

## Section 6

**Personnel Exposure and Monitoring***Contents*

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## A. Radiation Dosimetry

Radiation dosimetry concepts and units are not rigorously defined in this manual. Attempts are made to keep explanations in general terms. Regulatory descriptions and formulas are contained in the Washington Administrative Code (WAC) 246-220

### 1. Absorbed Dose (Dose)

Strictly, the term dose refers to the concept of absorbed dose. This is the amount of energy absorbed per unit mass of material. The traditional unit of absorbed dose is the rad (100 erg/gram), but this unit has been superseded by the International System (SI) unit called the gray (1 Gy = 1 Joule/Kg). Conversion between energy and mass units yields the relationship between gray and rad (1 Gy = 100 rad). Modern dosimetry employs some other concepts related to absorbed dose, yet modified to account for biological effects and partial body irradiation.

### 2. Dose Equivalent

Dose equivalent is a concept that attempts to account for the different biological consequences resulting from different types and energies of radiation at the same absorbed dose. For example, one gray of alpha particle radiation is more damaging to human tissue than one gray of x-rays. To apply this concept, the absorbed dose (in gray or rad) is multiplied by a quality factor (Q) related to the

damaging ability of the radiation. A quality factor of 1 is given to x-rays, gamma rays, and beta particles. Alpha particles are given a quality factor of 20, and neutrons of unknown energy are given a quality factor of 10. The resulting units of dose equivalent are called the rem in traditional units and the sievert (Sv) in SI units. One sievert is equal to 100 rem.

### **3. Deep Dose Equivalent**

The deep dose equivalent is a concept that applies to external whole body radiation. It is the dose equivalent at a tissue depth of 1 centimeter. This quantity is usually determined using a "whole body" dosimeter. It does not apply to weakly penetrating radiation such as alpha particles or low-energy electrons. Units of deep dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

### **4. Lens Dose Equivalent**

The lens dose equivalent applies to external exposure to the lens of the eye. It is the dose equivalent at a tissue depth of 0.3 centimeters. This quantity is usually determined using a "whole body" dosimeter worn at or near the collar level. It does not apply to weakly penetrating radiation such as alpha particles or low-energy electrons. Units of lens dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

### **5. Shallow Dose Equivalent**

The shallow dose equivalent applies to external exposure of the skin of the whole body or the skin of an extremity. It is the dose equivalent just below the cornified layer of the skin at a tissue depth of 0.007 centimeter averaged over an area of 10 square centimeters. Units of shallow dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

### **6. Committed Dose Equivalent**

The committed dose equivalent is the dose equivalent to individual internal organs or tissues that will be received from an intake of radioactive material into the body. Committed Dose Equivalent is rarely directly measurable and must be inferred by external measurement or calculated estimates. Units of committed dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

### **7. Total Organ Dose Equivalent**

The total organ dose equivalent is the sum of the deep dose equivalent from external radiation and the committed dose equivalent to the organ or tissue receiving the highest dose equivalent. Units of total organ dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

## 8. Effective Dose Equivalent

In situations where only portions of the body are irradiated, it would be nice to express the expected risk in a consistent manner, no matter which portion of the body was irradiated. A concept was developed to convey this risk as an overall risk to the whole body, resulting from partial body irradiation. This is accomplished by assigning the individual a weighted average of organ dose equivalents, called “effective” dose equivalent. Procedures for calculating the effective dose equivalent are described in the Washington Administrative Code (WAC 246-220). Units of effective dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

## 9. Committed Effective Dose Equivalent

The committed effective dose equivalent is similar to effective dose equivalent, but applies to long-term irradiation of individual organs or tissues resulting from inhalation or ingestion of long-lived radioactive material. In these situations, the total dose is delivered slowly over long periods of time (perhaps years or even a working lifetime). The committed effective dose equivalent is the calculated 50-year total life-long effective dose equivalent resulting from an intake that will be “committed” to the individual. This “commitment” is assigned in the year the intake occurs, although it is recognized the effective dose equivalent will continue to accumulate. Units of committed effective dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

## 10. Total Effective Dose Equivalent

The total effective dose equivalent is the sum of the deep dose equivalent for external radiation and the committed effective dose equivalent for internal radiation. Units of total effective dose equivalent are the same as dose equivalent (rem in traditional units and sievert (Sv) in SI units).

# B. Dose Limits

Dose Limits are promulgated in the Washington Administrative Code (WAC 246-221). These limits were determined by national and international agencies after careful consideration of the best available information on the biological effects of radiation. The current prudent assumption is that any dose, no matter how small, might cause some degree of harm. Therefore, a radiation dose limit does not identify a line of demarcation between “safe” and “dangerous”. Instead, current dose limits are set to assure that short-term effects of radiation are avoided, and the risk of long term effects (induction of cancer, genetic effects, and effects on the fetus) are held to an acceptable level.

## 1. Occupational Dose Limits for Adults

The annual limit for adult occupational dose is the more limiting of:

The total effective dose equivalent being equal to 0.05 Sv (5 rem); or  
The sum of the deep dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 0.5 Sv (50 rem).

The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities are:

A lens dose equivalent of 0.15 Sv (15 rem); and  
A shallow dose equivalent of 0.5 Sv (50 rem) to the skin of the whole body or to the skin of any extremity.

## **2. Occupational Dose Limits for Minors**

Occupationally exposed individuals under the age of 18 must not receive a dose in excess of 10 percent of the annual occupational dose equivalent specified above for adults.

## **3. Occupational Dose Equivalent to an Embryo or Fetus**

The dose equivalent to an embryo or fetus during the entire pregnancy, due to occupational exposure of a declared pregnant woman, must not exceed 5 mSv (0.5 rem).

## **4. Non-Occupational Dose Limits**

The total effective dose equivalent to individual members of the public from UW licensed or registered operations must not exceed 1 mSv (0.1 rem) in a year.

The dose in any unrestricted (public) area from external sources must not exceed 0.02 mSv (0.002 rem) in any one hour.

# **C. Declared Pregnant Worker**

If you are a radiation worker and are pregnant, you should know that you have the option of declaring your pregnancy in writing to the Radiation Safety Office to take advantage of voluntary limits for dose to the embryo/fetus.

## **1. Radiation Exposure during Pregnancy**

Radiation is one of many environmental factors that can affect the long-term health of an individual exposed while in the uterus. Other factors that you should consider include diet, smoking, exercise, stress, and exposure to hazardous chemicals.

The risk from radiation exposure is dependent upon the amount of exposure. The

exposures allowed for declared pregnant workers are small (500 mrem over the pregnancy), and the resulting risk is extremely small compared to other risks that are always present during a pregnancy. Although it is prudent to keep occupational radiation doses low during your pregnancy, remember that this will not affect the risks that are not related to radiation.

## 2. Prenatal Radiation Effects

The effects of radiation exposure on the fetus are clearly dependent upon the magnitude of the radiation exposure. For perspective, the following is a discussion of radiation risks for various exposure levels.

### a. Prenatal Exposures Below 500 mrem (the voluntary fetal dose limits)

There is no indication from scientific studies that harm to the fetus can result from these levels of prenatal radiation exposure. However, harm has been demonstrated at much higher doses. So, caution is wise. Pregnant workers are encouraged to voluntarily comply with a 500 mrem limit for the duration of the pregnancy.

### b. Prenatal Exposures - 500 to 5,000 mrem (up to the occupational limits for adult radiation workers)

- 1) There are no observable effects on the growth or development of the embryo or fetus in this dose range. Exposure to radiation has not been associated with birth defects, miscarriages or other abnormalities for fetal exposures at these levels.
- 2) There may be an increased risk of cancer later in life for those exposed prenatally to radiation at these levels (500 to 5,000 mrem). Several studies of children exposed prenatally to diagnostic x-rays (pelvimetry) between 1940 and 1960 have shown an elevated risk of childhood leukemia and other cancers. It has been suggested that factors other than radiation may account for this increase, since the x-rays were often taken because of medical problems that increase the risk of cancer (for example, a maternal history of miscarriages or maternal age over 40). Even if these studies are inconclusive, it is prudent to assume that a risk of cancer may exist from prenatal irradiation in this dose range (500-5,000 mrem).

### c. Higher Exposures - 5,000 to 50,000 mrem

Fetal exposures in excess of 5,000 mrem are very unlikely because of existing occupational limits for radiation exposure.

- 1) Mental Retardation

Within this region is the possible threshold for an increased incidence of

mental retardation and other central nervous system abnormalities. This threshold has been estimated as occurring between 10,000 to 25,000 mrem.

2) Early Lethality

This region (5,000 to 50,000 mrem) is also the possible threshold for early lethality to the embryo in the 0-4 week gestational period. This has been documented in mice, but has not for humans.

3) Risk of Cancer

It is very likely that some risk of cancer exists from prenatal exposures between 5,000 and 50,000 mrem. The increase in cancer risk can only be conclusively documented for prenatal exposures greater than 50,000 mrem, but probably exists to a lesser degree in this dose range as well.

**d. Very High Exposures - Above 50,000 mrem**

1) 50,000 to 100,000 mrem

For fetal exposures greater than 50,000 mrem (such as in the atomic bomb survivors), there is a marked increase in the incidence of severe mental retardation and small head size (microcephaly). Exposures at levels greater than 50,000 mrem also produced a detectable increase in the cancer rate of atomic bomb survivors whom were irradiated prenatally.

2) Greater Than 100,000 mrem

Fetal exposures greater than 100,000 mrem led to a very high degree (possibly 60%) of miscarriages and neonatal deaths after Hiroshima. The percentage of severe mental retardation and microcephaly among surviving fetuses was high at this level. Doses over 100,000 mrem also caused radiation sickness in adults.

**3. Reducing Potential for Large Exposures to the Fetus**

To avoid situations where the occupational dose limits could be exceeded, abstention from or extreme caution should be used if a declared pregnant worker participates in the following activities:

**a. Radioactive Iodine**

Handling large (>1 millicurie) quantities of radioactive iodine in unsealed form.

**b. Accelerator/Cyclotron**

Performing maintenance procedures involving particle accelerator or cyclotron targets.

### **c. Fluoroscopy**

Standing directly in a x-ray field during fluoroscopic procedures. Use of a lead apron is adequate for protection if the worker's torso remains out of the direct x-ray beam path. However, extra caution is necessary.

## **4. Declaring Pregnancy**

State and Federal regulations allow you to reduce your occupational exposures to below 500 mrem during pregnancy by declaring this in writing to the Radiation Safety Office. The 500 mrem voluntary gestational limit is 10% of the normal occupational limit for radiation workers. Because the risk is believed to be small even at the 5,000 mrem occupational limits for nonpregnant workers, the declaration of pregnancy is voluntary. After pregnancy is declared, the 500 mrem limit becomes a requirement.

### **a. Evaluating Need to Declare Pregnancy**

One guideline to consider is the occupational dose you receive in a year. If you are not a radiation worker, there is no need to declare pregnancy. If you are a radiation worker who receives less than 50 mrem whole-body dose in a year, you do not need to declare pregnancy.

- 1) If you are not currently monitored for radiation exposure (either through a whole body dosimeter, TLD ring, or bioassay), you probably receive less than this amount.
- 2) If you work with radionuclides, such as tritium, carbon-14, and phosphorus-32, which do not emit penetrating gamma radiation, the use of good laboratory practices (so that you do not ingest radioactive materials) would be sufficient to protect the fetus.
- 3) If you work with small quantities of gamma emitting radionuclides, your doses may still be far below the limit for declared pregnant workers.
- 4) If you have questions about your occupational radiation exposure, consult the monthly radiation exposure reports or call the Radiation Safety Office (RSO) at 543-0463.

## **b. Formal Declaration of Pregnancy**

Since this is a formal request to change your occupational dose limits, you must submit the proper information to the Radiation Safety Office.

- 1) To declare a pregnancy, request the application form(s) from the Radiation Safety Office. The forms become part of the radiation dosimetry records and are required for compliance with State and Federal regulations for dosimetry record keeping. The forms must be filled out completely so that the appropriate doses may be assigned for the duration of the pregnancy.

- 2) If you already have a dosimeter:

RSO Form 9 (Request for Fetal Dosimeter) may be obtained from the Area Dosimetry Coordinator (ADC) in your area or the Radiation Safety Office at 543-0463.

- 3) If you are a radiation worker who does not have a dosimeter, but still wish to declare pregnancy:

Call the Radiation Safety Office to ask for:

- RSO Form 7 - Request for Radiation Worker Dosimetry, and
- RSO Form 9 - Request for Fetal Dosimeter.

## **5. Not Declaring Pregnancy**

If no written declaration by a radiation worker is made concerning pregnancy, the normal occupational dose limit of 5,000 mrem per year (deep dose equivalent) remains applicable.

If you decide not to declare pregnancy or if you have already had children while working as a radiation worker, there is no undue cause for concern. The voluntary limit of 500 mrem is a means to further minimize risks. It is not a line between “safe” and “dangerous.” However, radiation workers who are concerned about the potential health effects of radiation during pregnancy are highly encouraged to take advantage of the lower limits for fetal dose.

## **6. Estimating Fetal Dose Equivalent**

Radiation workers who declare pregnancy receive a “fetal dosimeter” in addition to their regular whole body dosimeter or TLD ring.

### **a. Position**

The fetal dosimeter is worn at the waist level.

### **b. Lead Apron**

If a lead apron is worn (as for workers using fluoroscopic x-ray equipment), the fetal dosimeter is to be worn under the lead apron and the regular dosimeter is to be worn outside the lead apron at the collar level. Please pay special attention to not get the two dosimeters confused and switch locations.

**c. Monthly Exchange**

The dosimeter is exchanged monthly, whenever you receive a new whole body dosimeter or TLD ring from your Area Dosimetry Coordinator (ADC).

If you do not have a dosimeter prior to your declaration of pregnancy, your workplace may not have an ADC. The Radiation Safety Office will provide instructions for handling the dosimeters when the dosimeters are first issued.

**d. Measure of External Radiation**

The fetal dosimeter only measures external radiation. It is not a substitute for bioassays (thyroid scans for workers using > 1 mCi of radioactive iodine in volatile form).

If you are a declared pregnant worker using radioactive iodine, please call the Radiation Safety Lab (206-543-6328) to ensure that you receive bioassay measurements.

## **7. Compliance with Occupational Exposure Limits**

Once a pregnancy has been declared, it is very important to stay within the 500 mrem gestational limit. Declaring pregnancy is optional, but the 500 mrem limit becomes a legal requirement once your pregnancy is declared.

**a. Notifying the Radiation Safety Office**

It is a declared pregnant worker's responsibility to contact the Radiation Safety Office if she knows that she might exceed the 500 mrem limit or routinely receive more than 50 mrem per month. Without this information, it will not always be possible for the Radiation Safety Office to identify the potential for exceeding the 500 mrem limit.

This is especially important if you think that your dose may be increased as the result of changes in the work environment, work schedule, or job rotation.

**b. Job Modification**

If it is determined that a job modification is necessary to comply with the limit of 500 mrem, the Radiation Safety Office will contact UW Personnel Services to help the employee and supervisor arrange for a satisfactory accommodation of the exposure conditions.

It is your supervisor's responsibility to accommodate a declaration of pregnancy and the resulting limitation on occupational dose. Exceeding this limit would cause the UW to violate the terms of its Radioactive Materials License and the State Radiation Protection Standards (WAC 246-221-055).

- 1) It may be possible to stay within the 500 mrem limit by making relatively minor changes in the work environment.
- 2) In rare instances, it may be necessary to restructure or reassign job duties, make changes in your work schedule, or arrange for a leave of absence. Such changes would be arranged through the Human Resources representative for your department, under the same rules that allow for accommodation due to temporary disabilities.
- 3) If you have any questions about your options for reducing your occupational dose below the 500 mrem gestational limit, please contact the Radiation Safety Office (543-0463).

## **8. Pregnancy Declared after Receiving more than 450 mrem**

The State of Washington Radiation Protection Standards (WAC 246-221-055) contain the following provision:

“If the worker has received more than 450 mrem during the time between conception and declaration of pregnancy, a 50 mrem dose limit applies to the duration of the pregnancy.”

Since this 50 mrem secondary limit is very small, any declared pregnant worker who has already received more than 450 mrem during the pregnancy must seek immediate reassignment to duties which do not involve occupational radiation exposure.

Workers who are pregnant are encouraged to declare pregnancy even if their cumulative dose during the pregnancy has already exceeded 500 mrem. This will enable them to stay as close as possible to the 500 mrem limit.

## **9. Confidentiality**

### **a. Declaration**

Once a declaration of pregnancy is made, this information is retained as part of a worker's radiation dosimetry record.

**b. Reports**

Reports, showing an individual's monthly or quarterly radiation exposure, are normally distributed through the Area Dosimetry Coordinator for each area.

**c. Privacy**

If you wish to keep your pregnancy confidential, please contact the Radiation Safety Office at 206-543-0463. Otherwise, your fetal dosimeter will be mailed directly to the Area Dosimetry Coordinator who handles your regular dosimeter.

You are not required to disclose the declaration of pregnancy to anyone outside of the Radiation Safety Office. However, if your job duties or schedule must be modified in order to comply with the 500 mrem limit, then your department and your Human Resources representative must be included in this process.

**10. Nondiscrimination****a. Pregnancy Discrimination Act**

Employees who are pregnant are protected against job discrimination under the Pregnancy Discrimination Act and Title VII of the Civil Rights Act. You cannot be fired or penalized for declaring a pregnancy.

**b. Potential for Childbearing**

Additionally, an employer may not discriminate against any worker because of her potential for childbearing. There is no scientific or legal justification for restricting the duties or employment potential of nonpregnant radiation workers (ICRP 1990). Such discrimination is illegal.

**11. Lead Aprons****a. Work Areas**

Lead aprons are required for work with certain types of diagnostic x-ray equipment, being beneficial only in a few work environments where low energy x-rays are present.

**b. Not Recommended to Protect Fetus**

Unless you work in an environment where lead aprons are already required, a lead apron is not recommended as a means of protecting the fetus.

- 1) A lead apron is heavy and uncomfortable, especially during pregnancy,

and would usually add to fatigue. Also, the total amount of lead in an apron is limited by weight constraints and so lead aprons are not effective for many high-energy gamma-emitting radionuclides.

- 2) Your supervisor cannot require you to wear a lead apron unless it is already required for non-pregnant workers under state regulations.

## **12. Medical X-rays and Nuclear Medicine Procedures**

### **a. Personal Medical Procedures**

The occupational limits for declared pregnant workers do not apply to medical procedures when you are the patient. Your dosimeter(s) should not be worn if you receive medical diagnostic x-ray or nuclear medicine procedures.

### **b. Declaration Prior to Procedures**

If you are pregnant and are scheduled for a diagnostic x-ray or nuclear medicine exam, you should tell the doctor and/or the technologist prior to the exam. In many cases, they may decide not to perform the examination. However, it is possible that the risk to the embryo/fetus from the radiation may be much smaller than the risk from allowing a medical condition to go untreated. You should discuss this with your doctor.

### **c. After Procedure**

If you received a medical exam involving radiation while you were unaware that you were pregnant, you should discuss this with your doctor. In most cases, the doses are so low that there is no reason for concern.

### **d. Information on Risks from Exposure**

If you or your doctor require additional information about risks from exposure to radiation or radiopharmaceuticals during pregnancy and lactation, you may contact Care Northwest. This service is provided through the University of Washington Medical Center and is not affiliated with the Radiation Safety Office. Care Northwest has a 900 number listed in the University of Washington directory. A small fee is involved.

## **D. Personnel Dosimeters**

Personnel dosimeters are used for determining compliance with external occupational dose limits.

## 1. Types

### a. Whole Body Dosimeters

#### 1) Type of Measurement

A whole body dosimeter measures deep, lens and shallow dose equivalent from external radiation sources. The standard "whole body" badge is used primarily for gamma rays, x-rays and mid to high-energy beta radiation. A neutron detector can be incorporated, creating a dosimeter referred to as a "whole body plus neutron" badge.

#### 2) Location of Use

The whole body badge is worn on the torso, at the chest or collar level. If a lead apron is used, the whole body (chest or collar) badge must be worn outside the lead apron. In rare instances, a second badge (waist badge) is also issued. When issued, the waist badge is worn under the lead apron.

#### 3) Description

The type of whole body dosimeter currently in use is the "Luxel" optically stimulated luminescence dosimeter. This type of dosimeter consists of a thin aluminum oxide layer coated on a plastic base. Metal and plastic filters built into the dosimeter allow differentiation between different types and energies of radiation, enabling calculations of the radiation doses at several depths in tissue. "Luxel" dosimeters have a large dynamic range, excellent sensitivity, and long-term stability.

#### 4) Detection Method

When energy is deposited in the material by radiation, the atoms of the material store some of the energy through excitation processes. Later the stored energy is "read" by cooling the dosimeter to very low temperatures, stimulating the material with laser light, and allowing the material to return to room temperature rapidly. The amount of luminescence produced by this process is proportional to the amount of radiation exposure the dosimeter received.

### b. Extremity Dosimeters (Ring or Wrist Badges)

#### 1) Reason for Use

In some cases, a radiation exposure involves a significantly greater dose to the hands than to the torso. In these instances, it is more important to monitor extremity dose than whole body dose. Ring badges are the primary mechanism for measuring extremity dose. Occasionally, it may be impractical or cumbersome to use a ring badge. In these instances, a

worker may request issuance of a wrist badge (in lieu of a ring badge) to monitor extremity dose

## 2) Directions for Wearing Extremity Badges

The ring badge should be worn with the label facing the source of radiation on the hand likely to receive the highest dose. When high extremity doses are possible, ring badges may be issued for both hands.

The wrist badge consists of a Luxel dosimeter worn on a wristband. It is worn on the wrist likely to receive the highest dose.

## 3) Detection Method

A ring badge consists of a plastic ring containing a chip of thermoluminescent material (TLD). The TLD chip functions similarly to the optically stimulated luminescence detector described in the preceding section. When the dosimeter is “read,” it is heated to approximately 300 degrees centigrade. The amount of light emitted by the TLD is proportional to the radiation dose.

### c. Pocket or Self-Reading Dosimeters

#### 1) Description

These dosimeters are roughly pocket sized and can be clipped to a belt or a pocket. Some of these units are air filled ion chambers, and others use a Geiger-Muller (G-M) counter. These instruments are usually only useful for measuring accumulated gamma or x-ray exposure, but they give immediate output. Self-reading dosimeters often have "chirping" alarms that inform the user after they accumulate a pre-set dose (like every 1/10 mR or 1 mR).

#### 2) Conditions of Use

Self-reading dosimeters give immediate information about the work environment and are small enough to be worn like a whole-body dosimeter. They can be quite useful for evaluating which part of a procedure or experiment gives the highest dose to the operator. However, they provide an informal record of dose. In situations where whole body or ring dosimeters are mandated, a self-reading dosimeter does not replace the required whole body or extremity badges.

## 2. Working Conditions Requiring Personnel Dosimeters

### a. Medicine

#### 1) Nuclear Medicine and Radiotherapy

- a) Personnel working directly with radiopharmaceuticals – *whole body and ring dosimeters*.
  - b) Individuals administering brachytherapy or handling brachytherapy sources - *whole body and ring dosimeters*.
  - c) Individuals providing care for patients who have source implants or radiopharmaceutical administrations greater than 20 millicurie – *whole body dosimeter*.
  - d) Individuals providing external beam radiation therapy using the cyclotron or linear accelerators – *whole body or whole body with neutron dosimeter*.
- 2) Diagnostic Medical X-ray
- a) Individuals having frequent and direct association with patients during radiographic and/or fluoro exams:
    - No likelihood of hands in direct fluoro beam – *whole body dosimeter*.
    - Likelihood of hands in direct fluoro beam – *whole body and ring dosimeters*.
  - b) Multiple whole body dosimeters may be required by the Radiation Safety Office (collar and waist badges) during interventional radiology procedures where the worker could receive a significant fraction of the annual occupational dose limits.
- 3) Dental or Veterinary X-ray
- a) Infrequent entry of the room during radiographs – *dosimeter not required*.
  - b) Routine entry of the room during x-ray operation:
    - For a fixed-direction tube where procedures ensure sufficient distance from the x-ray unit to avoid potential exposures – *dosimeter not required*.
    - For systems where individuals could remain near the x-ray but where there is no likelihood of direct beam exposure to the hands – *whole body dosimeter*.
    - For individuals with a likelihood of direct beam exposure to the hands – *whole body and ring dosimeters*.

## b. Research

- 1) Accelerators (Non-Hospital)
  - a) Nuclear Physics Laboratory – *whole body or whole body with neutron dosimeter (depending on whether a significant neutron component is present).*
  - b) Other Facilities – *no monitoring required unless the Radiation Safety Office determines that there is a potential for occupational exposure exceeding 10% of the annual dose limits. Whole body or whole body with neutron dosimeter may be required in some instances.*
- 2) X-ray Units (Non-medical use)
  - a) Analytical x-ray units with no accessible beam – *dosimeter not required.*
  - b) Analytical x-ray units with accessible beam – *ring dosimeter.*
- 3) Radioactive Materials (other than sealed sources)
  - a) Using exclusively low energy beta emitters (beta  $E_{max} < 0.5$  MeV, no gamma or x-ray) – *dosimeter not required.*

Includes:  
H-3            C-14            P-33            S-35
  - b) Using between 1 and 10 mCi of high-energy beta or beta-gamma emitters (beta  $E_{max} > 1$  MeV regardless of gamma energy) – *ring dosimeter.*

Includes:  
Na-24        P-32            K-40            K-42            Ca-47  
Mn-56        Fe-59            Co-60            Y-90            Mo-99  
Ag-110m     I-132            Cs-137            Au-198            Bi-213  
Sr-90 (unless it is confirmed that the Y-90 daughter is absent)
  - c) Using between 1 and 10 mCi of any positron emitter – *ring dosimeter.*

Includes:  
C-11        N-13            O-15            F-18  
Co-58        Cu-64            Zn-65
  - d) Using more than 10 mCi of any radionuclide (except pure beta emitters with beta  $E_{max} < 0.5$  MeV) – *ring and whole body dosimeters.*

- 4) Sealed Source Use
  - a) Gamma, x-ray or beta sources that are completely shielded and enclosed during operation (no accessible beam) – *dosimeter not required.*
  - b) Gamma, x-ray or high energy beta ( $E_{max} > 1$  MeV) sources greater than 10 mCi source with accessible beams – *ring and whole body dosimeters.*
  - c) AmBe, PuBe or other neutron sources larger than 10 mCi – *whole body with neutron dosimeter.*

**c. Declared Pregnant Occupational Workers**

- 1) Declared pregnant workers who work in an environment with the potential to exceed 100 mrem per year deep dose equivalent.
- 2) Declared pregnant workers who are not monitored and believe they may exceed the above levels should contact the Radiation Safety Office.

### 3. Application for Dosimetry Service

Personnel dosimeters are provided to the University community through the Radiation Safety Office (RSO). To facilitate the distribution of dosimeters, each group using dosimeters is assigned a Series Code and has an appointed Area Dosimetry Coordinator.

**a. Area Dosimetry Coordinator (ADC) Responsibilities**

- 1) Submits dosimeter applications to the RSO.
- 2) Distributes and collects monthly dosimeters.
- 3) Requests change in service.
- 4) Receives monthly reports, making them available to dosimetry users.
- 5) Receives and distributes annual reports to individuals.

**b. Setting up New Series Code**

If a new group requires dosimeters, call the RSO (206-543-0463). If possible, we will handle the request through an existing group. If not, a new Series Code will be created.

**c. Forms**

- 1) Request for Radiation Worker Dosimeter – RSO Form 7
- 2) Request for Fetal Monitoring – RSO Form 9.

If confidentiality is preferred, call the RSO for a Form 9 instead of contacting the ADC. See part C of this Section, Declared Pregnant Worker.

## **4. Use of Luxel Dosimeters**

### **a. Occupational Exposures**

Wear dosimeters only to measure occupational exposures. Do not wear dosimeters when receiving medical or dental radiation exposure.

### **b. Positioning on the Body**

- 1) Face the dosimeter away from the body, with the holder's clip toward the body.
- 2) Keep the front of the Luxel dosimeter clear of tapes or clips, as these items may interfere with the radiation exposure reading.
- 3) Unless it is a fetal monitor, wear the Luxel whole body dosimeter near the collar, in order to include radiation exposure to the lens of the eye.
- 4) Wear Luxel fetal monitors at the waist and under leaded protective aprons, if applicable.

### **c. Storage**

- 1) Remove dosimeters from unworn aprons or lab coats stored in radiation areas.
- 2) When not using your dosimeter(s), store them in an office area away from environments where radiation exposure above background would be encountered.

### **d. Single Wearer**

Do not share dosimeters among multiple workers. Call the Radiation Safety Office for individual badges.

## **5. Over Exposure Notifications**

In addition to notifications to individual workers, the Radiation Safety Office is required to report doses exceeding the maximum permissible dose limits (listed under Part B of this section) to the State of Washington Department of Health,

Division of Radiation Protection.

## E. Bioassay and Internal Dosimetry

The University of Washington applies techniques suggested by the US NRC Regulatory Guides 8.9 and 8.20, NUREG/CR 4884, and Committee 2 of the International Commission on Radiological Protection (ICRP Report 30) as principle basis for internal dose calculation.

The radionuclides iodine (iodine-125 and iodine-131) and tritium (hydrogen-3) are of primary concern for internal dosimetry for various reasons. Radioiodines are among the most hazardous and most volatile radionuclides. Tritium is among the least hazardous, but is easily absorbed through the skin. An *in vivo* counting procedure provides a rather simple method for evaluation of the internal dose for iodine-125 and iodine-131, while an *in vitro* procedure for hydrogen-3 is used.

The internal dose from other radionuclides may occasionally require some level of evaluation following an accident. An ad hoc program will be established when needed.

### 1. Radioiodine

#### a. University of Washington Policy

Each person who works in a laboratory where more than 0.5 mCi of radioiodine (iodine-125 or iodine-131) is ordered or stored in a calendar quarter is included in the Radiation Safety Office *in vivo* thyroid bioassay program. This activity (0.5 mCi per calendar quarter) is a conservative adjustment of the recommendations of USNRC Regulatory Guide 8.20.

##### 1) Calendar-Quarter Requirements

Since all radioiodinations at the UW must be performed in a fume hood, Regulatory Guide 8.20 indicates that bioassay would not be required for processes involving less than 10% of 10 mCi (1 mCi) over “any three month period.”

From an administrative standpoint, setting a lower activity limit of 0.5 mCi and determining need for and performing bioassay on a quarterly basis versus “any three month period” is much more practical. The bioassay program consists of at least one measurement per person each calendar quarter, taken several days after the radioiodine work.

##### 2) Single Use Requirements

In addition to the calendar-quarter bioassay requirements, single use bioassay requirements have been established that are consistent with

Regulatory Guide 8.20. Each person who directly handles more than 1 mCi of radioiodine on any single occasion is required to have a thyroid bioassay measurement taken by the Radiation Safety Office staff within one week of the work.

For medical personnel administering radioiodine in capsule form, thyroid bioassays are not required (Regulatory Guide 8.20 and WAC 246-239-035).

#### **b. Thyroid Measurement**

The *in vivo* thyroid bioassays are made with an instrument that is calibrated for the thyroid measurements and has a sensitivity for detecting at least 5 nCi of iodine-125 and 1 nCi of iodine-131.

#### **c. Measurement Exceeding 14 nCi**

When a measurement indicates an individual has exceeded a thyroid burden of 14 nCi since the last measurement, the RS staff shall investigate the cause of the exposure. The activity, 14 nCi, indicates that potentially an intake of 10% of the Annual Limit on Intake for I-131 has occurred since the last bioassay. I-131 is the "worse case" radionuclide of iodine commonly used at the UW. Multiple bioassay measurements will be performed if the RS staff's investigation reveals the likelihood of an individual's intake being greater than 10% of the Annual Limit on Intake for the radionuclide(s) involved.

#### **d. Dose Calculations**

The thyroid dose calculation includes an extrapolation of inhaled or ingested activity or the time of a thyroid measurement back to the intake at the time of exposures. Standard dosimetry and retention information is used for dose calculations. However, biological information for the exposed individual should be substituted when available. The committed dose equivalent and a committed effective dose equivalent to the thyroid are determined and expressed in millirem.

#### **e. Measurement Exceeding 40 rem**

An individual who has a measurable thyroid burden which indicates a committed dose equivalent to the thyroid of more than 40 rem will be restricted for the remainder of the year from further work with radioiodine. The value of 40 rem was established to assure that the sum of the deep dose equivalent (from external exposure) and the committed dose equivalent to the thyroid do not exceed 50 rem.

A finding of a sum total of deep dose equivalent and committed dose equivalent to the thyroid for any calendar year of more than 50 rem is considered in excess of the limits of WAC-246-221-010 and will be reported to DOH in accordance with WAC-246-221-250 and 260.

## f. Annual Report

The Radiation Safety Office will provide an annual report of internal dose records to every individual who has received a measurable dose during the annual period. An annual summary of employee dosimetry will also be provided to the RSC, including a comment on corrective action, if taken.

## 2. Tritium (H-3)

It is usually necessary to establish a bioassay program for the evaluation of possible internal dose when working with large amounts of tritium (H-3). An exception to this requirement is when H-3 is contained in any sealed source or when it is absorbed on metal foils in quantities less than two curies.

Authorization for more than 100 mCi of H-3 will normally be limited to work that can be done in a hood with a face velocity greater than 100 linear feet per minute. Proposed work that cannot meet this condition must be supported by a detailed description of alternative protection measures.

### a. Specific Rules

Specific rules for bioassay of large amounts of unsealed/unattached tritium are defined as follows:

- 1) Anyone working with more than 100 millicurie (mCi) of H-3 in a single use must have a bioassay within one week of each single use.
- 2) Anyone working with a throughput of more than 100 mCi in a month must have a bioassay once a month.

### b. Tritium Urine Analysis

Analysis of urine for tritium content has proven to be the most reliable method for determining the concentration of tritium in body water. In most cases, after H-3 enters the body, it will distribute into body water and will not concentrate. It is eliminated with a biological half-life of 10 to 15 days due to the normal turnover of body water. The internal dose can be calculated if the concentration in urine is determined. The results must be reported on Radiation Safety Office (RSO) Form 202.

- 1) Arrangements for urine bioassays are the responsibility of the Authorized Investigator (AUI) and can usually be done with resources available in the laboratory where tritium is used.
- 2) Urine samples should not be collected until after a complete voiding. This assures that any intake of tritium will have the opportunity to be equally distributed in all body fluids, including urine. Care must be taken to avoid contamination of the sample by contaminated hands. The

preferred sampling time is first thing in the morning following an exposure and before any other laboratory work. A sample must be taken within one week of exposure.

a) Gross Count

A simple gross count can be made by adding 1.0 milliliter (ml) of sample fluid to 15 ml of a water miscible liquid scintillation cocktail, e.g., Aquasol. Count the sample for 10 minutes and compare to a 10-minute background count. If the sample count minus background is less than MDC (see calculation D), the result can be reported as negligible and no further analysis is necessary. Results must be reported on RSO Form 202.

b) Controlled Analysis

Most laboratories routinely counting tritium with liquid scintillation methods have already established procedures that will allow an accurate analysis of tritium content in urine. These procedures are acceptable, provided that they are documented and include quality control of the background and counting standards. The procedures must be available for review by RS staff or Department of Health inspectors, if requested. In lieu of established procedures, the procedures for analysis of tritium in urine should be followed.

**c. Tritium Bioassay using Internal Standard Method**

Urine in a liquid scintillation cocktail sample will induce quench and result in reduced counting efficiency. The result is the inability to directly quantify the amount of tritium the sample contains. A simple way around this problem is through the use of an internal standard. This provides quench correction and a counting efficiency for your individual sample.

An uncontaminated (background) urine sample is processed in parallel with the actual (target) sample. The uncontaminated sample may be obtained from a co-worker or the individual being bioassayed prior to the tritium procedure. The uncontaminated sample is counted to determine the background count rate. The target sample is counted and background is subtracted to establish the net sample count rate. Subsequently, the target sample is "spiked" with a known quantity of tritium (internal standard), and then counted again to establish the added count rate corresponding to a known amount of tritium.

1) Definitions

bkg	=	background
cpm	=	counts per minute
dpm	=	disintegrations per minute
EFF	=	efficiency

MDA	=	minimum detectable activity
MDC	=	minimum detectable counts
ml	=	milliliter
std	=	standard
$\mu\text{Ci}$	=	microcurie

## 2) Procedure

- a) A counting standard containing a known amount of tritium must be prepared to provide an activity concentration of approximately 2000 dpm/ml. Enter exact dpm/ml in calculation (a.) of the following section.
- b) A one-milliliter sample of non-contaminated (background) urine must be obtained.
- c) A one-milliliter sample of unknown (target) urine to be analyzed must be obtained.
- d) Prepare two scintillation vials. Introduce one milliliter of background urine to one of the vials. Introduce one milliliter of target urine to the other.
- e) Add 15 milliliter of an appropriate scintillation cocktail to both vials and count both with a liquid scintillation counter (LSC). Convert the raw counts into count rates (cpm) by dividing by the counting time.
- f) The net sample count rate equals the target sample count rate minus the background sample count rate. See Calculations (b.) in the section below.
- g) One milliliter of standard tritium solution is then added to the target sample vial and again it is counted with a LSC. Convert this raw count into a count rate (cpm) by dividing by the counting time.
- h) Subtract the count rate obtained when you first counted the target vial from the count rate you obtained after adding the standard solution. This value equals the net standard count rate (in cpm). See calculation (c.) in section below.
- i) Since samples and standards were processed in one-milliliter quantities, count rates can be directly expressed in count rate concentrations (cpm/ml).

3) Calculations

a)  $std = \text{_____} dpm/ml$

b)  $target\ sample\ (cpm) - bkg\ sample\ (cpm) =$   
 $net\ sample\ \text{_____} cpm/ml$

c)  $target\ sample\ with\ std\ (cpm) - target\ sample\ (cpm) =$   
 $net\ std\ \text{_____} cpm/ml$

d)  $\frac{net\ std\ (cpm/ml)}{std\ (dpm/ml)} = EFF\ (cpm/dpm)$

e)  $\frac{net\ sample\ (cpm/ml)}{EFF\ (cpm/dpm)} = sample\ activity\ (dpm/ml)$

f)  $\frac{sample\ activity\ (dpm/ml)}{2.22 \times 10^6\ (dpm/\mu Ci)} = sample\ activity\ (\mu Ci/ml)$

g)  $4.65 \times [bkg\ (cpm) / counting\ time\ (min)]^{1/2} = MDC\ (cpm)$

h)  $\frac{MDC\ (cpm)}{EFF\ (cpm/dpm) \times 2.22 \times 10^6\ (dpm/\mu Ci)} = MDA\ (\mu Ci/ml)$

4) Sample Results

If greater than “0”, the results of these procedures must be documented on RSO Form 202. The Authorized Investigator should retain the white copy. Send the yellow copy to the Radiation Safety Office (RSO) at Box 354400 or hand carry it to the Radiation Safety Lab in HSB T556. The RSO's copy will be placed in the individual's dosimetry file and kept as part of their permanent record.

Results which indicate a concentration of more than 0.001  $\mu Ci/ml$  must be immediately reported to Radiation Safety (206-543-6328) and arrangements made to provide a urine sample for analysis by an outside organization.

## F. Personnel Exposure Records

### 1. Monthly Reports

#### a. Processing

Dosimeters are due at the Radiation Safety Office by the 15<sup>th</sup> of each month. Upon receipt, the dosimetry service provider processes the dosimeters and then sends two copies of the monthly report to the RSO.

#### b. Report copies

- 1) The original copy of the monthly report is retained by the RSO.
- 2) The duplicate copy is sent to the Area Dosimetry Coordinator (ADC) for posting.

#### c. No Exposure Reading

“Absent” in column 5 of the report indicates an unreturned dosimeter. If the dosimeter is lost, report it to the RSO.

### 2. Annual Reports

All individuals assigned a dosimeter and/or had an internal radiation exposure (bioassay) greater than “0” will receive an annual report. In the spring, these reports are sent to the ADC for distribution to participants. Duplicate copies are kept by the RSO.

An individual may request information about their exposure history at any time by calling the RSO.

### 3. Request for Exposure History

There are situations where individual records of exposure history may be generated.

#### a. Individual Request

An individual may request a record of their exposure history. The individual’s supervisor may also make this request for exposure history.

#### b. Former Worker Request

A subsequent employer, or a worker formerly employed at the UW may request a record of the worker’s exposure history.

### **c. Terminating Worker Request**

A worker who is terminating their employment at the UW may request a record of their personal exposure history. This record can be provided to the worker or the worker's designee. If the most recent individual monitoring results are not available at that time, a written estimate of the dose will be provided along with a disclaimer that this is only an estimate.

## **4. Notification of Concurrent Employment**

### **a. State Regulations**

Under State regulations, the University of Washington must ensure that worker doses are within the annual occupational limits. These annual limits apply regardless of whether the exposure is received solely at the University of Washington, or at some combination of UW along with other facilities. If an individual goes to work at another facility while still employed by the University of Washington, the UW retains the responsibility to track the combined occupational dose.

### **b. UW Radiation Worker's Responsibility**

Any worker who is currently issued a dosimeter by the University of Washington must inform the Radiation Safety Office if another employer (concurrently) monitors their radiation exposure. This information must be provided in writing to the Radiation Safety Office and must include the name, address, and telephone number of the other employer as well as the dates of employment at the other facility. Such notification is only necessary when an individual concurrently receives dosimeters or bioassays at UW and non-UW facilities.

It is not required if the individual terminates employment at the University of Washington before working for the other facility or if the individual works at a job that does not require dosimeters or bioassays.