom this tissue belongs. Therefore, if 30 workers are used to do a job instead of 10, and if both groups get the same collective dose (person-rems), the total cancer risk is the same, and nothing was gained for the group by using 30 workers. From this viewpoint the answer is "no." The risk was not reduced but simply spread around among a larger number of persons.

Unfortunately, spreading the risk around often results in a larger collective dose for the job. Workers are exposed as they approach a job, while they are getting oriented to do the job, and as they withdraw from the job. The dose received during these actions is called nonproductive. If several crew changes are required, the nonproductive dose can become very large. Thus it can be seen that the use of extra workers may actually increase the total occupational dose and the resulting collective risks.

The use of extra workers to comply with NRC dose limits is not the way to reduce the risk of radiation-induced cancer for the worker population. At best, the total risk remains the same, and it may even be increased. The only way to reduce the risk is to reduce the collective dose; that can be done only by reducing the radiation levels, the working times, or both.

17. Why doesn't the NRC impose collective dose limits?

Compliance with individual dose limits can be achieved simply by using extra workers. However, compliance with a collective dose limit (such as 100 person-rems per year for a licensee) would require reduction of radiation levels, working times, or both. But there are many problems associated with setting appropriate collective dose limits.

For example, we might consider applying a single collective dose limit to all licensees. The selection of such a collective dose limit would be almost impossible because of the wide variations in collective doses among licensees. A power reactor could reasonably be expected to have an average annual collective dose of several hundred person-rems. However, a small industrial radiography licensee could very well have a collective dose of only a few person-rems in a year.

Even choosing a collective dose limit for a group of similar licensees would be almost as difficult. Radiography licensees as a group had an average collective dose in 1977 of 9 person-rems. However, the smallest collective dose for a radiography licensee was less than 1 person-rem, and the largest was 401 person-rems.

Setting a reasonable collective dose limit for each individual licensee would also be very difficult. It would require a record of all past collective doses on which to base such limits. Setting an annual collective dose limit would then amount to an attempt to predict a reasonable collective dose for each future year. In order to do this, it would be necessary to be able to predict changes in each licensed activity that would increase or decrease the collective dose. In addition, annual collective doses vary significantly from year to year according to the kind and amount of maintenance required, which cannot generally be predicted in advance. Following all such changes and revising limits up and down would be very difficult if not impossible. However, these efforts would be necessary if a collective dose limit were to be reasonable and help minimize doses and risks.

18. How are radiation dose limits established?

The NRC establishes occupational radiation dose limits based on guidance to Federal agencies from the Environmental Protection Agency (EPA) and, in addition, considers NCRP and ICRP recommendations. Scientific reviews of research data on biological effects such as the BEIR report are also considered.

For example, recent EPA guidance recommended that the annual whole-body dose limit be established at 5 rems per year and indicated that exposure, year after year, to 5 rems would involve a risk to a worker comparable to the average risks incurred by workers in the higher risk jobs

such as mining. In fact, few workers ever reach such a limit, much less year after year, and the risks associated with actual exposures are considered by the EPA to be comparable to the safer job categories. A 5-rem-per-year limit would allow occasional high dose jobs to be done without excessive risk.

19. What are the typical radiation doses received by workers?

The NRC requires that certain categories of licensees report data on annual worker doses and doses for all workers who leave employment with licensees. Data were received on the occupational doses in 1977 of approximately 100,000 workers in power reactors, industrial radiography, fuel processing and fabrication facilities, and manufacturing and distribution facilities. Of this total group, 85 percent received an annual dose of less than 1 rem; 95 percent received less than 2 rems; fewer than 1 percent exceeded 5 rems in 1 year. The average annual dose of those workers who were monitored and had measurable exposures was about 0.65 rem. A study completed by the EPA, using 1975 exposure data for 1,260,000 workers, indicated that the average annual dose for all workers who received a measurable dose was 0.34 rem.

Table 5 lists average occupational exposures for workers (persons who had measurable exposure above background levels) in various occupations, based on the 1975 data.

TABLE 5

U.S. Occupational Exposure Estimates[a]

Occupational Subgroup	Average Whole-Body Dose (millirems)	Collective Dose (person-rems)
Medicine	320	51,400
Industrial Radiography	580	5,700
Source Manufacturing	630	2,500
Power Reactors	760	21,400
Fuel Fabrication and Reprocessing	560	3,100
Uranium Enrichment	70	400
Nuclear Waste Disposal	920	100
Uranium Mills	380	760
Department of Energy Facilities	300	11,800
Department of Defense Facilities	180	10,100
Educational Institutions	206	1,500
Transportation	200	2,300

[a] Adapted from Cook and Nelson, *Occupational Exposures to Ionizing Radiation in the United States: A Comprehensive Summary for 1975*, Draft, Environmental Protection Agency.

20. What happens if a worker exceeds the quarterly exposure limit?

Radiation protection limits, such as 3 rems in 3 months, are not absolute limits below which it is safe and above which there is danger. Exceeding a limit does not imply that you have suffered an injury. A good comparison is with the highway speed limit, which is selected to limit accident risk and still allow you to get somewhere. If you drive at 75 mph, you increase your risk of an auto accident to levels that are not considered acceptable by the people who set speed limits, even though you may not actually have an accident. If a worker's radiation dose repeatedly exceeds 3 rems in a quarter, the risk of health effects could eventually increase to a level that is not considered acceptable to the NRC. Exceeding an NRC protection limit does not mean that any adverse health effects are going to occur. It does mean that a licensee's safety program has failed in some respect and that the NRC and the licensee should investigate to make sure the problems are corrected.

If an overexposure occurs, the regulations prohibit any additional occupational exposure to that person during the remainder of the calendar quarter in which the overexposure occurred. The licensee is required to file an overexposure report to the NRC and may possibly be subject to a fine, just as you are subject to a traffic fine for exceeding the speed limit. In both cases, the fines and, in some serious or repetitive cases, suspension of license are intended to encourage efforts to operate within the limits. The safest limits would be 0 mph and 0 rem per quarter. But then we wouldn't get anywhere.

21. Why do some facilities establish administrative limits that are below the NRC limits?

There are two reasons. First, the NRC regulations state that licensees should keep exposures to radiation ALARA. By requiring specific approval for worker doses in excess of set levels, more careful risk-benefit analysis can be made as each additional increment of dose is approved for a worker. Secondly, a facility administrative limit that is set lower than the quarterly NRC limit provides a safety margin designed to help the licensee avoid overexposures.

22. Several scientists have suggested that NRC limits are too high and should be lowered. What are the arguments for lowering the limits?

In general, those critical of present dose limits say that the individual risk is higher than is estimated by the BEIR Committee, the ICRP, and UNSCEAR. Based on studies of low-level exposures to large groups, some researchers have concluded that a given dose of radiation may be more likely to cause biological effects than previously thought. Some of these studies are listed in the bibliography (Mancuso, Archer) and the BEIR-80 report includes a section analyzing the findings of these and other studies. Scientific opinion differs on the validity of the research methods used and the methods of statistical analysis. The problem is that the expected additional incidence of radiation-caused effects such as cancer is difficult to detect in comparison with the much larger normal incidence. It cannot be shown without question that these effects were more frequent in the exposed study group than in the unexposed group used for comparison, or that the observed effects were caused

by radiation. The BEIR committee concluded that claims of higher risk had "no substance."

The NRC staff continually reviews the results of research on radiation risks. With respect to large-scale studies of radiation-induced health effects in human populations exposed to low-level ionizing radiation, the NRC and EPA have recently concluded that there is no one population group available for which such a study could be expected to provide a more meaningful estimate of the low-level radiation risk. This is due, in large part, to the observed and estimated low incidence of radiation health effects from low doses. However, the results of ongoing studies, such as that on nuclear shipyard workers, will be carefully reviewed and the development of a radiation-worker registry is being considered as a possible data base for future studies.

23. What are the reasons for not lowering the NRC dose limits?

Assuming that the 5-rem-per-year limit is adopted, there are three reasons:

a. Health risks are already low.

The estimated health risks associated with current average occupational radiation doses (e.g., 0.5 rem/yr for 50 years) are comparable to or less than risk levels in other occupational areas considered to be among the safest. If a person were exposed to the maximum of 5 rems per year for 50 years, which virtually never occurs, he or she might incur a risk comparable to the average risks in mining and heavy construction. An occasional 5-rem annual dose might be necessary to allow some jobs to be done without a significant increase in the collective dose. If the dose limits were lowered significantly, the number of people required to complete many jobs would increase. The collective dose would then increase since more individuals would be receiving nonproductive exposure while entering and leaving the work area and preparing for the job. The total number of health effects might go up as the collective dose increased.

b. The current regulations are considered sound.

The regulatory standards for dose limits are based on the recommendations of the Federal Radiation Council. At the time these standards were developed, about 1960, it was considered unlikely that exposure to these levels during a working lifetime would result in clinical evidence of injury or disease different from that occurring in the unexposed population. The scientific data base for the standards consisted primarily of human experience (x-ray exposures to medical practitioners and patients, ingestion of radium by watch dial painters, early effects observed in Japanese atomic bomb survivors, radon exposures of uranium miners, occupational radiation accidents) involving very large doses delivered at high dose rates. The data base also included the results of a large number of animal experiments involving high doses and dose rates. The animal experiments were particularly useful in the evaluation of genetic effects. The observed effects were related to low-level radiation according to the linear model explained in Question 7. Based on this approach, the regulations in 10 CFR Part 20, "Standards for Protection Against Radiation," also state that licensees should maintain all radiation exposures, and releases of radioactive materials in effluents, as low as is reasonably achievable. More recent scientific reviews of the large body of experimental data, such as the BEIR-80 and the recent EPA guidance, continue to support the view that use of a 5-rem-per-year limit is acceptable in practice. Experience has shown that, under this limit, the average dose to workers is near 0.5 rem/yr with very few workers consistently approaching the limit.

c. There is little to gain.

Reducing the dose limits, for example, to 0.5 rem/yr has been analyzed by the NRC staff. An estimated 2.6 million person-rems could be saved from 1980 through the year 2000 by nuclear power plant licensees if compliance with the new limit were achieved by lowering the radiation levels, working times, or both, rather than by using extra workers. It is estimated that something like $23 billion would be spent toward this purpose. Spending $23 billion to save 2.6 million person-rems would amount to spending $30 to $90 million to prevent each potential radiation-induced premature cancer death. Society considers this cost unacceptably high for individual protection.

24. Are there any areas of concern about radiation risks that might result in changing the NRC dose limits?

Yes. Three areas of concern to the NRC staff are specifically identified below:

a. An independent study by Rossi and Mays and other biological research have indicated that a given dose of neutron radiation may be more likely to cause biological effects than was previously thought. Other recent studies cast doubt on the issue. The NCRP is currently studying the data related to the neutron radiation question and is expected to make recommendations as to whether neutron dose limits should be changed. Although the scientific community has not yet come to agreement on this question, workers should be advised of the possibility of higher risk when entering areas where exposure to neutrons will occur.

b. It has been known for some time that rapidly growing living tissue is more sensitive to injury from radiation than tissue in which the cells are not reproducing rapidly. Thus the embryo or fetus is more sensitive to radiation injury than an adult. The NCRP recommended in Report No. 39 that special precautions be taken when an occupationally exposed woman could be pregnant in order to protect the embryo or fetus. In 1975, the NRC issued Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure," in which it is recommended that licensees instruct all workers concerning this special risk. The guide recommends that all workers be advised that the NCRP recommended that the maximum permissible dose to the embryo or fetus from occupational exposure of the mother should not exceed 0.5 rem for the full 9-month pregnancy period. In addition, the guide suggests options

available to the female employee who chooses not to expose her embryo or fetus to this additional risk.

The United States Department of Health and Human Services is similarly concerned about prenatal exposure from medical x-rays. In 1979 they published proposed guidelines for physicians concerning abdominal x-rays for possibly pregnant women. The guidelines in effect encourage the x-ray staff to make efforts to determine whether a female patient is pregnant and to defer x-rays if possible until after the child is born.

c. Also of special interest is the indication that female workers are subject to more risk of cancer incidence than male workers. In terms of all types of cancer except leukemia, the BEIR-80 analysis indicates that female workers have a risk of developing radiation-induced cancer that is approximately one and one-half times that for males. This increased risk is primarily due to the incidence of breast and thyroid cancer in women. These types of cancer, however, have a high cure rate. Thus the difference between men and women in cancer mortality is not great. Incidence of radiation-induced leukemia is about the same for both sexes. Female workers should be aware of this difference in the risks of radiation-induced cancer in deciding whether or not to seek work involving exposure to radiation.

25. How much radiation does the average person who does not work in the nuclear industry receive?

We are all exposed from the moment of conception to ionizing radiation from several sources. Our environment, and even the human body, contains naturally occurring radioactive materials that contribute some of the background radiation we receive. Cosmic radiation originating in space and in the sun contributes additional exposure. The use of x-rays and radioactive materials in medicine and dentistry adds considerably to our population exposure.

Table 6 shows estimated average individual exposure in millirems from natural background and other sources.

TABLE 6

U.S. General Population Exposure Estimates (1978)[8]

Source	Average Individual Dose (mrem/yr)
Natural background (average in U.S.)	100
Release of radioactive material in natural gas, mining, milling, etc.	5
Medical (whole-body equivalent)	90
Nuclear weapons (primarily fallout)	5-8
Nuclear energy	0.28
Consumer products	0.03
Total	~200 mrem/yr

[8] Adapted from a report by the Interagency Task Force on the Health Effects of Ionizing Radiation published by the Department of Health, Education, and Welfare.

Thus, the average individual in the general population receives about 0.2 rem of radiation exposure each year from sources that are a part of our natural and man-made environment. By the age of 20 years, an individual has accumulated about 4 rems. The most likely target for reduction of population exposure is medical uses.

26. Why aren't medical exposures considered as part of a worker's allowed dose?

Equal doses of medical and occupational radiation have equal risks.[7] Medical exposure to radiation should be justified for reasons quite different, however, from those applicable to occupational exposure. A physician prescribing an x-ray should be convinced that the benefit to the patient of the resulting medical information justifies the risk associated with the radiation. Each worker must decide on the acceptance of occupational radiation risk just as each worker must decide on the acceptability of any other occupational hazard.

For another point of view, consider a worker who receives a dose of 2 rems from a series of x-rays or a radioactive medicine in connection with an injury or illness. This dose and the implied risk should be justified on medical grounds. If the worker had also received a dose of 2 rems on the job, the combined dose of 4 rems would not incapacitate the worker. A dose of 4 rems is not especially dangerous and is not large compared to the cumulative lifetime dose. Restricting the worker from additional job exposure during the remainder of the quarter would have no effect one way or the other on the risk from the 2 rems already received from medical exposure. If the individual worker accepts the risks associated with the x-rays on the basis of the medical benefits and the risks associated with job-related exposure on the basis of employment benefits, it would be unfair to restrict the individual from employment in radiation areas for the remainder of the quarter.

Some therapeutic medical doses such as those received from cobalt-60 treatment can range as high as 6000 rems to a small part of the body, spread over a period of several weeks or months.

27. What is meant by internal exposure?

The total radiation dose to the worker is the external dose (measured by the film badge and reported as "whole-body dose") plus the dose from internal emitters. The monitoring of the additional internal dose is difficult. Because there is the possibility of internal doses occurring, a good air-monitoring program should be established when warranted.

The uptake of radioactive materials by workers is generally due to breathing contaminated air. Radioactive materials may be present as fine dust or gases in the workplace atmosphere. The surfaces of equipment and workbenches

[7] It is likely that a significant portion of reported medical x-ray exposure is to parts of the body only. An exposure of 100 mrem to the whole body is more significant than a 100-mrem chest x-ray.

may be contaminated. Radioactive materials may enter the body by being breathed in, taken in with food or drink, or being absorbed through the skin, particularly if the skin is broken.

After entering the body, the radioactive material will migrate to particular organs or particular parts of the body depending on the biochemistry of the material. For example, uranium will tend to deposit in the bones where it will remain for a long time. It is slowly eliminated from the body, mostly by way of the kidneys. Radium will also tend to deposit in the bones. Radioactive iodine will seek out the thyroid glands (located in the neck) and deposit there.

The dose from these internal emitters cannot be measured either by the film badge or by other ordinary dosimeters carried by the worker. This means that the internal radiation dose must be separately monitored using other detection methods.

Internal exposure can be estimated by measuring the radiation emitted from the body or by measuring the radioactive materials contained in biological samples such as urine or feces. Dose estimates can also be made if one knows how much radioactive material is in the air and the length of time during which the air was breathed.

28. How are the limits for internal exposure set?

Standards have been established for the maximum permissible amount of each radionuclide that may be accumulated in the critical organs[8] of the worker's body.

Calculations are made to determine the quantity of radioactive material that has been taken into the body and the total dose that would result. Then, based on limits established for particular body organs similar to 1¼ rems in a calendar quarter for whole-body exposure, the regulations specify maximum permissible concentrations of radioactive material in the air to which a worker can be exposed for 40 hours per week over 13 weeks or 1 calendar quarter. The regulations also require that efforts be made to keep internal exposure ALARA.

Internal exposure is controlled by limiting the release of radioactive material into the air and by carefully monitoring the work area for airborne radioactivity and surface contamination. Protective clothing and respiratory (breathing) protection should be used whenever the possibility of contact with loose radioactive material cannot be prevented.

29. Is the dose a person received from internal exposure added to that received from external exposure?

Exposure to radiation that results from radioactive materials taken into the body is measured, recorded, and reported to the worker separately from external dose. The internal dose to the whole body or to specific organs does not at this time count against the 3-rem-per-calendar-quarter limit. ICRP recommends that the internal and external doses should be appropriately added. This recommendation is currently under study by the staffs of the NRC, the EPA, and the Occupational Safety and Health Administration (OSHA).

30. How is a worker's external radiation dose determined?

A worker may wear three types of radiation-measuring devices. A self-reading pocket dosimeter records the exposure to incident radiation and can be read out immediately upon finishing a job involving external exposure to radiation. A film badge or TLD badge records radiation dose, either by the amount of darkening of the film or by storing energy in the TLD crystal. Both these devices require processing to determine the dose but are considered more reliable than the pocket dosimeter. A worker's official report of dose received is normally based on film or TLD badge readings, which provide a cumulative total and are more accurate.

31. What are my options if I decide not to accept the risks associated with occupational radiation exposure?

If the risks from exposure to radiation that may be expected to occur during your work are unacceptable to you, you could request a transfer to a job that does not involve exposure to radiation. However, the risks associated with exposure to radiation that workers, on the average, actually receive are considered acceptable, compared to other occupational risks, by virtually all the scientific groups that have studied them. Your employer is probably not obligated to guarantee you a transfer if you decide not to accept an assignment requiring exposure to radiation.

You also have the option of seeking other employment in a nonradiation occupation. However, the studies that have compared occupational risks in the nuclear industry to those in other job areas indicate that nuclear work is relatively safe. Thus, you will not necessarily find significantly lower risks in another job.

A third option would be to practice the most effective work procedures so as to keep your exposure ALARA. Be aware that reducing time of exposure, maintaining distance from radiation sources, and using shielding can all lower your exposure. Plan radiation jobs carefully to increase efficiency while in the radiation area. Learn the most effective methods of using protective clothing to avoid contamination. Discuss your job with the radiation protection personnel who can suggest additional ways to reduce your exposure.

32. Where can I get additional information on radiation risk?

The following list suggests sources of useful information on radiation risk:

a. Your Employer

The radiation protection or health physics office in the facility where you are employed.

[8] Critical organ refers to those parts of the body vulnerable to radiation damage such as bone, lungs, thyroid, and other systems where certain radioactive materials will concentrate if taken into the body.

b. Nuclear Regulatory Commission

Regional Offices

King of Prussia, PA 19406	215-337-5000
Atlanta, GA 30303	404-221-4503
Glen Ellyn, IL 60137	312-932-2500
Arlington, TX 76012	817-334-2841
Walnut Creek, CA 94596	415-943-3700

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U.S. Nuclear Regulatory Commission
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Telephone: 301-443-5970

c. Department of Health and Human Services

Office of the Director
Bureau of Radiological Health (HFX-1)
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5600 Fishers Lane
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d. Environmental Protection Agency

Office of Radiation Programs
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401 M Street, SW
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