

# CHAPTER 6 – PERSONNEL MONITORING AND BIOASSAY

**External Radiation Monitoring:** We use two types of external personnel monitoring devices: Optically Stimulated Luminescence (OSL) and Thermoluminescent Dosimeters (TLD). OSL dosimeters are used for monitoring exposures to the whole body. TLD are used to measure extremity exposures.



Our OSL dosimeter measures radiation exposure due to x-ray, beta, and gamma radiation through a thin layer of aluminum oxide. After use, the aluminum oxide is stimulated with a laser light in the dosimeter supplier's laboratory causing it to become luminescent in proportion to the amount of radiation exposure. The luminescence is measured and a report of exposure results is generated.

Inside the whole body dosimeter is the OSL detector and filter packet. The dosimeter is enclosed in a water resistant blister pack, independent of the holder. Snap the dosimeter out of its holder and return it for processing after each wear period (retain the holder). The dosimeter consists of a layer of aluminum oxide enclosed in a specially designed holder with various filters. The dosimetry service uses the luminescent response in the different filter areas to determine the quality of radiation received by the badge and then calculates the effective dose equivalent (mrem) at specific depths in tissue.



Our TLD rings are NVLAP accredited for extremity monitoring. The dosimeter uses 100% TL grade lithium fluoride, with no binder. Each ring contains one TLD. Rings measure: 30 mrem to 1,000 rad for X and gamma radiation; and 40 mrem to 1,000 rad for energetic beta. Rings may be cold sterilized in ethylene oxide and in disinfectants including Cidex™ and Betadine™. The TLD rings come in small, medium and large sizes to comfortably fit any individual.

**Certification:** The accuracy and precision of our dosimetry service is independently tested by the National Institute of Standards and Technology, in accordance with American National Standards Institute ANSI N13.11-1993. Our dosimetry service is fully accredited in all testing categories for Ionizing Radiation Dosimetry by NVLAP (United States Department of Commerce, NIST, National Voluntary Laboratory Accreditation Program) for satisfactory compliance with criteria established under Title 15, Part 285, Code of Federal Regulations. These criteria encompass the requirements of ISO/IEC Guide 25 and the relevant requirements of ISO 9002 (ANSI/ASQC-1987) as suppliers of calibration or test results.

**Monitoring Requirements:** The use of radiation monitoring devices for external dose is required for adults who are likely to receive an annual dose in excess of any of the following (each evaluated separately):

- 0.5 rem (5 mSv) deep-dose equivalent
- 1.5 rems (15 mSv) eye dose equivalent
- 5 rems (50 mSv) shallow-dose equivalent to the skin
- 5 rems (50 mSv) shallow-dose equivalent to any extremity

The use of radiation monitoring devices for external dose is required for minors who are likely to receive an annual dose in excess of any of the following (each evaluated separately):

- 0.05 rem (0.5 mSv) deep-dose equivalent
- 0.15 rem (1.5 mSv) eye-dose equivalent
- 0.5 rem (5 mSv) shallow-dose equivalent to the skin
- 0.5 rems (5 mSv) shallow-dose equivalent to any extremity

The use of radiation monitoring devices for external dose is required for declared pregnant women who are likely to receive an annual dose from occupational exposure in excess of 0.05 rem (0.5 mSv) deep-dose equivalent, although the dose limit applies to the entire gestation period.

The use of radiation monitoring devices for external dose is required for individuals entering a high or a very high radiation area.

**Care in Handling:** Dosimeters should be stored and handled with care. Although OSL dosimeters are fairly rugged, they may be damaged if subjected to excessive heat, humidity, or mechanical pressure. Exposure to laboratory chemicals may interfere with accurate interpretation of dosimeter readings. OSL dosimeters should be stored in a cool, dry area away from all sources of radiation and chemically active gases or vapors.

**Control Badges:** Control badges must be kept in a location designated as a radiation-free area. This will ensure effective and valid background radiation readings. Under no circumstances should the control badge be used in any capacity other than for monitoring background radiation. It should not be assigned to a wearer or taken into a designated radiation area. The control badge must be returned to the dosimetry service for processing with the other dosimeters from the same date. Control badges with high readings will be investigated for misuse and/or improper handling.

**Dosimetry Service:** Individuals wishing to obtain a dosimeter should call 789-9391 and provide:

1. Department, building, contact's name and telephone number;
2. The number and type (whole body, extremity, area) of badges (OSL and/or TLD) you require;
3. Name, birth date, social security number and gender of individual wearers; and
4. Each individual's previous exposure history.

The information should be provided on the Dosimeter Request Form.

**Wearing the Dosimeter:** Personnel monitoring devices should be worn on the body region and body part specified on the badge label. Wear the whole body dosimeter close to the body at chest level with the labeled side facing away from the body. The dosimeters should be worn under any protective covering (lead aprons, coveralls, etc.) for a more representative dose assessment. If using a lead apron, a second dosimeter should be worn outside the apron at collar level.

Declared Pregnant women will be issued a whole body dosimeter which typically is worn on the front of the upper torso and as an additional precaution a second badge to be worn over the fetal area.

The extremity dosimeter should be worn on the part of the finger closest to and facing the direction of the source of radiation. Normally, this will be the inside of the middle finger on the dominant hand.

**Dosimeter Exchange:** All dosimeters should be collected on the last day of the scheduled period for use, packaged and mailed for processing to the Radiation Safety Office. The Radiation Safety Office will return all dosimeters and the control packet from that monitoring period in a single shipment to assure proper assessment and deduction of transit and storage exposure from personnel badges for the monitoring period.

Dosimeters must be returned immediately after wear periods. (See Late Dosimeter section)

You will receive dosimeters for the next monitoring period approximately one week prior to the date to begin use. Do not start using these badges until the date stamped on the dosimeter. At that time, insert the new dosimeter into your holder so the wearer's name can be read and promptly return the used badges to the Radiation Safety Office.

The Radiation Safety Office will send all badges of the same wear date with the control badge to the dosimetry service for timely processing.

**Missing Dosimeter:** State regulations require us to maintain complete records on every person for whom monitoring is required. If a badge is not returned, the Radiation Safety Office will request information from the affected individual to estimate the radiation exposure received during the missing badge's assignment period.

**Late Dosimeter:** If a dosimeter isn't returned within forty-five days of its start date, the Radiation Safety Office will consider the dosimeter to be late and request information from the affected individual to estimate the radiation exposure received during the badge's assignment period.

**Dosimeter Cancellation:** When an individual ceases work with radioactive materials and/or radiation-producing equipment, dosimetry is no longer required. The department contact or the Authorized User should ask the affected individual to complete and sign the Dosimeter Cancellation Form and forward it to the Radiation Safety Office. Summary exposure reports will be sent to the affected individuals if requested.

**Bioassay:** Bioassay is the determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body. Bioassays may be conducted by direct measurement (*in vivo* counting) or by analysis and evaluations of materials excreted or removed from the human body.

The primary methods of bioassay used at URI are the liquid scintillation counting of urine samples for a variety of radioisotopes and the *in vivo* counting of radioactive iodine in the thyroid. Whole body counting may be used for other gamma-emitting radioisotopes. In whole body counting, scintillation detectors are used to determine the radioactivity in body organs by measuring the gamma rays escaping from the body.

The primary purpose of the bioassay is the determination of the committed dose equivalent (CDE) and the committed effective dose equivalent (CEDE). CDE is the dose equivalent to organs or tissues that will be received from an intake of radioactive material by an individual during the 50-year period following the intake. The CEDE is the dose to the whole body from the internal uptake of radioisotopes.

Bioassays also act as an independent check on the adequacy of working habits and engineered safety features.

**Regulatory:** Bioassays may be required for personnel handling or using unsealed radioactive sources, and are required for adults likely to receive an annual intake in excess of 10 percent of the applicable annual intake limits found in the regulations.<sup>1</sup> Minors and declared pregnant women likely to receive an

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<sup>1</sup> Table 1, Columns 1 and 2 of Appendix B to Part A of the Rhode Island state regulations.

annual committed effective dose equivalent in excess of 10 percent of any of the dose limits may be required to submit bioassay samples.

The annual limit on intake (ALI) is the activity of an intake of radioactive material which if taken alone would irradiate a person,<sup>2</sup> to the limit set for each year of occupational exposure. The ALIs for commonly used radioisotopes are provided in Appendix A.

**Pulmonary Clearance:** For inhaled radioisotopes, the Radiation Safety Office uses the pulmonary clearance classifications established by the International Commission on Radiation Protection (ICRP) and used by the U. S. Environmental Protection Agency (EPA) and other federal agencies. Pulmonary clearance means clearance from the lung but does not imply systemic removal from the entire body. Pulmonary clearance could indicate the translocation of radioisotopes to other bioassay compartments.

In the ICRP scheme, Class D compounds have maximum clearance half-times of less than 10 days. Class W compounds have clearance half-times of from 10 to 100 days. Class Y compounds have clearance half-times of more than 100 days.

**Tritium:** Regulatory agencies consider Tritium compounds to be pulmonary class D. In keeping with regulatory practice, the Radiation Safety Office assumes that Tritium (in the form of tritiated water) is uniformly distributed throughout the body water whether it is inhaled, ingested or absorbed through the skin. As a result, any sample representative of the body water may, in principle, be used to estimate the body content. Urine is a convenient and practical sample of body water for all forms of tritium in the body.

**Carbon-14:** Regulatory agencies list differing values for carbon monoxide, carbon dioxide and carbon compounds but do not indicate pulmonary classes for each. The EPA considers Carbon-14 labeled organic compounds to be pulmonary class W. The Radiation Safety Office assumes Carbon-14 labeled organic compounds to be pulmonary class W.

Most Carbon-14 labeled organic compounds are not very volatile under normal circumstances. The Radiation Safety Office considers the likelihood of those organic compounds being inhaled as vapors small. In circumstances where they are inhaled, the Radiation Safety Office assumes that once they enter the respiratory system they are instantaneously and completely transported to the systemic circulation without changing their chemical form.

Exposure to the oxidation products of Carbon-14 labeled compounds is considered possible under laboratory conditions. The inhalation of CO and its retention in body tissues has been studied extensively. Since gas has a relatively low solubility in tissue water, doses due to absorbed gas in tissues are

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<sup>2</sup> Represented by Reference Man

insignificant in comparison with doses due to the retention of CO bound to hemoglobin. CO<sub>2</sub> in the blood exists mainly as bicarbonate.

The Radiation Safety Office assumes inhaled or ingested Carbon-14 labeled compounds are instantaneously and uniformly distributed throughout all organs and tissues of the body where they are retained with a biological half-life of 12-40 days.

Many Carbon-14 labeled metabolic products are excreted through the kidneys. Urine is a convenient and practical bioassay medium for Carbon-14 in the body.

**Sodium-24:** In keeping with regulatory practice, the Radiation Safety Office assumes that all Sodium-24 compounds are pulmonary class D. Sodium-24 is excreted through the kidneys. Urine is a convenient and practical bioassay medium for Sodium-24.

**Phosphorus-32:** Regulatory agencies consider all phosphorus compounds to be pulmonary class D except certain phosphates (class W). However, the Radiation Safety Office assumes that most Phosphorus-32 labeled organic compounds are phosphates likely to be pulmonary class W.

About 11% of the ingested intake of Phosphorus-32 is eliminated in the urine in the first 24 hours. About 3% of a pulmonary class W phosphorus compound is excreted in urine over the first 24 hours. Thus, urine is a convenient and practical bioassay medium for Phosphorus-32 intakes.

**Phosphorus-33:** Regulatory agencies consider all phosphorus compounds to be pulmonary class D except certain phosphates (class W). As with Phosphorus-32, the Radiation Safety Office assumes that most Phosphorus-33 labeled organic compounds are pulmonary class W.

About 11% of the ingested intake of Phosphorus-33 is eliminated in the urine in the first 24 hours. About 3% of a pulmonary class W phosphorus compound is excreted in urine over the first 24 hours. Urine is a convenient and practical bioassay medium for Phosphorus-33 intakes.

**Sulfur-35:** Regulatory agencies separate sulfur vapor from sulfur compounds. They consider some sulfides and sulphates to be pulmonary class D and others class W. The U.S. Nuclear Regulatory Commission considers elemental sulfur inhalation Class W.

In general, the Radiation Safety Office considers Sulfur-35 labeled organic compounds are pulmonary class W.

Sulfur-35 labeled methionine and cysteine show significant inherent volatility. The radiolysis of those Sulfur-35 labeled amino acids during storage and use

may lead to the release of volatile impurities. The amount of the volatile impurities is small (~0.05%).

The metabolic behavior of organic compounds of sulfur (cysteine and methionine) differs considerably from the metabolic behavior of inorganic compounds. Proteins may incorporate labeled cysteine and methionine. If Sulfur-35 enters the body as an organic compound, it is often tenaciously retained.

Sulfur entering the lungs as the gases  $\text{SO}_2$ ,  $\text{COS}$ ,  $\text{H}_2\text{S}$ , and  $\text{CS}_2$  is rapidly translocated to a transfer compartment. From the transfer compartment, its metabolism is the same as sulfur entering the transfer compartment following ingestion or inhalation of an organic compound of sulfur.

The fractional absorption of sulfur from the gastrointestinal (GI) tract is typically greater than 60% for organic compounds of sulfur. Elemental sulfur is less well absorbed from the GI tract in comparison with its inorganic compounds, (80% for all inorganic compounds and 10% for sulfur in its elemental form).

About 33% of the initial intake of a Sulfur-35 labeled pulmonary class D compound is excreted in the urine in the first 24 hours. About 17% of the initial intake of a Sulfur-35 labeled pulmonary class W compound is excreted in the urine in the first 24 hours. About 53% of ingested Sulfur-35 is excreted in the urine during the first 24 hours following an intake. If the time of initial intake is known, urine is a convenient and practical bioassay medium for Sulfur-35 in the body.

**Chlorine-36:** The Radiation Safety Office assumes that most Chlorine-36 labeled compounds are pulmonary class W.

Metabolized Chlorine-36 is frequently excreted as chloride ion in the urine. About 2% of the intake of a pulmonary class W Chlorine-36 is eliminated in the urine in the first 24 hours. About 6% of the ingested Chlorine-36 is excreted in the urine in the first 24 hours following an intake. Urine is a suitable bioassay medium for Chlorine-36.

**Calcium-45:** The Radiation Safety Office assumes that most Calcium-45 labeled compounds are pulmonary class W.

Metabolized Calcium-45 is excreted through the kidneys. About 10% of ingested Calcium-45 is eliminated in the urine in the first 24 hours following an intake. About 0.5% of pulmonary class W Calcium-45 compound is eliminated in the urine in the first 24 hours after an intake. Urine is a suitable bioassay medium for Calcium-45.

**Chromium-51:** Regulatory agencies consider chromium compounds to be pulmonary class D except for halides, nitrates, oxides and hydroxides. Halides and nitrates are pulmonary class W. Oxides and hydroxides are pulmonary class Y. The Radiation Safety Office assumes that most Chromium-51 labeled organic compounds are pulmonary class W.

Chromium-51 body burdens can be determined by whole body counting.

**Iron-59:** Regulatory agencies consider all iron compounds are pulmonary class D except oxides, hydroxides and halides. Oxides, hydroxides and halides are pulmonary class W. The Radiation Safety Office assumes that most Iron-59 labeled organic compounds are pulmonary class W.

Iron-59 body burdens can be determined by whole body counting.

**Zinc-65:** Regulatory agencies consider all zinc compounds are pulmonary class Y. Consistent with regulatory practice, the Radiation Safety Office assumes that Zinc-65 labeled compounds are pulmonary class Y.

Zinc-65 body burdens can be determined by whole body counting.

**Urine Samples:** The samples will be taken within 24 to 48 hours after a single large procedure or known intake, following a spill, at monthly intervals for continuing operations, or upon request of the Radiation Safety Officer.

Users should collect the entire 24-hour urinary output in a plastic container with a screw-tight lid. The Radiation Safety Office suggests that users start the 24-hour sampling period with the first urinary elimination in the morning and continue until the next morning.

**Derived Investigation Levels:** For routine bioassay samples, the Radiation Safety Officer or designee will determine urine concentrations requiring further investigation.

**Determining the Initial Intake:** For accidental intakes, the Radiation Safety Officer or designee will estimate the initial intake using intake retention fractions<sup>3</sup> until sufficient bioassay data is available for more exact metabolic modeling.

**Iodine-125/131:** The Radiation Safety Office assumes that all forms of radioactive iodine are pulmonary class D compounds. Since the thyroid gland accumulates 20 - 30% of the soluble radioactive iodine taken in by the body, *in vivo* measurement of the radioactivity associated with the thyroid is a useful bioassay procedure.

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<sup>3</sup> See NUREG/CR-4884, *Interpretation of Bioassay Measurements*, USNRC, July 1987.

Radioactive iodine in the body is eliminated quite rapidly via the urine. The Radiation Safety Office may also use urine bioassay samples to estimate early clearance.

**Thyroid Counts**<sup>4</sup>: Individuals using more than ten (10) millicuries of Iodine-131 or Iodine-125 in a volatile or dispersible form will be considered for *in vivo* thyroid counts. The threshold activities may be increased if the iodine:

- Remains chemically bound;
- Is processed in a manner that it remains nonvolatile; and/or
- Is diluted to concentrations less than 100  $\mu\text{Ci}/\text{mg}$ .

In laboratories working only with RIA kits, the limits will be increased to one hundred (100) millicuries.

The affected individuals should have a thyroid count monthly, or at other intervals as deemed appropriate for the particular isotope and procedure by the Radiation Safety Officer or the Radiation Safety Committee. Thyroid counts should be performed within seventy-two (72) hours, but no sooner than six (6) hours, after working with unsealed sources of radioactive iodine.

**Dose Assessment**: As a minimum, the Radiation Safety Office will need the following information to complete a dose assessment:

1. Date and time of intake;
2. Exposure pathway (intake mode);
3. Radioisotopes present and/or likely (bioassay results);
4. Pulmonary clearance class of compounds (if applicable);
5. Particle size (if applicable);
6. Metabolic models;<sup>5</sup> and
7. Measurement system error.

**CDE**: Generally, the Radiation Safety Office will consider bioassay results indicating the presence of specific radioisotopes are correct and represent an actual intake. The bioassay results will provide the basis for the calculation of committed effective dose equivalents. Once the intake is known, the dose equivalents to the various organs can be estimated using the dose conversion values.

The Radiation Safety Office will base the quantity of intake and committed effective dose equivalent on ICRP models<sup>6</sup> when specific data is unavailable.

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<sup>4</sup> Adapted from NRC Regulatory Guide 8.20, *Applications Of Bioassay For I-125 and I-131*.

<sup>5</sup> The metabolic models used to derive ALI values are described in ICRP 30 and are generally suitable for dose assessment in the absence of other data.

<sup>6</sup> ICRP 30, *Limits for intakes of radionuclides by workers*, Parts 1,2 and 3.

The Radiation Safety Office will use the respiratory system and gastrointestinal models used in ICRP 30. The Radiation Safety Office will consider intakes by absorption through the skin, a wound, or injection as direct uptake incidents. NUREG/CR-4884 is consistent with ICRP transport models and may be used in dose assessment.

For intakes less than 0.1 ALI, the initial assessment of committed effective dose equivalent will be recorded if the bioassay measurement is confirmed. For intakes greater than 0.25 ALI, variations in physical and metabolic characteristics of the individual will be considered when it is clear these differences significantly affect the magnitude of the committed effective dose equivalent.

In general, the absorption of one microcurie of Iodine-125 in the thyroid gland produces a CDE of about 3.5 rems. The absorption of one microcurie of Iodine-131 in the thyroid gland results in a CDE of about 5 rems.

**Inhalation CEDE:** Federal Guidance Report No. 11<sup>7</sup> lists the committed effective dose equivalent per unit intake by inhalation in its Table 2.1. The units used in Table 2.1 are Sieverts per Becquerel. These values can be converted to millirem per  $\mu\text{Ci}$  by multiplying the EPA table value by  $3.7 \times 10^9$ . The following table provides the committed effective dose equivalent (in millirem) per  $\mu\text{Ci}$  intake by inhalation.

<b>Isotope</b>	<b>CEDE (mrem/<math>\mu\text{Ci}</math>)</b>
H-3	0.064
C-14	2.09 <sup>8</sup>
Na-24	1.21
P-32	15.5 <sup>9</sup>
P-33	2.32 <sup>8</sup>
S-35	2.48 <sup>8</sup>
Cl-36	21.94 <sup>8</sup>
Ca-45	6.62
Cr-51	0.26
Fe-59	12.20
Zn-65	20.40
I-125	24.38
I-131	32.89

**Ingestion CEDE:** Federal Guidance Report No. 11 also lists the committed effective dose equivalents for ingestion (see its Table 2.2). The following table provides the committed effective dose equivalent (in millirem) per  $\mu\text{Ci}$  intake by ingestion.

<sup>7</sup> EPA-520/1-88-020, *Limiting Values of Radionuclide Intake And Air Concentration and Dose Conversion Factors For Inhalation, Submersion, And Ingestion*, September 1988.

<sup>8</sup> Labeled organic compounds

<sup>9</sup> Pulmonary Class W

<u>Isotope</u>	<u>CEDE (mrem/μCi)</u>
H-3	0.064
C-14	2.09
Na-24	1.42
P-32	8.77
P-33	0.92
S-35	0.45
Cl-36	3.03
Ca-45	3.16
Cr-51	0.15
Fe-59	6.70
Zn-65	14.40
I-125	38.48 <sup>10</sup>
I-131	53.28

**Records:** The Radiation Safety Office maintains occupational radiation exposure records including bioassay results.

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<sup>10</sup> The dose equivalent to the thyroid must also be considered.

## APPENDIX A: ANNUAL LIMITS ON INTAKE (ALI)

Isotope	Form	ALI Inhalation ( $\mu\text{Ci}$ )	ALI Ingestion ( $\mu\text{Ci}$ )
H-3	Water vapor	8.00E+05	8.00E+05
C-14	Labeled organic compounds	2.00E+05	2.00E+05
C-14	CO	2.00E+07	*
C-14	CO <sub>2</sub>	2.00E+06	*
Na-24	D Class	5.00E+04	4.00E+04
P-32	D Class	9.00E+03	6.00E+03
P-32	W Class	4.00E+03	*
P-33	D Class	8.00E+04	6.00E+04
P-33	W Class	3.00E+04	*
S-35	D Class	2.00E+05	1.00E+05
S-35	W Class	2.00E+04	*
Cl-36	D Class	2.00E+04	2.00E+04
Cl-36	W Class	2.00E+03	*
Ca-45	W Class	8.00E+03	2.00E+04
Cr-51	D Class	5.00E+05	4.00E+05
Cr-51	W Class	2.00E+05	4.00E+05
Cr-51	Y Class	2.00E+05	*
Fe-59	D Class	3.00E+03	8.00E+03
Fe-59	W Class	5.00E+03	*
Zn-65	Y Class	3.00E+03	4.00E+03
I-125	D Class	6.00E+02	4.00E+02
I-131	D Class	5.00E+02	3.00E+02

\* EPA-520/1-88-020 does not provide a specific value.

## APPENDIX B: DOSE CONVERSION FACTORS

Isotope	INHALATION		Isotope	INGESTION	
	Organ	mrem/ $\mu$ Ci		Organ	mrem/ $\mu$ Ci
H-3	Gonad	0.06	H-3	Gonad	0.06
H-3	Breast	0.06	H-3	Breast	0.06
H-3	Lung	0.06	H-3	Lung	0.06
H-3	R Marrow	0.06	H-3	R Marrow	0.06
H-3	B Surface	0.06	H-3	B Surface	0.06
H-3	Thyroid	0.06	H-3	Thyroid	0.06
H-3	Remainder	0.06	H-3	Remainder	0.06
H-3	Effective	0.06	H-3	Effective	0.06
C-14	Gonad	2.09	C-14	Gonad	2.09
C-14	Breast	2.09	C-14	Breast	2.09
C-14	Lung	2.09	C-14	Lung	2.09
C-14	R Marrow	2.09	C-14	R Marrow	2.09
C-14	B Surface	2.09	C-14	B Surface	2.09
C-14	Thyroid	2.09	C-14	Thyroid	2.09
C-14	Remainder	2.09	C-14	Remainder	2.09
C-14	Effective	2.09	C-14	Effective	2.09
Na-24	Gonad	0.66	Na-24	Gonad	1.64
Na-24	Breast	0.60	Na-24	Breast	1.00
Na-24	Lung	4.63	Na-24	Lung	0.96
Na-24	R Marrow	0.79	Na-24	R Marrow	1.38
Na-24	B Surface	0.95	Na-24	B Surface	1.73
Na-24	Thyroid	0.57	Na-24	Thyroid	0.96
Na-24	Remainder	0.87	Na-24	Remainder	1.96
Na-24	Effective	1.21	Na-24	Effective	1.42
P-32	Gonad	1.25	P-32	Gonad	2.42
P-32	Breast	1.25	P-32	Breast	2.42
P-32	Lung	94.72	P-32	Lung	2.42
P-32	R Marrow	15.43	P-32	R Marrow	29.93
P-32	B Surface	14.99	P-32	B Surface	29.12
P-32	Thyroid	1.25	P-32	Thyroid	2.42
P-32	Remainder	4.37	P-32	Remainder	0.99
P-32	Effective	15.50	P-32	Effective	8.77
P-33	Gonad	0.19	P-33	Gonad	0.35
P-33	Breast	0.19	P-33	Breast	0.35
P-33	Lung	15.61	P-33	Lung	0.35
P-33	R Marrow	1.00	P-33	R Marrow	1.85
P-33	B Surface	2.65	P-33	B Surface	4.88
P-33	Thyroid	0.19	P-33	Thyroid	0.35
P-33	Remainder	0.56	P-33	Remainder	1.19
P-33	Effective	2.32	P-33	Effective	0.92

INHALATION			INGESTION		
Isotope	Organ	mrem/ $\mu$ Ci	Isotope	Organ	mrem/ $\mu$ Ci
S-35	Gonad	0.17	S-35	Gonad	0.28
S-35	Breast	0.17	S-35	Breast	0.28
S-35	Lung	18.76	S-35	Lung	0.28
S-35	R Marrow	0.17	S-35	R Marrow	0.28
S-35	B Surface	0.17	S-35	B Surface	0.28
S-35	Thyroid	0.17	S-35	Thyroid	0.28
S-35	Remainder	0.43	S-35	Remainder	0.08
S-35	Effective	2.48	S-35	Effective	0.45
Cl-36	Gonad	1.86	Cl-36	Gonad	2.96
Cl-36	Breast	1.86	Cl-36	Breast	2.96
Cl-36	Lung	168.72	Cl-36	Lung	2.96
Cl-36	R Marrow	1.86	Cl-36	R Marrow	2.96
Cl-36	B Surface	1.86	Cl-36	B Surface	2.96
Cl-36	Thyroid	1.86	Cl-36	Thyroid	2.96
Cl-36	Remainder	1.98	Cl-36	Remainder	3.19
Cl-36	Effective	21.94	Cl-36	Effective	3.03
Ca-45	Gonad	0.17	Ca-45	Gonad	0.20
Ca-45	Breast	0.17	Ca-45	Breast	0.20
Ca-45	Lung	35.78	Ca-45	Lung	0.20
Ca-45	R Marrow	10.80	Ca-45	R Marrow	12.84
Ca-45	B Surface	16.24	Ca-45	B Surface	19.35
Ca-45	Thyroid	0.17	Ca-45	Thyroid	0.20
Ca-45	Remainder	1.58	Ca-45	Remainder	3.11
Ca-45	Effective	6.62	Ca-45	Effective	3.16
Cr-51	Gonad	0.08	Cr-51	Gonad	0.15
Cr-51	Breast	0.06	Cr-51	Breast	0.03
Cr-51	Lung	1.39	Cr-51	Lung	0.02
Cr-51	R Marrow	0.07	Cr-51	R Marrow	0.05
Cr-51	B Surface	0.06	Cr-51	B Surface	0.03
Cr-51	Thyroid	0.04	Cr-51	Thyroid	0.01
Cr-51	Remainder	0.18	Cr-51	Remainder	0.32
Cr-51	Effective	0.26	Cr-51	Effective	0.15
Fe-59	Gonad	5.14	Fe-59	Gonad	6.14
Fe-59	Breast	4.66	Fe-59	Breast	2.73
Fe-59	Lung	51.06	Fe-59	Lung	2.35
Fe-59	R Marrow	4.85	Fe-59	R Marrow	3.13
Fe-59	B Surface	4.11	Fe-59	B Surface	2.45
Fe-59	Thyroid	4.33	Fe-59	Thyroid	2.23
Fe-59	Remainder	10.95	Fe-59	Remainder	13.17
Fe-59	Effective	12.21	Fe-59	Effective	6.70

INHALATION			INGESTION		
Isotope	Organ	mrem/ $\mu$ Ci	Isotope	Organ	mrem/ $\mu$ Ci
Zn-65	Gonad	7.51	Zn-65	Gonad	13.17
Zn-65	Breast	11.40	Zn-65	Breast	12.14
Zn-65	Lung	77.70	Zn-65	Lung	11.40
Zn-65	R Marrow	13.39	Zn-65	R Marrow	16.65
Zn-65	B Surface	12.43	Zn-65	B Surface	16.65
Zn-65	Thyroid	11.17	Zn-65	Thyroid	11.88
Zn-65	Remainder	17.24	Zn-65	Remainder	16.98
Zn-65	Effective	20.39	Zn-65	Effective	14.43
I-125	Gonad	0.07	I-125	Gonad	0.11
I-125	Breast	0.35	I-125	Breast	0.54
I-125	Lung	0.44	I-125	Lung	0.15
I-125	R Marrow	0.16	I-125	R Marrow	0.25
I-125	B Surface	0.16	I-125	B Surface	0.25
I-125	Thyroid	799.20	I-125	Thyroid	1272.80
I-125	Remainder	0.12	I-125	Remainder	0.21
I-125	Effective	24.16	I-125	Effective	38.48
I-131	Gonad	0.09	I-131	Gonad	0.15
I-131	Breast	0.29	I-131	Breast	0.45
I-131	Lung	2.43	I-131	Lung	0.38
I-131	R Marrow	0.23	I-131	R Marrow	0.35
I-131	B Surface	0.21	I-131	B Surface	0.32
I-131	Thyroid	1080.40	I-131	Thyroid	1761.20
I-131	Remainder	0.30	I-131	Remainder	0.58
I-131	Effective	32.89	I-131	Effective	53.28