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# Design and Operation of Internal Dosimetry Programs

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A Professional Enrichment Program Session Presented at the 24th Midyear Topical Meeting of the Health Physics Society in Raleigh, North Carolina on January 20, 1991

## Abstract

The proposed revision to USNRC 10 CFR 20 and the USDOE Order 5480.11 require intakes of radioactive material to be evaluated. Radiation dose limits are based on the sum of effective dose equivalent from intakes and the whole body dose from external sources. These significant changes in the regulations will require, at a minimum, a complete review of personnel monitoring programs to determine their adequacy.

In this session we will review a systematic method of designing a routine personnel monitoring program that will comply with the requirements of the new regulations. Specific questions discussed are:

a. What are the goals and objectives of a routine personnel monitoring program?

b. When is a routine personnel monitoring program required?

c. What are the required capabilities of the routine personnel monitoring program?

d. What should be done with the information generated in a personnel monitoring program?

Specific recommendations and interpretations are given in the session.

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# Design and Operation of Internal Dosimetry Programs

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A Professional Enrichment Program Session Presented at the 24th Midyear Topical Meeting of the Health Physics Society in Raleigh, North Carolina on January 26, 1991



## Objectives

Discuss approaches to systematically designing a routine personnel monitoring program that complies with the requirements of the USNRC or USDOE.

basic criteria and performance objectives —system of rules→ personnel monitoring



## Overview

- Review some terminology and basic concepts
- Discuss when routine personnel monitoring is required
- Discuss what monitoring methods should be used
- Discuss how frequently monitoring should be done
- Briefly outline what should be done with monitoring results
- Briefly discuss assessing chronic intakes
- Briefly discuss controlling exposures with personnel monitoring
- Discuss additional topics of interest



## Resources

USNRC 10 CFR Part 20 (effective 1-1-92)

USDOE Order 5480.11 (effective 1-1-89)

NCRP 87, Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition

ICRP 54, Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation

USDOE Draft Performance Standard for Internal Dosimetry Programs



## Dose Terminology

EDE - effective dose equivalent

Annual EDE - sum of EDE from internal and external sources received in a calendar year

Committed EDE - EDE received in the 50 years following an intake of radioactive material

Total EDE - sum of CEDE from intakes and EDE from external sources received in a calendar year

12-month EDE - EDE received in the 12-months following an intake of radioactive material

Routine personnel monitoring programs tend to be designed around effective dose equivalent rather than organ dose equivalent because the design doses are considerably below any organ threshold.



## Routine Personnel Monitoring

Monitoring personnel for exposure to and intake of radioactive material at prescribed times, i.e., not in response to an incident.

Can consist of

a. bioassay, both in-vivo and in-vitro, and

b. breathing zone air sampling (fixed and personal).

## Routine Workplace Monitoring

Monitoring the workplace to detect and assess exposure of workers to radioactive materials.

Can consist of

a. area air sampling, and

b. contamination surveys.



## Role of Personnel and Workplace Monitoring

Two exposure scenarios are usually encountered:

a. The worker is exposed intentionally.

b. The worker is exposed inadvertantly.

For intentional exposures, workplace monitoring, not personnel monitoring, should be the primary means of controlling exposures.

For inadvertant exposures, workplace monitoring, not personnel monitoring, should be the primary means of detecting exposures.



## Purposes of Routine Personnel Monitoring

a. Detect inadvertant intakes, i.e., a QC check on the workplace monitoring program.

b. Assess chronic intakes.

c. Control exposures to radioactive materials in special cases.



## Probability of Worker Exposure

Three classifications of the likelihood of worker exposure are

a. Worker is "likely" to receive over a specified EDE.

b. Worker is "not likely" to receive over a specified EDE but still has a reasonable potential for exposure to radioactive materials.

c. Worker has no reasonable potential to be exposed to radioactive materials.

The methods and frequencies selected for routine personnel monitoring will depend on the classification a worker is given.



## When is Routine Personnel Monitoring Required?

Routine personnel monitoring is required for workers likely to receive

a. > 500 mrem CEDE (USNRC), or

b. > 100 mrem CEDE (USDOE).

This required program is referred to as a worker monitoring program.



## USDOE 5480.11 g.2

"Such programs are required for radiation workers exposed to surface or airborne radioactive contamination where the worker could receive 0.1 rem (0.001 sievert) 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 (0.05 sievert) annual dose equivalent"

## AEDE?

Because AEDE includes dose from previous years, it is unsuitable for designing internal dosimetry programs. Suitable alternatives to AEDE are CEDE and 12-month EDE.

CEDE was selected as best interpretation of the USDOE Order because

a. Definition of radiation worker in the Order mentions 100 mrem CEDE plus EDE from external sources.

b. USDOE endorses use of CEDE for design and operation of facilities.



## Worker Monitoring

The goal of the routine worker monitoring program is to ensure that workers who receive a dose of regulatory significance are identified and the dose properly assessed and assigned.

Worker monitoring is the most rigorous routine personnel monitoring program and works in concert with the workplace monitoring program.



## Performance Objectives for Worker Monitoring: USDOE

The Internal Dosimetry DOELAP specifies that a worker monitoring program in a USDOE facility must be able to detect 100 mrem 12-month EDE from intakes in a calendar year for each independent source.

One source is independant from another if an intake from the first source does not imply an intake from the second source.

Specifing the performance objective for each independant source simplifies the design of monitoring programs for personnel who work in multiple facilities and/or different rooms in one facility.



## Performance Objectives for Worker Monitoring: USNRC

Because worker monitoring is required by the USNRC at 500 mrem CEDE, it is reasonable to conclude that the program must detect doses at the same level, i.e., 500 mrem CEDE in a calendar year.

Although not specified, USNRC facilities should consider using the independant source concept because of its convenience.



## Technical Shortfall

All radioactive materials can be detected at the USNRC and USDOE performance objectives with the appropriate monitoring program consisting of breathing zone air sampling and bioassay.

The performance objectives are convenient guides for designing routine personnel monitoring programs. In any event, the personnel monitoring program must be able to detect intakes that would cause an individual to exceed 5 rem AEDE (USDOE) or 5 rem TEDE (USNRC).



## Summary of Worker Monitoring

| | USDOE | USNRC |
|---|---|---|
| Worker monitoring required | >100 mrem CEDE | >500 mrem CEDE |
| Program must detect from each independent source | 100 mrem 12-month EDE | 500 mrem CEDE |

## Workgroup Monitoring

If a worker is not likely to exceed 100 mrem CEDE (USDOE) or 500 mrem CEDE (USNRC) he is not required to be on a monitoring program.

But, if the worker still has a reasonable potential for exposure to radioactive materials you may elect to place him on a workgroup monitoring program to supplement the workplace monitoring program.



## The Workgroup

A workgroup is a collection of workers with approximately the same potential for exposure to the same radioactive materials.

Any one member of the workgroup is assumed to be exposed to the same materials at the same time as any other member of the workgroup.

Therefore, by monitoring one worker in the workgroup we can in theory monitor all the workers.



## Statistical Monitoring

Some fraction of the workgroup members should be monitored so that information is received from the workgroup at even intervals throughout the year. NCRP 87 recommends the following fractions:

> 100 workers - sample 10% of the workers

10 to 100 workers - sample 10 workers

< 10 workers - sample all the workers



## Things to Remember About Workgroup Monitoring

Workgroup monitoring is a minimal personnel monitoring program for workers who are not being exposed to radioactive material. The primary purpose of workgroup monitoring is to verify that workplace monitoring is adequate and that workers are indeed not being exposed.

If one worker in a workgroup has an intake you must assume that all workers in the workgroup had an intake and respond accordingly.



## Performance Objectives for Workgroup Monitoring

Performance objectives for workgroup monitoring are less stringent than those for worker monitoring (because the workers are not being exposed) and are given in terms of the workgroup and not the individual worker.

The Internal Dosimetry DOELAP requires a workgroup monitoring program in concert with the workplace monitoring program to detect 100 mrem CEDE for the workgroup in a calendar year from each independent source.

A performance objective of 500 mrem CEDE for the workgroup and workplace monitoring programs in a calendar year for each independent source would be reasonable for USNRC regulated facilities.



## Example of Workgroup Monitoring

If monthly urine bioassay is required to achieve the workgroup performance objective then 12 members of the workgroup may be selected to submit urine samples once a year, each in a different month.

## Technical Shortfall

If for some reason the performance objectives for workgroup monitoring are not achieved, then the following actions should be taken:

a. The reasons for not meeting the performance objective should be documented along with the capabilities of the current workgroup and workplace program.

b. The evidence for assigning the personnel to a workgroup program rather than a worker program should be reexamined to determine its validity.

c. Consideration should be given to placing some members of the workgroup on a worker monitoring program to verify the workplace monitoring program.



## Restrictions on Workgroup Monitoring

The following workers should not be on a workgroup monitoring program:

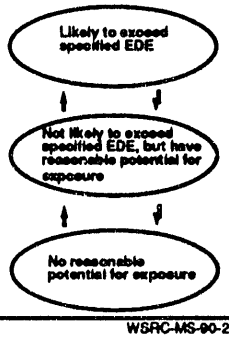
a. Workers with radioactive material in their bodies that interferes with detection and assessment of additional intakes.

b. Workers who use respiratory protection.

c. Workers entering Airborne Radioactivity Areas.



## Monitoring Programs




workplace monitoring and personnel monitoring

workplace monitoring and minimal personnel monitoring

minimal workplace monitoring



## Summary

We have discussed

a. when worker and workgroup monitoring is required, and

b. what doses each monitoring program should detect.

We now need a method for selecting bioassay types and frequencies that will permit us to detect doses at the performance objectives.

One such method is called a missed dose analysis.



## Missed Dose

A bioassay that results in a "less-than detectable amount" can always be associated with a certain intake at a given time before the bioassay. This intake will deliver an EDE that is not detected - a "missed dose."

Select monitoring type and frequency so that missed dose is less than the performance objectives.



## Missed Dose

$$D(t) = DCF\ MDA / IRF(t)$$

D(t) = missed dose for bioassay at time t after intake.

DCF = intake to dose conversion factor, either CEDE or 12-month EDE.

MDA = minimum detectable amount of bioassay method.

IRF(t) = the fraction of an acute intake that will be present in the bioassay compartment measured by the bioassay method at time t after intake.

Note that D(t) is the missed dose for the time t, which may not be the same as the annual missed dose we seek.

## Example of Missed Dose

MDA = 56 nCi Ce-144 and 14 nCi Ce-141 for 2 minute whole body count

DCF = 0.38 mrem/nCi CEDE for class Y 1.0 um Ce-144 and 0.009 mrem/nCi CEDE for class Y 1.0 um Ce-141

| | Time (days) | IRF(t) | D(t) mrem |
|---|---|---|---|
| Ce-144 | 30 | 0.1395 | 150 |
| | 90 | 0.1143 | 190 |
| | 180 | 0.0850 | 250 |
| | 365 | 0.0467 | 450 |

| | Time (days) | IRF(t) | D(t) mrem |
|---|---|---|---|
| Ce-141 | 30 | 0.0792 | 2 |
| | 90 | 0.0209 | 6 |
| | 180 | 0.0028 | 44 |
| | 365 | 0.0001 | 2700 |



## Missed Dose for Ce-144

Missed dose at 90 days after intake is 190 mrem. Assuming no buildin, the annual missed dose is

4 x 180 mrem = 720 mrem.

But, the missed dose at 365 days after intake is 450 mrem, so the annual missed dose must be less than 450 mrem.

We will assume the annual missed dose for quarterly whole body counts for class Y Ce-144 is 450 mrem. If this conservative estimate causes problems, a more complicated analysis may be performed.



## Missed Dose for Ce-141

Missed dose at 90 days after intake is 6 mrem. Assuming no buildin, the annual missed dose is

4 x 6 mrem = 24 mrem.

The missed dose at 365 days after intake is 2700 mrem, so the annual missed dose must be less than 24 mrem.

We will assume the annual missed dose for quarterly whole body counts for class Y Ce-141 is 24 mrem. If this conservative estimate causes problems, a more complicated analysis may be performed.



## MDA

When we refer to MDA we usually mean that quantity of material that will have a 5% chance of a false negative while at the same time having a 5% chance of a false positive in a blank sample.

In practice, a truely meaningful MDA can be difficult to obtain, so do the best you can.

There are no "acceptable MDAs" for an occupational personnel monitoring program. In particular, the AMDAs given in ANSI N13.30 are not intended for use in occupational bioassay programs.



## Intake Patterns

If the retention function is monotonically decreasing, an acute intake at time zero will give a larger missed dose than an equal intake given in any other pattern. Most missed dose tables are therefore based on the conservative assumption of acute intakes.

Missed dose analysis gives a minimal program for chronic or recurring intakes. Controlling exposures and assessing the chronic intakes will usually require more frequent monitoring than indicated by a missed dose analysis.



## Monitoring Methods

The monitoring method selected should meet the performance objectives. Other considerations in selecting the method are

a. Bioassay should always be used to augment breathing zone air sampling.

b. Urine, feces, and chest counting should all be used in some capacity for worker monitoring for actinides that may be retained in the lungs for long periods of time.

## Radionuclides of Interest in a Mixture

The radionuclides of interest in a mixture are those that

a. contribute more than 90% of the CEDE, or

b. are useful as tracers for the mixture.



## Tracers

The radionuclide in a mixture that has the highest activity relative to its MDA will be detected at the lowest level. For example, in a 50% Ce-144 / 50% Ru-106 mixture, at one year after the intake Ru-106 is detected first:

| Nuclide | Activity / MDA |
|---|---|
| Ce-144 | (0.047)(0.5) / 55 = 0.00042 |
| Ru-106 | (0.055)(0.5) / 25 = 0.0011 |

In an 80% Ce-144 / 20% Ru-106 mixture, Ce-144 is detected first:

| Nuclide | Activity / MDA |
|---|---|
| Ce-144 | (0.047)(0.8) / 55 = 0.00068 |
| Ru-106 | (0.055)(0.2) / 25 = 0.00044 |



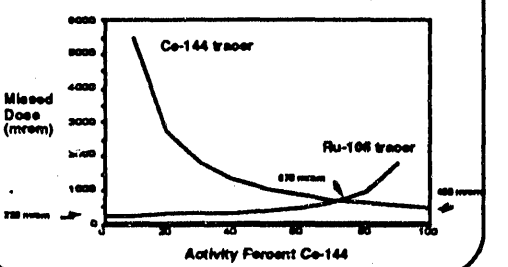
## Mixture Paradox

For a mixture of radioactive materials there is a certain proportion of components that will produce a missed dose that is equal to or greater than the sum of the missed dose of the individual components.

For example, let us examine the missed dose for a mixture of class Y Ce-144 and class Y Ru-106 for an annual whole body count.



## Missed Dose for Ce-144/ Ru-106 Mixture for Annual WBC






## Solving the Mixture Paradox

Three approaches to solving the paradox are

a. Characterize the composition of radioactive materials in your facility and select a suitable design mixture.

b. Design the program based on the single most restrictive component present in the mixture.

c. Design the program based on the missed dose for the sum of all radionuclides that sound be present in the mixture.



## Missed Dose for BZA

Assuming

a. MDA of 0.0006 nCi for alpha emitter on gas flow proportional counter,

b. BZA sampling rate 2 l/m,

c. sampling period 8 h/d,

d. breathing rate 20 l/m, and

e. DCF in mrem/nCi,

then the missed dose per day for a BZA is

D = (0.0006 nCi)(20 l/m)/(2 l/m) DCF = 0.006DCF mrem.

Assuming 250 work days per year, the annual missed dose is 1.5DCF. For class Y U-234, this is 195 mrem CEDE. For class Y Pu-239, this is 460 mrem CEDE. Lower missed doses may be achieved by compositing samples and performing radiochemistry.

## Missed Dose for Chest Count

Based on missed dose, routine chest counts for uranium and transuranics are of little use. Routine annual chest counts are still recommended because

a. they monitor for the buildup of long-lived material in the lung,

b. they help ensure that the chest counter will be working properly when it is really needed - for special monitoring.

c. they provide baseline data that is useful for evaluating subsequent positive counts, and

d. the missed dose tables may not accurately describe the detection capability for a specific person.



## Limitations of Missed Dose

A missed dose analysis provides a systematic way of selecting monitoring methods and frequencies that will meet USNRC or USDOE monitoring requirements.

A missed dose analysis will usually provide a minimal personnel monitoring program. Most health physicist, for one reason or another, tend to increase the frequency over that derived in the missed dose analysis.

A generic missed dose analysis can not ensure that a particular worker has not exceeded a given dose. This is particularly true for workers who have radioactive material in their bodies that interferes with detection and evaluation of additional intakes.

Missed dose addresses detection of intakes, not the accuracy of the intake assessment.



## Summary

We have discussed

a. when a routine personnel monitoring program is required,

b. the performance objectives for these programs,

c. how to use missed dose to select a monitoring method and frequency that would meet the performance objectives.

We now need to address how assessing chronic intakes and controlling exposures will influence the routine program.



## Assessing Chronic Intakes

We need to monitor frequently enough to resolve significant changes in excretion or retention. Here we are concerned with accuracy in addition to detection. The frequency you select should be based on

a. the biokinetics of the material,

b. fluctuations in the exposures,

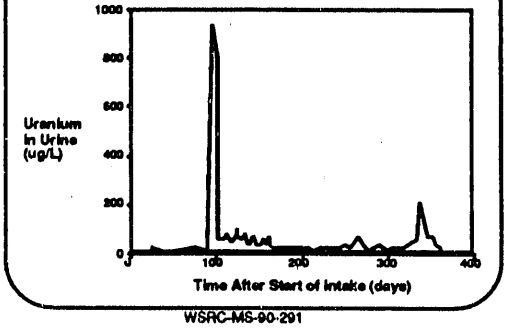
c. the time required for analysis of bioassay and BZA samples, and

d. previous experience.

A BZA will probably be required to assess chronic intakes in terms of CEDE.



## Chronic Uranium Intake






## Controlling Exposures

If routine personnel monitoring is used to control exposures of personnel, then the frequency should be based on

a. how quickly things can go bad,

b. how bad things can get,

c. the time required for analysis of bioassay and BZA samples, and

d. capabilities of workplace monitoring.

## Baseline and Termination Bioassay

Obtain baseline on all types of bioassay that will be performed on a worker prior to work in restricted areas.

Obtain termination bioassay on all workers terminated from the routine personnel monitoring program.



## Results from Program

The routine personnel monitoring program will generate alot of results, some of which are bound to be positive. We need to decide on reference levels:

a. Recording level - result we will keep and interpret in terms of CEDE and/or AEDE.

b. Investigation level - result that will trigger a special bioassay program, a review of workplace monitoring, or an investigation of the root cause of an intake.

c. Intervention level - result that will trigger work restrictions in addition to an investigation.



## Recording Level

All results of personnel monitoring programs should be recorded.

You must select criteria for deciding whether or not activity above background is present in a sample or a person and apply these criteria to every analysis.

If a positive result is not expected it should be interpreted in terms of EDE.

If a positive result is expected it should be interpreted immediately in terms of EDE if it is significantly higher than expected.



## Investigation Level

Investigation levels should be based to a large degree on experience with what is typical in a facility, i.e., unusual results should be investigated. Specific guidance on investigation levels is not given in 10 CFR 20 or 5480.11.

Reasonable numerical guidelines are:

a. USNRC - investigate incidents that, on the basis of early monitoring results, are likely to exceed 500 mrem CEDE.

b. USDOE - investigate incidents that, on the basis of early monitoring results, are likely to exceed 100 mrem 12-month EDE.



## Intervention Level

Both USNRC and USDOE facilities should impose work restrictions and investigate incidents where, on the basis of early monitoring results, workers are likely to exceed 5 rem CEDE.

In addition, USDOE facilities should impose work restrictions if a worker could exceed 5 rem AEDE.



## Summary

- Terminology and basic concepts
- When routine personnel monitoring is required
- What monitoring methods should be used
- How frequently monitoring should be done
- What should be done with monitoring results
- Monitoring for assessing chronic intakes
- Monitoring for controlling exposures
- Other topics

## Topics for Next Workshop

**Special Personnel Monitoring, Intake Assessment, and Dose Assessment**

a. Designing special bioassay programs.

b. Evaluating bioassay data.

c. The role of breathing zone air monitoring.

d. The role of computer codes in intake assessment.

e. Assigning dose.

# Design and Operation of Internal Dosimetry Programs

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A Professional Enrichment Program Session Presented at the 24th Midyear Topical Meeting of the Health Physics Society in Raleigh, North Carolina on January 20, 1991

## Preface

In my oral presentation I describe a systematic method for designing routine personnel monitoring programs. To help clarify the method I have provided this document which gives you an some examples of how one might go about implementing the ideas discussed at a USDOE facility. The program for a USNRC facility would look very similar.

Section 1 gives the information necessary to calculate missed doses for routine bioassay methods and various radionuclides of interest. Section 2 uses this information to design generic worker and workgroup monitoring programs for personnel exposed to radioactive materials. A third section, which is not provided, would use the information given in Section 2 along with facility specific information to produce the routine personnel monitoring program for a facility. This final section would take into account other factors in addition to missed dose.

As I stress in the presentation, the great strength of this approach is that it forces you to

a. logically define the goals of your monitoring program,

b. select monitoring techniques that allow you to achieve your goals, and

c. properly document the technical basis for the program.

## 1.0 Missed Dose Tables

For a given intake scenario and bioassay program, the missed dose is the maximum effective dose equivalent associated with a less-than-MDA bioassay result. These tables are used to design routine bioassay programs needed to comply with dose performance goals and should not be used for any other purpose. The tables were calculated with the following information:

a. The Minimum detectable amounts (MDA) for all bioassay techniques used, which are given in section 1.1.

b. Intake to dose conversion factors (DCF), which are given in section 1.2.

c. Intake retention fraction (IRF) tables, which are given in section 1.3.

### 1.1 Minimum Detectable Amounts

The minimum detectable amount (MDA) quoted for each radiobioassay method is that quanitity of material that has a 5% chance of not being detected under the assay conditions indicated. The MDA is a representative quantity used to design internal dosimetry programs. The MDA should not be used to decide if a specific radiobioassay has detected activity or not.

Whole-body counts are performed with a "quick" counter which uses two large NaI detectors. The routine count time for the whole body count is 2 minutes.

Chest counts for low energy photon emitters is performed with a pair of thin NaI-CsI phoswich detectors or a planar germanium detector array. The routine count time for a chest count is 30 minutes.

Silicon surface barrier detectors are used for both gross alpha and alpha spectrometry measurements of alpha emitters in urine. The typical count time is 1000 minutes.

Tritium in urine is quantified by liquid scintillation counting of a 0.5 ml sample for 1 minute.

Fecal samples are processed by an off-site vendor. The MDA for alpha emitting isotopes of thorium, uranium, neptunium, plutonium, americium, and curium is 0.1 pCi per sample. The MDA for Sr-89 and Sr-90 in feces is 20 pCi per sample.

| Radionuclide | MDA for Urine Bioassay (pCi) | MDA for Whole-body Count (nCi) | MDA for Chest Count (nCi) |
|---|---|---|---|
| Cf-252 | 0.2 | NA | 30 |
| Cm-242 | 0.2 | NA | 27 |
| Cm-244 | 0.2 | NA | 29 |
| Am-241 | 0.2 | NA | 0.13 |
| Pu-238 | 0.02 | NA | 43 |

| Radionuclide | MDA for Urine Bioassay (pCi) | MDA for Whole-body Count (nCi) | MDA for Chest Count (nCi) |
|---|---|---|---|
| Pu-239 | 0.02 | NA | 110 |
| Np-237 | 0.2 | 13 | 0.35 |
| U-234 | 0.4 | NA | 43 |
| U-235 | 0.4 | 13 | 0.10 |
| U-236 | 0.4 | NA | 91 |
| U-238 | 0.4 | NA | 1.1 |
| Th-228 | 0.1 | NA | 3.4 |
| Th-232 | 0.1 | NA | 28 |
| Eu-152 | NA | 16 | 0.13 |
| Eu-154 | NA | 10 | NA |
| Ce-141 | NA | 14 | 0.10 |
| Ce-144 | NA | 55 | 0.43 |
| Ba-140 | NA | 17 | NA |
| La-140 | NA | 3 | NA |
| Cs-134 | NA | 4 | NA |
| Cs-137 | NA | 3 | NA |
| I-131 | NA | 4 | NA |
| I-133 | NA | 5 | NA |
| Sb-125 | NA | 13 | NA |
| Ru-103 | NA | 5 | NA |
| Ru-106 | NA | 25 | NA |
| Zr-95 | NA | 5 | NA |
| Nb-95 | NA | 2 | NA |
| Sr-89 | 6 | NA | NA |
| Sr-90 | 6 | NA | NA |
| Zn-65 | NA | 4 | NA |
| Co-58 | NA | 4 | NA |
| Co-60 | NA | 4 | NA |
| Fe-59 | NA | 6 | NA |
| Mn-54 | NA | 4 | NA |
| H-3 | 20000 | NA | NA |

NA = not applicable, method not used.

## 1.2 Intake to Dose Conversion Factors

Intake to effective dose equivalent conversion factors are presented in Table 1 and 2 for two time intervals:

a. 50 years following the intake, i.e., the committed effective dose equivalent, and

b. 12 months following the intake, i.e., the 12-month effective dose equivalent.

Table 1. Intake to dose conversion factors for thorium, uranium and transuranics. Please note that this table has the units of mrem/nCi.

| Radionuclide | | Committed mrem/nCi | 12-month mrem/nCi | Reference |
|---|---|---|---|---|
| Cf-252 | W | 140 | 43 | RADOSE |
| Cf-252 | Y | 160 | 62 | RADOSE |
| Am-241 | W | 450 | 20 | RADOSE |

| Radionuclide | | Committed mrem/nCi | 12-month mrem/nCi | Reference |
|---|---|---|---|---|
| Cm-242 | W | 17 | 13 | RADOSE |
| Cm-244 | W | 250 | 21 | RADOSE |
| Pu-238 | W | 390 | 20 | RADOSE |
| Pu-238 | Y | 290 | 32 | RADOSE |
| Pu-239 | W | 420 | 18 | RADOSE |
| Pu-239 | Y | 300 | 29 | RADOSE |
| Pu-241 | W | 10 | 0.014 | Dunning |
| Pu-241 | Y | 5.8 | 0.026 | Dunning |
| Np-237 | W | 370 | 16 | RADOSE |
| U-234 | D | 2.7 | 0.85 | RADOSE |
| U-234 | W | 7.9 | 7.3 | RADOSE |
| U-234 | Y | 130 | 27 | RADOSE |
| U-235 | D | 2.5 | 0.79 | RADOSE |
| U-235 | W | 7.3 | 6.7 | RADOSE |
| U-235 | Y | 120 | 25 | RADOSE |
| U-236 | D | 2.5 | 0.82 | Dunning |
| U-236 | W | 7.4 | 6.8 | Dunning |
| U-236 | Y | 130 | 26 | Dunning |
| U-238 | D | 2.4 | 0.76 | RADOSE |
| U-238 | W | 7.0 | 6.4 | RADOSE |
| U-238 | Y | 120 | 24 | RADOSE |
| Th-228 | W | 250 | 100 | Dunning |
| Th-228 | Y | 340 | 160 | Dunning |
| Th-232 | W | 1600 | 16 | Dunning |
| Th-232 | Y | 1200 | 25 | Dunning |

Table 2. Intake to dose conversion factors for fission and activation products. Please note that this table has the units of mrem/$\mu$Ci.

| Radionuclide | | Committed mrem/$\mu$Ci | 12-month mrem/$\mu$Ci | Reference |
|---|---|---|---|---|
| Eu-152 | W | 220 | --- | EPA |
| Eu-154 | W | 290 | --- | EPA |
| Ce-141 | W | 8.3 | 8.3 | Dunning |
| Ce-141 | Y | 9.0 | 8.9 | Dunning |
| Ce-144 | W | 220 | 160 | Dunning |
| Ce-144 | Y | 380 | 260 | Dunning |
| Ba-140 | D | 3.7 | 3.7 | Dunning |
| La-140 | D | 3.4 | 3.4 | Dunning |
| La-140 | W | 4.8 | 4.8 | Dunning |
| Cs-134 | D | 46 | 43 | Dunning |
| Cs-137 | D | 32 | 29 | Dunning |
| I-131 | D | 33 | 33 | Dunning |
| I-133 | D | 5.9 | 5.9 | Dunning |
| Sb-125 | D | 2.1 | --- | EPA |
| Sb-125 | W | 12 | --- | EPA |
| Ru-103 | D | 3.1 | 3.1 | Dunning |
| Ru-103 | W | 6.5 | 6.5 | Dunning |
| Ru-103 | Y | 9.0 | 9.0 | Dunning |
| Ru-106 | D | 57 | 40 | Dunning |
| Ru-106 | W | 120 | 110 | Dunning |
| Ru-106 | Y | 480 | 310 | Dunning |
| Zr-95 | D | 24 | 23 | Dunning |
| Zr-95 | W | 16 | 16 | Dunning |
| Zr-95 | Y | 23 | 23 | Dunning |

| Radionuclide | | Committed mrem/μCi | 12-month mrem/μCi | Reference |
|---|---|---|---|---|
| Nb-95 | W | 4.8 | 4.8 | Dunning |
| Nb-95 | Y | 5.8 | 5.8 | Dunning |
| Sr-89 | D | 6.6 | 6.5 | Dunning |
| Sr-89 | Y | 41 | 41 | Dunning |
| Sr-90 | D | 220 | 35 | Dunning |
| Sr-90 | Y | 1300 | 320 | Dunning |
| Zn-65 | Y | 20 | 16 | Dunning |
| Co-58 | W | 6.4 | 6.3 | Dunning |
| Co-58 | Y | 11 | 11 | Dunning |
| Co-60 | W | 33 | 27 | Dunning |
| Co-60 | Y | 220 | 79 | Dunning |
| Fe-59 | D | 15 | 15 | Dunning |
| Fe-59 | W | 12 | 12 | Dunning |
| Mn-54 | D | 5.3 | 5.2 | Dunning |
| Mn-54 | W | 6.7 | 6.6 | Dunning |
| H-3 | - | 0.060 | 0.060 | Dunning |

## 1.3 Intake Retention Fraction Tables

The intake retention fraction IRF is the fraction of an acute inhalation intake I expected to be present in bioassay compartment at time T following the intake:

$$IRF = q / I ,$$

where q is the quantity of material in B at time T. The IRF tables given in Tables 3 through 7 were generated with INDOS for stable elements (radioactive decay was accounted for in the calculation of the missed dose tables).

## 1.4 Missed Dose Tables

Given

a. the intake retention fraction IRF for time T and bioassay type B,
b. the minimum detectable amount MDA for B in nCi, and

c. the dose conversion factor DCF for the intake I in mrem/nCi,

the missed dose D in mrem is given by

$$D = DCF \cdot MDA / IRF \quad mrem.$$

The values for missed committed and 12-month effective dose equivalent are given in Tables 8 through 15 for pure radionuclides for the indicated bioassay period.

The missed dose for a bioassay period other than 365 days is determined by dividing the missed dose by the fraction of a year the bioassay period represents. If this dose is lower than the 365 day missed dose then it is used, if it is not, then the 365 day missed dose is used. For example, referring to Table 10, the missed committed dose for a 180 day whole-body count for Eu-154 is 47 mrem. The missed dose for the year is thus 47 mrem/0.5 = 94 mrem.

The missed dose for an annual whole-body count is 55 mrem, and because it is less than 94 mrem it is used as the missed dose for semi-annual whole-body counts. Strictly speaking, the missed dose is less than 55 mrem, but this approximation does not indicate how much lower.

The missed dose for a mixture of radionuclides may be calculated from the tables in the following manner. Assume, for example, that the missed committed effective dose equivalent is needed for annual chest counts for commercial-grade class Y enriched uranium, which has the following composition:

| Isotope | Mass Fraction | Activity Fraction | MDA (nCi) | Missed Dose (mrem) |
|---|---|---|---|---|
| U-234 | 0.0003 | 0.82774 | 43 | 54000 |
| U-235 | 0.0296 | 0.02825 | 0.10 | 120 |
| U-238 | 0.9701 | 0.14401 | 1.1 | 1300 |

The radionuclide that has the most activity relative to its MDA will be detected at the lowest level. Assuming negligible radioactive decay and identical biological elimination rates:

| Isotope | Activity / MDA |
|---|---|
| U-234 | 0.82774 / 43 = 0.019 |
| U-235 | 0.02825 / 0.10 = 0.28 |
| U-238 | 0.14401 / 1.1 = 0.13 |

Thus, U-235 will be detected in this mixture before any of the other uranium isotopes. The intake I of U-235 that would produce a lung content of 0.1 nCi (the MDA) one year after the intake is given by the ratio of the missed dose D and the dose conversion factor DCF:

$$I = D / DCF = 120 \text{ mrem} / 120 \text{ mrem/nCi} = 1 \text{ nCi}.$$

The missed dose $D_j$ for component j with activity fraction $f_j$ is given by

$$D_j = (1 \text{ nCi})(f_j/f_{U-235})\ DCF_j \quad \text{mrem}.$$

Thus, the missed dose $D_{U-234}$ for U-234 is

$$(1 \text{ nCi})(0.82774/0.02825)(130 \text{ mrem/nCi}) = 3800 \text{ mrem}.$$

The missed dose $D_{U-238}$ for U-238 is

$$(1 \text{ nCi})(0.14401/0.02825)(120 \text{ mrem/nCi}) = 610 \text{ mrem}.$$

The missed dose for the uranium mixture is the sum of the missed dose for its components, 4530 mrem.

## 1.5 Missed Dose For Intakes of Tritiated Water

Workers frequently have chronic or repeated intakes of tritiated water. Missed dose tables for such intakes are difficult to generate and read. Therefore, the missed dose for tritium is presented as the concentration of tritium in urine at various times following intakes in a year that will deliver a committed effective dose equivalent of 10 mrem (approximately 170 μCi of tritiated water). Four intake patterns are presented:

a. an intake of 170/365 μCi at the beginning of every day for a year (Figure 1),

b. an intake of 170/52 μCi at the beginning of every week for a year (Figure 2),

c. an intake of 170/12 μCi at the beginning of every month for a year (Figure 3), and

d. an intake of 170/4 μCi at the beginning of every three months for a year (Figure 4).

## 1.6 Chemical Toxicity of Uranium

Chemical toxicity is a concern for low specific activity uranium. Assuming standard ICRP 30 biokinetic models, the intakes of uranium that would cause an individual to exceed the 900 μg nephrotoxic limit (Spoor 1973) are

| Class | Intake (mg) |
|---|---|
| D | 20 |
| W | 99 |
| Y | 1900 |

The following table gives ICRP 30 stocastic ALIs for uranium isotopes in terms of activity and mass:

| | class D | | class W | | class Y | |
|---|---|---|---|---|---|---|
| Isotope | (nCi) | (mg) | (nCi) | (mg) | (nCi) | (mg) |
| U-234 | 1900 | 0.30 | 700 | 0.11 | 38 | 6.1E-3 |
| U-235 | 2000 | 940 | 760 | 350 | 41 | 19 |
| U-236 | 2000 | 30 | 760 | 12 | 41 | 0.63 |
| U-238 | 2000 | 6300 | 780 | 2300 | 43 | 130 |

The following table gives the concentration of uranium in the urine at various times following a 20 mg intake of class D uranium and a 99 mg intake of class W uranium.

| Time After Intake (days) | Uranium Excreted in Urine After a Class D Intake (μg/day) | Class W Intake (μg/day) |
|---|---|---|
| 1.00 | 3900 | 4200 |
| 7.00 | 190 | 210 |
| 15.00 | 94 | 130 |
| 30.00 | 34 | 72 |
| 60.00 | 9.0 | 41 |
| 90.00 | 3.1 | 27 |
| 180.00 | 0.17 | 9.4 |
| 365.00 | 0.033 | 1.1 |

## 1.7 Missed Dose for Lapel Air Samplers

Lapel air samplers may be used for two purposes:

a. The filter paper is counted at the end of each shift to determine if the individual was exposed to relatively high levels of radioactive material.

b. The filter paper is held for two weeks (to allow the radon daughters to decay) and counted to quantify exposures to low levels of radioactive material.

The missed dose for case (b) above is calculated assuming

a. an MDA of 0.6 pCi for an alpha emitter on a filter paper (20 minute count on a gas-flow proportional counter),

b. a sampling rate of 2 liters per minute,

c. a sampling period of 8 hours per day,

d. a breathing rate of 20 liters per minute, and

e. a dose conversion factor (DCF) in mrem per nCi intake.

The missed effective dose equivalent for a worker would be

$$(0.6\ \text{pCi})(20\ \text{l/m})/(2\ \text{l/m})(10^{-3}\text{nCi/pCi})\ \text{DCF},$$

which equals $6 \cdot 10^{-3}$DCF mrem per day or 1.5·DCF mrem per year, assuming 250 work days per year. Because the missed dose for a particular alpha emitter is simply 1.5·DCF, tables of missed dose for lapel air samplers will not be presented. Lower missed doses may be achieved by combining filter papers and analyzing them by radiochemical methods.

## 1.8 Missed Dose for Chest Counts of Transuranics

Chest counts for transuranics have very high missed doses, so high in fact that they may seem to be of little use in a routine bioassay program. To a certain extent this is true, chest counting has its greatest usefulness in special bioassay. Routine chest counts are still performed for the following reasons:

a. they monitor the buildup of long-lived radioactive materials in the chest,

b. they help ensure that the chest counting equipment is operating properly for when it is really needed, i.e., for special chest counts,

c. they provide baseline information that can be useful for evaluating subsequent chest counts, and

d. the missed dose tables may not accurately describe the ability of a chest count to detect radioactive material in the chest for a specific application. For example, the tables do not address the use of Am-241 as a tracer for Pu-239 or the possibility of a person having a very thin chest wall (which decreases the missed dose).

The objective of this section is to point out that routine chest counts are useful but that the frequency at which they should be performed is largely a matter of professional judgement.

## 2.0 Routine Monitoring Programs

Minimum routine monitoring programs based on the DOELAP guidelines and the missed dose tables in section 1 are given for workers exposed to the following radioactive materials:

2.2 Plutonium
2.3 Transuranics Other Than Plutonium
2.4 Uranium
2.5 Thorium
2.6 Strontium
2.7 Gamma-Emitting Fission and Activation Products
2.8 Tritium

Additional monitoring may be recommended for a specific facility based on the mixtures of radionuclides encountered there and the need for addiational feedback.

## 2.1 Worker and Workgroup Monitoring Programs

Workers who are

a. likely to be exposed in excess of 40 DAC-h of a radioactive material in a calandar year,

b. use any form of respiratory protection,

c. enter Airborne Radioactivity Areas, or

d. enter a Radiation Control Area (RCA) and have radioactive material in their body that interferes with detecting and assessing additional intakes

are required to be on a worker monitoring program.

Workers who have a reasonable potential for exposure to radioactive material but do not meet any of the criteria given above shall be on a workgroup monitoring program. As a minimum, workers who enter a RCA where protective clothing is required are considered to have a reasonable potential for exposure to radioactive materials.

## 2.2 Monitoring Program for Plutonium

The worker monitoring program for plutonium shall consist of:

a. annual urine bioassay,
b. annual chest count,
c. annual fecal bioassay, and
d. personal air sampling (PAS).

The requirements for when to perform fecal sampling or PAS or both are given in the facility specific guides.

The missed 12-month effective dose equivalent in mrem for each monitoring method is given below:

| | Annual Urine Bioassay | Annual Feces Bioassay | Annual Chest Count | PAS |
|---|---|---|---|---|
| Class W Pu-238 | 83 | 150 | >250000 | <100 |
| Class W Pu-239 | 74 | 140 | >250000 | <100 |
| Class Y Pu-238 | 800 | 38 | 13000 | <100 |
| Class Y Pu-239 | 720 | 34 | 31000 | <100 |

A missed dose of less than 100 mrem for the PAS may be achieved by analysis of composited filters. Chest counting is recommended to monitor the ingrowth of Am-241 from any Pu-241 that may be retained in the lungs.

The workgroup monitoring program for plutonium shall consist of:

a. annual urine bioassay, and
b. annual chest counts

for each worker in the workgroup. This individual frequency is assumed to result in at least a monthly frequency for monitoring the workgroup.

The missed committed effective dose equivalent in mrem for each monitoring method is given below, assuming a monthly frequency for the workgroup:

| | Monthly Urine Bioassay | Monthly Chest Count |
|---|---|---|
| Class W Pu-238 | 1600 | >250000 |
| Class W Pu-239 | 1700 | >250000 |
| Class Y Pu-238 | 7300 | 120000 |
| Class Y Pu-239 | 7500 | >250000 |

Chest counting is recommended to monitor the ingrowth of Am-241 from any Pu-241 that may be retained in the lungs. A special bioassay program is required for all members of a workgroup if any member of the workgroup has a confirmed intake of radioactive material.

## 2.3 Monitoring Program for Transuranics other then Plutonium

The worker monitoring program for neptunium, americum, curium, and californium shall consist of:

a. quarterly urine bioassay,
b. annual chest count,
c. semi-annual fecal bioassay, and
d. personal air sampling (PAS).

The requirements for when to perform fecal sampling or PAS or both are given in the facility specific guides.

The missed 12-month effective dose equivalent in mrem for each monitoring method is given below:

| | Quarterly Urine Bioassay | Semi-annual Feces Bioassay | Annual Chest Count | PAS |
|---|---|---|---|---|
| Class W Np-237 | 290 | 28 | 4100 | <100 |
| Class W Am-241 | 420 | 32 | 1900 | <100 |
| Class W Cm-242 | 440 | 44 | >250000 | <100 |
| Class W Cm-244 | 460 | 34 | >250000 | <100 |
| Class W Cf-252 | 1000 | 76 | 23000 | <100 |

The relatively high missed dose for urine bioassay is the result of the high MDA for these radionuclides (0.2 pCi/L). Work is currently being done to lower the MDA by a factor of 5 to 10, which will enable annual urine bioassay to meet the design objective. Until this work is completed semi-annual feces bioassay is required. A missed dose of less than 100 mrem for the PAS may be achieved by analysis of composited filters.

The workgroup monitoring program for neptunium, americium, curium, and californium shall consist of:

a. annual urine bioassay, and
b. annual chest counts

for each worker in the workgroup. This individual frequency is assumed to result in at least a monthly frequency for monitoring the workgroup.

The missed committed effective dose equivalent in mrem for each monitoring method is given below, assuming a monthly frequency for the workgroup:

| | Monthly Urine Bioassay | Monthly Chest Count |
|---|---|---|
| Class W Np-237 | 11000 | 16000 |
| Class W Am-241 | 9500 | 6800 |
| Class W Cm-242 | 710 | 61000 |
| Class W Cm-244 | 5500 | >250000 |
| Class W Cf-252 | 3800 | >250000 |

A special bioassay program is required for all members of a workgroup if any member of the workgroup has a confirmed intake of radioactive material.

## 2.4 Monitoring Program for Uranium

The worker monitoring program for uranium shall consist of:

a. semi-annual urine bioassay,
b. annual chest count,
c. annual fecal bioassay and/or personal air sampling (PAS) if class Y uranium is present.

The requirements for when to perform fecal sampling or PAS or both are given in the facility specific guides.

The missed 12-month effective dose equivalent in mrem for each monitoring method is given below:

| | Semi-annual Urine Bioassay | Annual Feces Bioassay | Annual Chest Count | PAS |
|---|---|---|---|---|
| Class D U-234 | 80 | -- | >250000 | <100 |
| Class W U-234 | 62 | 32 | 230000 | <100 |
| CLass Y U-234 | 590 | 84 | 11000 | <100 |

U-234, U-235, U-236, and U-238 have approximately equal missed doses for urine and feces bioassay. Therefore, only U-234, which has the highest missed dose, is listed. Lower missed doses for chest counting are possible if signficant quantities of U-235 or U-238 are present. Missed dose tables should be prepared for the specific uranium mixtures encountered in each facility. A missed dose of less than 100 mrem for the PAS may be achieved by analysis of composited filters.

This monitoring program is based on radiological toxicity alone. Depending on the specific activity of the uranium, monthly urine bioassay is required to detect intakes of uranium that exceed the chemical toxicity limit. An inhalation intake of 120 nCi class D U-234, U-235, U-236, or U-238 will deliver an effective dose equivalent of 100 mrem in the 12 months following the intake. The chemically toxic acute intake of class D uranium is 20 mg. Assuming intakes of uranium that deliver 100 mrem are detected and assessed,

workers exposed to class D uranium with a specific activity lower than

$$120 \text{ nCi}/20 \text{ mg} = 6 \text{ nCi/mg}$$

require a monthly urine bioassay for elemental uranium in addition to the semi-annual isotopic uranium urine bioassay. A similar analysis shows that there are no uranium isotopes with a specific activity low enough to warrant monthly urine bioassay for class W and class Y uranium. This assumes that the chemical hazard is assessed for all intakes of uranium detected by isotopic uranium urine bioassay.

The workgroup monitoring program for uranium shall consist of:

a. annual urine bioassay, and
b. annual chest counts

for each worker in the workgroup. This individual frequency is assumed to result in at least a monthly frequency for monitoring the workgroup.

The missed committed effective dose equivalent in mrem for each monitoring method is given below, assuming a monthly frequency for the workgroup:

| | Monthly Urine Bioassay | Monthly Chest Count |
|---|---|---|
| Class D U-234 | <12 | >250000 |
| Class W U-234 | 48 | 40000 |
| Class Y U-234 | 2800 | 54000 |

A special bioassay program is required for all members of a workgroup if any member of the workgroup has a confirmed intake of radioactive material.

## 2.5 Monitoring Program for Thorium

The worker monitoring program for thorium shall consist of:

a. annual urine bioassay,
b. annual chest count,
c. semi-annual fecal bioassay, and
d. personal air sampling (PAS).

The requirements for when to perform fecal sampling or PAS or both are given in the facility specific guides.

The missed 12-month effective dose equivalent in mrem for each monitoring method is given below:

| | Annual Urine Bioassay | Semi-annual Feces Bioassay | Annual Chest Count | PAS |
|---|---|---|---|---|
| Class W Th-228 | 570 | 200 | >250000 | <100 |
| Class W Th-232 | 64 | 28 | >250000 | <100 |
| Class Y Th-228 | 5600 | 270 | 7500 | <100 |
| Class Y Th-232 | 610 | 30 | 3100 | <100 |

Unsupported Th-228 (i.e., no Th-232) is not anticipated. The relatively high missed dose for Th-228 is therefore not viewed as a problem.

The missed dose for chest counting is based on detection of photons emitted by the Th-232 or Th-228. Lower missed doses may be achieved by counting the photons emitted by the daughters. Missed doses for thorium in specific facilities should be determined.

A missed dose of less than 100 mrem for the PAS may be achieved by analysis of composited filters.

The workgroup monitoring program for thorium shall consist of:

a. annual urine bioassay, and
b. annual chest counts

for each worker in the workgroup. This individual frequency is assumed to result in at least a monthly frequency for monitoring the workgroup.

The missed committed effective dose equivalent in mrem for each monitoring method is given below, assuming a monthly frequency for the workgroup:

| | Monthly Urine Bioassay | Monthly Chest Count |
|---|---|---|
| Class W Th-228 | 1400 | 100000 |
| Class W Th-232 | 6400 | >250000 |
| Class Y Th-228 | 12000 | 16000 |
| Class Y Th-232 | 29000 | 150000 |

A special bioassay program is required for all members of a workgroup if any member of the workgroup has a confirmed intake of radioactive material.

## 2.6 Monitoring Program for Strontium

The worker monitoring program for strontium shall consist of semi-annual urine bioassay.

The missed 12-month effective dose equivalent in mrem for this monitoring method is given below:

| | Semi-annual Urine Bioassay |
|---|---|
| Class W Sr-89 | 12 |
| Class W Sr-90 | 5 |
| Class Y Sr-89 | 380 |
| Class Y Sr-90 | 130 |

The relatively high missed dose for class Y Sr-89 is caused by its short physical halflife. Significant exposures to pure Sr-89 are not anticipated and this is not considered a problem.

The workgroup monitoring program for strontium shall consist of semi-annual urine bioassay for each member of the workgroup. This individual frequency is assumed to result in at least a semi-monthly frequency for monitoring the workgroup.

The missed committed effective dose equivalent in mrem for each monitoring method is given below, assuming a semi-monthly frequency (every 15 days) for the workgroup:

| | Semi-monthly Urine Bioassay |
|---|---|
| Class D Sr-89 | <12 |
| Class D Sr-90 | <12 |
| Class Y Sr-89 | 72 |
| Class Y Sr-90 | 530 |

## 2.7 Gamma-Emitting Fission and Activation Products

The worker and workgroup monitoring programs for gamma-emitting fission and activation products shall consist of semi-annual whole-body counts. The missed doses for various pure gamma-emitting radionuclides on a semi-annual frequency are given in Section 1. With the exception of Ce-144, Ru-106, and the short-lived radionuclides listed below, all the missed doses for individual radionuclides are less than 100 mrem:

Ba-140
La-140
I-131
I-133

These short-lived radionuclides can not be reliably detected by whole-body counts on a semi-annual frequency. Special efforts should be taken to detect them by air and surface monitoring. The missed 12-month EDE class Y Ru-106 is less than 200 mrem and is considered acceptable. Class Y Ce-144 can not be reliably detected by the standard whole-body counting methods. A special 5 minute chest count once a year is required to detect this material. Mixtures of gamma-emitters are likely to produce larger missed doses than any one gamma-emitter. This possibility should be explored if the composition of the mixture is known.

## 2.8 Tritium

Tritium is unique in that urine bioassay is the primary method used to monitor and control exposure of workers to tritiated water. For all other radionuclides workplace monitoring is the primary method used to monitor and control exposure of workers. For this reason a missed dose analysis alone can not be used to select the appropriate bioassay frequency, but it can be used to select a minimum frequency. With this in mind, the worker and workgroup monitoring programs for tritiated water shall consist of monthly urine bioassay. The missed dose for this frequency is less than 100 mrem as shown in Figures 1-4. The bioassay frequencies for specific facilities must be determined considering the degree of feedback needed.

## 2.9 Summary of Worker Monitoring Programs

The following table indicates the types and frequency of monitoring that should be performed for each catagory of radionuclide. The frequency is given as the number of times the monitoring should be performed for each worker in a calandar year.

| | Urine | Feces | Chest | Whole-Body | PAS |
|---|---|---|---|---|---|
| Plutonium | 1 | 1 | 1 | - | + |
| Other TRU | 4 | 2 | 1 | - | + |
| Uranium | 2** | 1* | 1 | - | +* |
| Thorium | 1 | 2 | 1 | - | + |
| Strontium | 2 | - | - | - | - |
| FP and AP | - | - | 1*** | 2 | - |
| Tritium | 12 | - | - | - | - |

\+ should be performed
\- should not be performed
* only if class Y uranium is present
** monthly urine bioassay for elemental uranium is also required for exposures to class D uranium with a specific activity of less than 6 nCi/mg
*** a 5 minute count on the germanium chest counter every year is required for workers exposed to class Y Ce-144

## 2.10 Summary of Workgroup Monitoring Programs

The following table indicates the types and frequency of monitoring that should be performed for each catagory of radionuclide. The frequency is given as the number of times the monitoring should be performed for each person in the workgroup in a calandar year.

| | Urine | Feces | Chest | Whole-Body | PAS |
|---|---|---|---|---|---|
| Plutonium | 1 | - | 1 | - | - |
| Other TRU | 1 | - | 1 | - | - |
| Uranium | 1 | - | 1 | - | - |
| Thorium | 1 | - | 1 | - | - |
| Strontium | 2 | - | - | - | - |
| FP and AP | - | - | - | 2 | - |
| Tritium | 12 | - | - | - | - |

+ should be performed
- should not be performed

## 2.11 References


Dunning
Dunning, D.E. "Estimates of Internal Dose Equivalents from Inhalation and Ingestion of Selected Radionuclides", WIPP-DOE-176 Rev. 1, 1985.

EPA
Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, EPA Federal Guidance Report Number 11, EPA-520/1-88-020, 1988.

INDOS
INDOS User's Manual, 12-15-89.

RADOSE
RADOSE Documentation, 1-8-89.

Spoor 1973
N.L. Spoor and J.B. Hursh, "Protection Criteria [for uranium]", Chapter 5 of Uranium, Plutonium, Transplutonic Elements, H.C. Hodge, J.N. Stannard, and J.B. Hursh, Editors (New York: Springer-Verlag).

Table 3. Intake Retention Fractions.

| Nuclide, class and Bioassay Type | | Intake Retention Fraction at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| BA D | C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| BA D | WB | 3.100E-01 | 4.431E-02 | 3.033E-02 | 2.734E-02 | 2.518E-02 | 2.345E-02 | 1.985E-02 | 1.618E-02 |
| BA D | U | 2.806E-02 | 5.637E-04 | 5.869E-05 | 9.155E-06 | 6.366E-06 | 5.234E-06 | 3.043E-06 | 1.303E-06 |
| BA D | F | 3.942E-02 | 5.927E-04 | 2.000E-07 | 6.117E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| CE W | C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| CE W | WB | 5.889E-01 | 2.202E-01 | 2.035E-01 | 1.876E-01 | 1.639E-01 | 1.481E-01 | 1.252E-01 | 1.133E-01 |
| CE W | U | 1.372E-06 | 1.452E-06 | 1.524E-06 | 1.645E-06 | 1.836E-06 | 1.974E-06 | 2.178E-06 | 2.216E-06 |
| CE W | F | 4.112E-02 | 8.711E-03 | 1.190E-03 | 9.472E-04 | 6.249E-04 | 4.123E-04 | 1.184E-04 | 9.111E-06 |
| CE Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| CE Y | WB | 5.791E-01 | 1.604E-01 | 1.522E-01 | 1.501E-01 | 1.462E-01 | 1.424E-01 | 1.319E-01 | 1.139E-01 |
| CE Y | U | 7.530E-08 | 8.021E-08 | 8.286E-08 | 8.782E-08 | 9.779E-08 | 1.078E-07 | 1.381E-07 | 1.998E-07 |
| CE Y | F | 5.095E-02 | 8.047E-03 | 1.601E-04 | 1.334E-04 | 1.280E-04 | 1.228E-04 | 1.084E-04 | 8.385E-05 |
| CF W | C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| CF W | WB | 5.861E-01 | 2.134E-01 | 1.955E-01 | 1.780E-01 | 1.527E-01 | 1.358E-01 | 1.113E-01 | 9.987E-02 |
| CF W | U | 2.560E-03 | 1.431E-04 | 9.804E-05 | 6.525E-05 | 4.376E-05 | 3.481E-05 | 1.997E-05 | 9.468E-06 |
| CF W | F | 4.131E-02 | 8.805E-03 | 1.236E-03 | 9.769E-04 | 6.444E-04 | 4.278E-04 | 1.274E-04 | 1.338E-05 |
| CF Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| CF Y | WB | 5.789E-01 | 1.603E-01 | 1.520E-01 | 1.499E-01 | 1.459E-01 | 1.420E-01 | 1.313E-01 | 1.130E-01 |
| CF Y | U | 1.453E-04 | 8.094E-06 | 5.150E-06 | 3.338E-06 | 2.524E-06 | 2.433E-06 | 2.464E-06 | 2.613E-06 |
| CF Y | F | 5.093E-02 | 8.047E-03 | 1.624E-04 | 1.349E-04 | 1.290E-04 | 1.238E-04 | 1.094E-04 | 8.496E-05 |
| CO W | C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| CO W | WB | 5.584E-01 | 1.779E-01 | 1.506E-01 | 1.245E-01 | 8.963E-02 | 6.599E-02 | 3.011E-02 | 1.274E-02 |
| CO W | U | 1.595E-02 | 1.036E-03 | 5.503E-04 | 2.821E-04 | 1.773E-04 | 1.324E-04 | 5.574E-05 | 1.146E-05 |
| CO W | F | 3.974E-02 | 8.229E-03 | 1.130E-03 | 9.000E-04 | 5.938E-04 | 3.918E-04 | 1.125E-04 | 8.657E-06 |
| CO Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| CO Y | WB | 5.751E-01 | 1.655E-01 | 1.548E-01 | 1.508E-01 | 1.456E-01 | 1.409E-01 | 1.283E-01 | 1.069E-01 |
| CO Y | U | 2.832E-03 | 3.055E-04 | 1.236E-04 | 4.016E-05 | 2.011E-05 | 1.736E-05 | 1.378E-05 | 1.169E-05 |
| CO Y | F | 4.924E-02 | 7.594E-03 | 1.520E-04 | 1.268E-04 | 1.216E-04 | 1.167E-04 | 1.030E-04 | 7.968E-05 |
| CS D | C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| CS D | WB | 6.135E-01 | 5.503E-01 | 5.175E-01 | 4.704E-01 | 3.894E-01 | 3.223E-01 | 1.828E-01 | 5.699E-02 |

U = urine bioassay  C = chest count  WB = whole body count  F = feces bioassay

Note: CF W (californium class W) tables apply to class W americium and curium.

Table 4. Intake Retention Fractions.

| Nuclide, class and Bioassay Type | Intake Retention Fraction at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CS D U | 1.322E-02 | 4.914E-03 | 2.750E-03 | 2.380E-03 | 1.969E-03 | 1.630E-03 | 9.245E-04 | 2.882E-04 |
| CS D F | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| EU W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| EU W WB | 5.794E-01 | 2.085E-01 | 1.901E-01 | 1.720E-01 | 1.460E-01 | 1.287E-01 | 1.035E-01 | 9.116E-02 |
| EU W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| EU W F | 4.110E-02 | 8.704E-03 | 1.189E-03 | 9.466E-04 | 6.245E-04 | 4.120E-04 | 1.183E-04 | 9.104E-06 |
| FE D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| FE D WB | 5.905E-01 | 4.906E-01 | 4.889E-01 | 4.864E-01 | 4.814E-01 | 4.764E-01 | 4.618E-01 | 4.331E-01 |
| FE D U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| FE D F | 3.942E-02 | 5.927E-04 | 2.000E-07 | 6.117E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| FE W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| FE W WB | 5.917E-01 | 2.608E-01 | 2.456E-01 | 2.308E-01 | 2.087E-01 | 1.935E-01 | 1.698E-01 | 1.529E-01 |
| FE W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| FE W F | 3.831E-02 | 7.749E-03 | 1.071E-03 | 8.526E-04 | 5.625E-04 | 3.711E-04 | 1.066E-04 | 8.200E-06 |
| I D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| I D WB | 3.096E-01 | 2.068E-01 | 2.026E-01 | 1.905E-01 | 1.627E-01 | 1.371E-01 | 8.144E-02 | 2.786E-02 |
| I D U | 3.203E-01 | 4.789E-04 | 6.433E-04 | 8.928E-04 | 9.112E-04 | 7.918E-04 | 4.735E-04 | 1.620E-04 |
| I D F | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| LA D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| LA D WB | 5.873E-01 | 4.759E-01 | 4.748E-01 | 4.734E-01 | 4.706E-01 | 4.678E-01 | 4.595E-01 | 4.430E-01 |
| LA D U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| LA D F | 4.263E-02 | 6.709E-04 | 2.264E-07 | 6.924E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| LA W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| LA W WB | 5.889E-01 | 2.205E-01 | 2.038E-01 | 1.879E-01 | 1.643E-01 | 1.485E-01 | 1.255E-01 | 1.136E-01 |
| LA W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| LA W F | 4.110E-02 | 8.704E-03 | 1.189E-03 | 9.466E-04 | 6.245E-04 | 4.120E-04 | 1.183E-04 | 9.104E-06 |
| MN D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| MN D WB | 4.972E-01 | 3.057E-01 | 2.638E-01 | 2.007E-01 | 1.161E-01 | 6.718E-02 | 1.301E-02 | 4.455E-04 |
| MN D U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |

U = urine bioassay  C = chest count  WB = whole body count  F = feces bioassay

Table 5. Intake Retention Fractions.

| Nuclide, class and Bioassay Type | Intake Retention Fraction at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| MN D F | 3.942E-02 | 5.927E-04 | 2.000E-07 | 6.117E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| MN W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| MN W WB | 5.690E-01 | 2.176E-01 | 1.913E-01 | 1.585E-01 | 1.090E-01 | 7.509E-02 | 2.461E-02 | 2.451E-03 |
| MN W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| MN W F | 3.831E-02 | 7.749E-03 | 1.071E-03 | 8.526E-04 | 5.625E-04 | 3.711E-04 | 1.066E-04 | 8.200E-06 |
| NB W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| NB W WB | 5.852E-01 | 2.024E-01 | 1.735E-01 | 1.473E-01 | 1.134E-01 | 8.991E-02 | 5.038E-02 | 2.175E-02 |
| NB W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| NB W F | 4.085E-02 | 8.616E-03 | 1.178E-03 | 9.380E-04 | 6.189E-04 | 4.083E-04 | 1.173E-04 | 9.022E-06 |
| NB Y C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| NB Y WB | 5.791E-01 | 1.626E-01 | 1.531E-01 | 1.500E-01 | 1.453E-01 | 1.409E-01 | 1.286E-01 | 1.071E-01 |
| NB Y U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| NB Y F | 5.062E-02 | 7.958E-03 | 1.585E-04 | 1.321E-04 | 1.267E-04 | 1.216E-04 | 1.073E-04 | 8.304E-05 |
| NP W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| NP W WB | 5.626E-01 | 1.909E-01 | 1.727E-01 | 1.545E-01 | 1.272E-01 | 1.089E-01 | 8.270E-02 | 7.186E-02 |
| NP W U | 1.316E-02 | 9.930E-05 | 9.217E-05 | 7.997E-05 | 5.966E-05 | 4.411E-05 | 1.746E-05 | 3.459E-06 |
| NP W F | 4.112E-02 | 8.713E-03 | 1.190E-03 | 9.474E-04 | 6.251E-04 | 4.124E-04 | 1.184E-04 | 9.113E-06 |
| PU W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| PU W WB | 5.885E-01 | 2.189E-01 | 2.019E-01 | 1.856E-01 | 1.617E-01 | 1.458E-01 | 1.231E-01 | 1.131E-01 |
| PU W U | 2.786E-04 | 3.384E-05 | 2.161E-05 | 1.743E-05 | 1.347E-05 | 1.156E-05 | 8.363E-06 | 4.876E-06 |
| PU W F | 4.117E-02 | 8.757E-03 | 1.209E-03 | 9.625E-04 | 6.367E-04 | 4.223E-04 | 1.256E-04 | 1.328E-05 |
| PU Y C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| PU Y WB | 5.790E-01 | 1.602E-01 | 1.520E-01 | 1.499E-01 | 1.459E-01 | 1.421E-01 | 1.316E-01 | 1.137E-01 |
| PU Y U | 1.510E-05 | 1.738E-06 | 1.072E-06 | 8.653E-07 | 7.186E-07 | 6.920E-07 | 7.238E-07 | 8.021E-07 |
| PU Y F | 5.096E-02 | 8.052E-03 | 1.611E-04 | 1.342E-04 | 1.236E-04 | 1.234E-04 | 1.090E-04 | 8.456E-05 |
| RU D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| RU D WB | 5.286E-01 | 3.204E-01 | 2.527E-01 | 1.887E-01 | 1.382E-01 | 1.156E-01 | 8.956E-02 | 7.525E-02 |
| RU D U | 4.826E-02 | 9.091E-03 | 5.279E-03 | 2.296E-03 | 8.362E-04 | 4.499E-04 | 1.137E-04 | 4.338E-05 |
| RU D F | 4.106E-02 | 6.318E-04 | 2.132E-07 | 6.521E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| RU W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| RU W WB | 5.769E-01 | 2.086E-01 | 1.786E-01 | 1.477E-01 | 1.079E-01 | 8.199E-02 | 4.346E-02 | 2.476E-02 |
| RU W U | 1.071E-02 | 1.828E-03 | 1.177E-03 | 6.577E-04 | 3.678E-04 | 2.573E-04 | 1.004E-04 | 2.257E-05 |

U = urine bioassay C = chest count WB = whole body count F = feces bioassay

Table 6. Intake Retention Fractions.

| Nuclide, class and Bioassay Type | Intake Retention Fraction at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| RU W F | 3.974E-02 | 8.229E-03 | 1.130E-03 | 9.000E-04 | 5.938E-04 | 3.918E-04 | 1.125E-04 | 8.657E-06 |
| RU Y C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| RU Y WB | 5.783E-01 | 1.746E-01 | 1.628E-01 | 1.569E-01 | 1.498E-01 | 1.444E-01 | 1.313E-01 | 1.101E-01 |
| RU Y U | 1.979E-03 | 5.460E-04 | 3.184E-04 | 1.454E-04 | 6.199E-05 | 4.055E-05 | 2.206E-05 | 1.797E-05 |
| RU Y F | 4.924E-02 | 7.594E-03 | 1.520E-04 | 1.268E-04 | 1.216E-04 | 1.167E-04 | 1.030E-04 | 7.968E-05 |
| SB D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SB D WB | 4.874E-01 | 1.707E-01 | 6.779E-02 | 2.227E-02 | 1.311E-02 | 1.057E-02 | 5.663E-03 | 1.571E-03 |
| SB D U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SB D F | 3.942E-02 | 5.927E-04 | 2.000E-07 | 6.117E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SB W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| SB W WB | 5.687E-01 | 1.729E-01 | 1.387E-01 | 1.104E-01 | 7.558E-02 | 5.216E-02 | 1.735E-02 | 2.002E-03 |
| SB W U | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SB W F | 4.085E-02 | 8.616E-03 | 1.178E-03 | 9.380E-04 | 6.189E-04 | 4.083E-04 | 1.173E-04 | 9.022E-06 |
| SR D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SR D WB | 4.983E-01 | 2.192E-01 | 1.371E-01 | 1.055E-01 | 9.631E-02 | 9.109E-02 | 8.010E-02 | 6.757E-02 |
| SR D U | 8.451E-02 | 1.690E-02 | 4.717E-03 | 6.162E-04 | 1.668E-04 | 1.336E-04 | 8.148E-05 | 4.153E-05 |
| SR D F | 3.230E-02 | 4.437E-04 | 1.497E-07 | 4.578E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| SR Y C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| SR Y WB | 5.778E-01 | 1.600E-01 | 1.504E-01 | 1.476E-01 | 1.431E-01 | 1.388E-01 | 1.269E-01 | 1.061E-01 |
| SR Y U | 1.305E-03 | 2.930E-04 | 9.080E-05 | 2.305E-05 | 1.592E-05 | 1.563E-05 | 1.530E-05 | 1.505E-05 |
| SR Y F | 5.062E-02 | 7.958E-03 | 1.585E-04 | 1.321E-04 | 1.267E-04 | 1.216E-04 | 1.073E-04 | 8.304E-05 |
| TH W C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| TH W WB | 5.836E-01 | 2.128E-01 | 1.957E-01 | 1.790E-01 | 1.543E-01 | 1.375E-01 | 1.130E-01 | 9.985E-02 |
| TH W U | 5.258E-03 | 6.953E-05 | 6.545E-05 | 6.069E-05 | 5.254E-05 | 4.607E-05 | 3.402E-05 | 2.503E-05 |
| TH W F | 4.112E-02 | 8.712E-03 | 1.190E-03 | 9.473E-04 | 6.250E-04 | 4.123E-04 | 1.184E-04 | 9.112E-06 |
| TH Y C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| TH Y WB | 5.788E-01 | 1.599E-01 | 1.517E-01 | 1.496E-01 | 1.456E-01 | 1.418E-01 | 1.311E-01 | 1.127E-01 |
| TH Y U | 2.878E-04 | 2.895E-06 | 2.808E-06 | 2.875E-06 | 3.006E-06 | 3.133E-06 | 3.493E-06 | 4.130E-06 |
| TH Y F | 5.095E-02 | 8.048E-03 | 1.601E-04 | 1.334E-04 | 1.280E-04 | 1.228E-04 | 1.084E-04 | 8.386E-05 |
| U D C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| U D WB | 3.944E-01 | 1.439E-01 | 9.178E-02 | 5.018E-02 | 2.393E-02 | 1.582E-02 | 1.151E-02 | 1.100E-02 |
| U D U | 1.946E-01 | 9.538E-03 | 4.723E-03 | 1.698E-03 | 4.499E-04 | 1.554E-04 | 8.490E-06 | 1.674E-06 |

U = urine bioassay C = chest count WB = whole body count F = feces bioassay

Table 7. Intake Retention Fractions.

| Nuclide, class and Bioassay Type | | Intake Retention Fraction at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| U D | F | 4.106E-02 | 6.318E-04 | 2.132E-07 | 6.521E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| U W | C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| U W | WB | 5.476E-01 | 1.743E-01 | 1.457E-01 | 1.168E-01 | 7.892E-02 | 5.441E-02 | 1.937E-02 | 4.785E-03 |
| U W | U | 4.265E-02 | 2.158E-03 | 1.291E-03 | 7.239E-04 | 4.110E-04 | 2.751E-04 | 9.471E-05 | 1.093E-05 |
| U W | F | 3.974E-02 | 8.229E-03 | 1.130E-03 | 9.000E-04 | 5.938E-04 | 3.918E-04 | 1.125E-04 | 8.657E-06 |
| U Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| U Y | WB | 5.768E-01 | 1.577E-01 | 1.490E-01 | 1.463E-01 | 1.416E-01 | 1.373E-01 | 1.253E-01 | 1.042E-01 |
| U Y | U | 2.281E-03 | 1.043E-04 | 5.980E-05 | 3.239E-05 | 2.147E-05 | 1.908E-05 | 1.817E-05 | 1.833E-05 |
| U Y | F | 5.089E-02 | 8.032E-03 | 1.598E-04 | 1.332E-04 | 1.278E-04 | 1.226E-04 | 1.082E-04 | 8.371E-05 |
| ZN Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| ZN Y | WB | 5.987E-01 | 3.819E-01 | 3.641E-01 | 3.438E-01 | 3.187E-01 | 3.028E-01 | 2.695E-01 | 2.166E-01 |
| ZN Y | U | 2.317E-04 | 4.924E-04 | 3.942E-04 | 2.665E-04 | 1.439E-04 | 9.855E-05 | 6.794E-05 | 5.249E-05 |
| ZN Y | F | 3.035E-02 | 3.758E-03 | 7.932E-05 | 6.672E-05 | 6.400E-05 | 6.139E-05 | 5.419E-05 | 4.193E-05 |
| ZR D | C | 7.995E-02 | 4.487E-05 | 1.201E-09 | 2.020E-18 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| ZR D | WB | 5.721E-01 | 3.634E-01 | 2.945E-01 | 2.504E-01 | 2.376E-01 | 2.363E-01 | 2.345E-01 | 2.307E-01 |
| ZR D | U | 5.515E-04 | 4.690E-04 | 2.129E-04 | 4.877E-05 | 3.202E-06 | 8.634E-07 | 7.314E-07 | 7.198E-07 |
| ZR D | F | 4.260E-02 | 6.700E-04 | 2.261E-07 | 6.916E-14 | 0.000E+00 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| ZR W | C | 2.115E-01 | 1.386E-01 | 1.243E-01 | 1.027E-01 | 6.999E-02 | 4.767E-02 | 1.498E-02 | 1.356E-03 |
| ZR W | WB | 5.856E-01 | 2.028E-01 | 1.752E-01 | 1.503E-01 | 1.199E-01 | 1.003E-01 | 7.202E-02 | 5.988E-02 |
| ZR W | U | 1.182E-04 | 7.095E-05 | 3.685E-05 | 1.426E-05 | 6.315E-06 | 4.468E-06 | 1.785E-06 | 3.656E-07 |
| ZR W | F | 4.107E-02 | 8.694E-03 | 1.188E-03 | 9.456E-04 | 6.239E-04 | 4.116E-04 | 1.182E-04 | 9.095E-06 |
| ZR Y | C | 2.141E-01 | 1.499E-01 | 1.477E-01 | 1.454E-01 | 1.410E-01 | 1.367E-01 | 1.247E-01 | 1.037E-01 |
| ZR Y | WB | 5.789E-01 | 1.600E-01 | 1.511E-01 | 1.485E-01 | 1.442E-01 | 1.402E-01 | 1.290E-01 | 1.095E-01 |
| ZR Y | U | 6.941E-06 | 4.704E-06 | 2.312E-06 | 7.777E-07 | 3.554E-07 | 3.376E-07 | 3.459E-07 | 3.549E-07 |
| ZR Y | F | 5.089E-02 | 8.032E-03 | 1.598E-04 | 1.332E-04 | 1.278E-04 | 1.226E-04 | 1.082E-04 | 8.371E-05 |

U = urine bioassay  C = chest count  WB = whole body count  F = feces bioassay

Table 8. Summary of missed committed dose for urine bioassay.

| Nuclide | Missed Committed Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | 35 | 630 | 920 | 1400 | 2100 | 2600 | 4500 | 9500 |
| CLASS Y CF-252 | 220 | 4000 | 6300 | 9800 | 13000 | 14000 | 15000 | 16000 |
| CLASS W CF-252 | 11 | 200 | 290 | 440 | 670 | 860 | 1600 | 3800 |
| CLASS W CM-242 | < 1 | 24 | 37 | 59 | 100 | 140 | 370 | 1700 |
| CLASS W CM-244 | 20 | 350 | 510 | 770 | 1100 | 1400 | 2600 | 5500 |
| CLASS W NP-237 | 6 | 750 | 800 | 930 | 1200 | 1700 | 4200 | 21000 |
| CLASS W PU-238 | 28 | 230 | 360 | 450 | 580 | 680 | 940 | 1600 |
| CLASS Y PU-238 | 380 | 3300 | 5400 | 6700 | 8100 | 8400 | 8000 | 7300 |
| CLASS Y PU-239 | 400 | 3500 | 5600 | 6900 | 8300 | 8700 | 8300 | 7500 |
| CLASS W PU-239 | 30 | 250 | 390 | 480 | 620 | 730 | 1000 | 1700 |
| CLASS D SR-89 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 6 | 140 |
| CLASS Y SR-89 | < 1 | < 1 | 3 | 16 | 35 | 54 | 190 | 2400 |
| CLASS D SR-90 | < 1 | < 1 | < 1 | 2 | 8 | 10 | 16 | 33 |
| CLASS Y SR-90 | 6 | 27 | 86 | 340 | 490 | 500 | 520 | 530 |
| CLASS Y TH-228 | 120 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 |
| CLASS W TH-228 | 5 | 360 | 390 | 420 | 510 | 590 | 880 | 1400 |
| CLASS W TH-232 | 30 | 2300 | 2400 | 2600 | 3000 | 3500 | 4700 | 6400 |
| CLASS Y TH-232 | 420 | 41000 | 43000 | 42000 | 40000 | 38000 | 34000 | 29000 |
| CLASS D U-234 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 130 | 650 |
| CLASS W U-234 | < 1 | < 1 | 2 | 4 | 8 | 11 | 33 | 290 |
| CLASS Y U-234 | 23 | 500 | 870 | 1600 | 2400 | 2700 | 2900 | 2800 |
| CLASS W U-235 | < 1 | < 1 | 2 | 4 | 7 | 11 | 31 | 270 |
| CLASS Y U-235 | 21 | 460 | 800 | 1500 | 2200 | 2500 | 2600 | 2600 |
| CLASS D U-235 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 120 | 600 |
| CLASS W U-236 | < 1 | < 1 | 2 | 4 | 7 | 11 | 31 | 270 |
| CLASS Y U-236 | 23 | 500 | 870 | 1600 | 2400 | 2700 | 2900 | 2800 |
| CLASS D U-236 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 120 | 600 |
| CLASS Y U-238 | 21 | 460 | 800 | 1500 | 2200 | 2500 | 2600 | 2600 |
| CLASS W U-238 | < 1 | < 1 | 2 | 4 | 7 | 10 | 30 | 260 |
| CLASS D U-238 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 110 | 570 |

Table 9. Summary of missed committed dose for chest counting.

| Nuclide | Missed Committed Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | 280 | 420 | 470 | 570 | 840 | 1200 | 3900 | 43000 |
| CLASS W CE-141 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 1500 |
| CLASS Y CE-141 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 21 |
| CLASS W CE-144 | < 1 | < 1 | < 1 | < 1 | 2 | 2 | 10 | 170 |
| CLASS Y CE-144 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 4 |
| CLASS W CF-252 | 20000 | 30000 | 34000 | 42000 | 63000 | 94000 | > 250000 | > 250000 |
| CLASS Y CF-252 | 22000 | 32000 | 33000 | 34000 | 36000 | 37000 | 44000 | 60000 |
| CLASS W CM-242 | 2200 | 3400 | 3900 | 5100 | 8500 | 14000 | 66000 | > 250000 |
| CLASS W CM-244 | 34000 | 52000 | 58000 | 71000 | 100000 | 150000 | > 250000 | > 250000 |
| CLASS W EU-152 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 22 |
| CLASS W NP-237 | 610 | 930 | 1000 | 1300 | 1900 | 2700 | 8600 | 96000 |
| CLASS Y PU-238 | 58000 | 83000 | 84000 | 86000 | 89000 | 91000 | 100000 | 120000 |
| CLASS W PU-238 | 79000 | 120000 | 130000 | 160000 | 240000 | > 250000 | > 250000 | > 250000 |
| CLASS Y PU-239 | 150000 | 220000 | 220000 | 230000 | 230000 | 240000 | > 250000 | > 250000 |
| CLASS W PU-239 | 220000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W TH-228 | 4000 | 6200 | 6900 | 8500 | 13000 | 19000 | 68000 | > 250000 |
| CLASS Y TH-228 | 5400 | 7800 | 7900 | 8200 | 8700 | 9200 | 11000 | 16000 |
| CLASS W TH-232 | 210000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS Y TH-232 | 73000 | 100000 | 110000 | 110000 | 110000 | 110000 | 130000 | 150000 |
| CLASS D U-234 | 1500 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS Y U-234 | 26000 | 37000 | 38000 | 38000 | 40000 | 41000 | 45000 | 54000 |
| CLASS W U-234 | 1600 | 2500 | 2700 | 3300 | 4900 | 7100 | 23000 | > 250000 |
| CLASS Y U-235 | 56 | 80 | 81 | 83 | 85 | 88 | 96 | 120 |
| CLASS W U-235 | 3 | 5 | 6 | 7 | 10 | 15 | 49 | 540 |
| CLASS D U-235 | 3 | 5600 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS Y U-236 | 55000 | 79000 | 80000 | 81000 | 84000 | 87000 | 95000 | 110000 |
| CLASS W U-236 | 3200 | 4900 | 5400 | 6600 | 9600 | 14000 | 45000 | > 250000 |
| CLASS D U-236 | 2800 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W U-238 | 36 | 56 | 62 | 75 | 110 | 160 | 510 | 5700 |
| CLASS Y U-238 | 620 | 880 | 890 | 910 | 940 | 970 | 1100 | 1300 |
| CLASS D U-238 | 33 | 59000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |

Table 10. Summary of missed committed dose for whole body counting.

| Nuclide | Missed Committed Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS D BA-140 | < 1 | 2 | 5 | 12 | 64 | 350 | 54000 | > 250000 |
| CLASS Y CE-141 | < 1 | < 1 | < 1 | 2 | 3 | 6 | 44 | 2700 |
| CLASS W CE-141 | < 1 | < 1 | < 1 | < 1 | 3 | 5 | 43 | 2500 |
| CLASS Y CE-144 | 36 | 130 | 140 | 150 | 170 | 180 | 250 | 450 |
| CLASS W CE-144 | 21 | 56 | 62 | 69 | 85 | 100 | 150 | 260 |
| CLASS W CO-58 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 5 | 72 |
| CLASS Y CO-58 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 15 |
| CLASS W CO-60 | < 1 | < 1 | < 1 | < 1 | 2 | 2 | 5 | 12 |
| CLASS Y CO-60 | 2 | 5 | 6 | 6 | 6 | 6 | 7 | 9 |
| CLASS D CS-134 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 5 |
| CLASS D CS-137 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 |
| CLASS W EU-152 | 6 | 17 | 19 | 21 | 24 | 28 | 35 | 41 |
| CLASS W EU-154 | 8 | 22 | 24 | 27 | 32 | 37 | 47 | 55 |
| CLASS D FE-59 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 60 |
| CLASS W FE-59 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 140 |
| CLASS D I-131 | < 1 | < 1 | 2 | 9 | 140 | 2300 | > 250000 | > 250000 |
| CLASS D I-133 | < 1 | 38 | 23000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS D LA-140 | < 1 | < 1 | 10 | 4400 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W LA-140 | < 1 | < 1 | 32 | 16000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W MN-54 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 25 |
| CLASS D MN-54 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 110 |
| CLASS W NB-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 7 | 610 |
| CLASS Y NB-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 150 |
| CLASS W NP-237 | 8500 | 25000 | 28000 | 31000 | 38000 | 44000 | 58000 | 67000 |
| CLASS Y RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 8 | 250 |
| CLASS W RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 18 | 810 |
| CLASS D RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 4 | 130 |
| CLASS D RU-106 | 3 | 5 | 6 | 8 | 12 | 15 | 22 | 38 |
| CLASS Y RU-106 | 21 | 70 | 76 | 81 | 90 | 98 | 130 | 220 |
| CLASS W RU-106 | 5 | 15 | 17 | 21 | 31 | 43 | 97 | 240 |
| CLASS W SB-125 | < 1 | < 1 | < 1 | < 1 | 2 | 3 | 10 | 100 |
| CLASS D SB-125 | < 1 | < 1 | < 1 | < 1 | 2 | 3 | 5 | 22 |
| CLASS W U-235 | 170 | 540 | 650 | 810 | 1200 | 1700 | 4900 | 20000 |
| CLASS D U-235 | 82 | 230 | 350 | 650 | 1400 | 2100 | 2800 | 3000 |
| CLASS Y U-235 | 2700 | 9900 | 10000 | 11000 | 11000 | 11000 | 12000 | 15000 |
| CLASS Y ZN-65 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 |
| CLASS Y ZR-95 | < 1 | < 1 | < 1 | < 1 | 2 | 2 | 6 | 55 |
| CLASS D ZR-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 4 | 27 |
| CLASS W ZR-95 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 8 | 70 |

Table 11. Summary of missed committed dose for 1-day fecal sample.

| Nuclide | Missed Committed Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | < 1 | 5 | 36 | 46 | 70 | 110 | 350 | 3400 |
| CLASS W CF-252 | < 1 | 2 | 11 | 15 | 23 | 35 | 130 | 1400 |
| CLASS Y CF-252 | < 1 | 2 | 100 | 120 | 130 | 140 | 170 | 240 |
| CLASS W CM-242 | < 1 | < 1 | < 1 | 2 | 3 | 6 | 29 | 600 |
| CLASS W CM-244 | < 1 | 3 | 20 | 26 | 39 | 59 | 200 | 1900 |
| CLASS W NP-237 | < 1 | 4 | 31 | 39 | 59 | 90 | 310 | 4100 |
| CLASS Y PU-238 | < 1 | 4 | 180 | 220 | 230 | 240 | 270 | 350 |
| CLASS W PU-238 | < 1 | 4 | 32 | 41 | 61 | 93 | 310 | 3000 |
| CLASS W PU-239 | < 1 | 5 | 35 | 44 | 66 | 99 | 330 | 3200 |
| CLASS Y PU-239 | < 1 | 4 | 190 | 220 | 230 | 240 | 280 | 350 |
| CLASS Y SR-89 | < 1 | < 1 | 6 | 9 | 15 | 23 | 90 | 1500 |
| CLASS Y SR-90 | < 1 | 3 | 160 | 200 | 210 | 220 | 250 | 320 |
| CLASS W TH-228 | < 1 | 3 | 21 | 27 | 42 | 66 | 250 | 3900 |
| CLASS Y TH-228 | < 1 | 4 | 220 | 260 | 280 | 300 | 380 | 580 |
| CLASS Y TH-232 | 2 | 15 | 750 | 900 | 940 | 980 | 1100 | 1400 |
| CLASS W TH-232 | 4 | 18 | 130 | 170 | 260 | 390 | 1400 | 18000 |
| CLASS W U-234 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 91 |
| CLASS Y U-234 | < 1 | 2 | 81 | 98 | 100 | 110 | 120 | 160 |
| CLASS W U-235 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 84 |
| CLASS Y U-235 | < 1 | < 1 | 75 | 90 | 94 | 98 | 110 | 140 |
| CLASS W U-236 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 85 |
| CLASS Y U-236 | < 1 | 2 | 81 | 98 | 100 | 110 | 120 | 160 |
| CLASS Y U-238 | < 1 | < 1 | 75 | 90 | 94 | 98 | 110 | 140 |
| CLASS W U-238 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 81 |

Table 12. Summary of missed 12-month dose for urine bioassay.

| Nuclide | Missed 12-Month Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | 2 | 28 | 41 | 61 | 91 | 110 | 200 | 420 |
| CLASS Y CF-252 | 85 | 1500 | 2400 | 3800 | 5100 | 5400 | 5700 | 6200 |
| CLASS W CF-252 | 3 | 60 | 89 | 130 | 210 | 260 | 490 | 1200 |
| CLASS W CM-242 | < 1 | 19 | 28 | 45 | 77 | 110 | 280 | 1300 |
| CLASS W CM-244 | 2 | 29 | 43 | 65 | 97 | 120 | 210 | 460 |
| CLASS W NP-237 | < 1 | 32 | 35 | 40 | 54 | 73 | 180 | 930 |
| CLASS W PU-238 | < 1 | 12 | 19 | 23 | 30 | 35 | 48 | 83 |
| CLASS Y PU-238 | 42 | 370 | 600 | 740 | 890 | 930 | 890 | 800 |
| CLASS Y PU-239 | 38 | 330 | 540 | 670 | 810 | 840 | 800 | 720 |
| CLASS W PU-239 | < 1 | 11 | 17 | 21 | 27 | 31 | 43 | 74 |
| CLASS D SR-89 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 6 | 140 |
| CLASS Y SR-89 | < 1 | < 1 | 3 | 16 | 35 | 54 | 190 | 2400 |
| CLASS D SR-90 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 3 | 5 |
| CLASS Y SR-90 | < 1 | 7 | 21 | 83 | 120 | 120 | 130 | 130 |
| CLASS W TH-228 | 2 | 140 | 160 | 170 | 200 | 240 | 350 | 570 |
| CLASS Y TH-228 | 56 | 5600 | 5800 | 5700 | 5600 | 5600 | 5500 | 5600 |
| CLASS W TH-232 | < 1 | 23 | 24 | 26 | 30 | 35 | 47 | 64 |
| CLASS Y TH-232 | 9 | 860 | 890 | 870 | 830 | 800 | 720 | 610 |
| CLASS D U-234 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 40 | 200 |
| CLASS W U-234 | < 1 | < 1 | 2 | 4 | 7 | 11 | 31 | 270 |
| CLASS Y U-234 | 5 | 100 | 180 | 330 | 500 | 570 | 590 | 590 |
| CLASS W U-235 | < 1 | < 1 | 2 | 4 | 7 | 10 | 28 | 250 |
| CLASS Y U-235 | 4 | 96 | 170 | 310 | 470 | 520 | 550 | 550 |
| CLASS D U-235 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 37 | 190 |
| CLASS W U-236 | < 1 | < 1 | 2 | 4 | 7 | 10 | 29 | 250 |
| CLASS Y U-236 | 5 | 100 | 170 | 320 | 480 | 550 | 570 | 570 |
| CLASS D U-236 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 39 | 200 |
| CLASS Y U-238 | 4 | 92 | 160 | 300 | 450 | 500 | 530 | 520 |
| CLASS W U-238 | < 1 | < 1 | 2 | 4 | 6 | 9 | 27 | 230 |
| CLASS D U-238 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 36 | 180 |

Table 13. Summary of missed 12-month dose for chest count.

| Nuclide | Missed 12-Month Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | 12 | 19 | 21 | 25 | 37 | 55 | 170 | 1900 |
| CLASS W CE-141 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 1500 |
| CLASS Y CE-141 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 21 |
| CLASS W CE-144 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 120 |
| CLASS Y CE-144 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 |
| CLASS W CF-252 | 6100 | 9400 | 10000 | 13000 | 19000 | 29000 | 98000 | > 250000 |
| CLASS Y CF-252 | 8700 | 12000 | 13000 | 13000 | 14000 | 15000 | 17000 | 23000 |
| CLASS W CM-242 | 1700 | 2600 | 3000 | 3900 | 6500 | 11000 | 50000 | > 250000 |
| CLASS W CM-244 | 2900 | 4400 | 4900 | 5900 | 8800 | 13000 | 41000 | > 250000 |
| CLASS W NP-237 | 26 | 40 | 45 | 55 | 80 | 120 | 370 | 4100 |
| CLASS Y PU-238 | 6400 | 9200 | 9300 | 9500 | 9800 | 10000 | 11000 | 13000 |
| CLASS W PU-238 | 4100 | 6200 | 6900 | 8400 | 12000 | 18000 | 58000 | > 250000 |
| CLASS Y PU-239 | 15000 | 21000 | 22000 | 22000 | 23000 | 23000 | 26000 | 31000 |
| CLASS W PU-239 | 9400 | 14000 | 16000 | 19000 | 28000 | 42000 | 130000 | > 250000 |
| CLASS W TH-228 | 1600 | 2500 | 2800 | 3400 | 5200 | 7800 | 27000 | > 250000 |
| CLASS Y TH-228 | 2500 | 3700 | 3700 | 3900 | 4100 | 4400 | 5200 | 7500 |
| CLASS W TH-232 | 2100 | 3200 | 3600 | 4400 | 6400 | 9400 | 30000 | > 250000 |
| CLASS Y TH-232 | 1500 | 2200 | 2200 | 2200 | 2300 | 2400 | 2600 | 3100 |
| CLASS D U-234 | 460 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS Y U-234 | 5400 | 7700 | 7900 | 8000 | 8200 | 8500 | 9300 | 11000 |
| CLASS W U-234 | 1500 | 2300 | 2500 | 3100 | 4500 | 6600 | 21000 | 230000 |
| CLASS Y U-235 | 12 | 17 | 17 | 17 | 18 | 18 | 20 | 24 |
| CLASS W U-235 | 3 | 5 | 5 | 7 | 10 | 14 | 45 | 490 |
| CLASS D U-235 | < 1 | 1800 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS Y U-236 | 11000 | 16000 | 16000 | 16000 | 17000 | 17000 | 19000 | 23000 |
| CLASS W U-236 | 2900 | 4500 | 5000 | 6000 | 8800 | 13000 | 41000 | > 250000 |
| CLASS D U-236 | 930 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W U-238 | 33 | 51 | 57 | 69 | 100 | 150 | 470 | 5200 |
| CLASS Y U-238 | 120 | 180 | 180 | 180 | 190 | 190 | 210 | 250 |
| CLASS D U-238 | 10 | 19000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |

Table 14. Summary of missed 12-month dose for whole body count.

| Nuclide | Missed 12-Month Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS D BA-140 | < 1 | 2 | 5 | 12 | 64 | 350 | 54000 | > 250000 |
| CLASS Y CE-141 | < 1 | < 1 | < 1 | 2 | 3 | 6 | 44 | 2700 |
| CLASS W CE-141 | < 1 | < 1 | < 1 | < 1 | 3 | 5 | 43 | 2500 |
| CLASS Y CE-144 | 25 | 91 | 97 | 100 | 110 | 130 | 170 | 310 |
| CLASS W CE-144 | 15 | 41 | 45 | 50 | 62 | 74 | 110 | 190 |
| CLASS W CO-58 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 5 | 70 |
| CLASS Y CO-58 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 15 |
| CLASS W CO-60 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 4 | 10 |
| CLASS Y CO-60 | < 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 |
| CLASS D CS-134 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 4 |
| CLASS D CS-137 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 |
| CLASS D FE-59 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 60 |
| CLASS W FE-59 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 7 | 140 |
| CLASS D I-131 | < 1 | < 1 | 2 | 9 | 140 | 2300 | > 250000 | > 250000 |
| CLASS D I-133 | < 1 | 38 | 23000 | > 250000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS D LA-140 | < 1 | < 1 | 10 | 4400 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W LA-140 | < 1 | < 1 | 32 | 16000 | > 250000 | > 250000 | > 250000 | > 250000 |
| CLASS W MN-54 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 24 |
| CLASS D MN-54 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 100 |
| CLASS W NB-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 7 | 610 |
| CLASS Y NB-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 150 |
| CLASS W NP-237 | 370 | 1100 | 1200 | 1300 | 1600 | 1900 | 2500 | 2900 |
| CLASS Y RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 8 | 250 |
| CLASS W RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 18 | 810 |
| CLASS D RU-103 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 4 | 130 |
| CLASS D RU-106 | 2 | 3 | 4 | 6 | 8 | 10 | 16 | 26 |
| CLASS Y RU-106 | 13 | 45 | 49 | 52 | 58 | 64 | 83 | 140 |
| CLASS W RU-106 | 5 | 13 | 16 | 20 | 29 | 40 | 89 | 220 |
| CLASS W U-235 | 160 | 500 | 600 | 750 | 1100 | 1600 | 4500 | 18000 |
| CLASS D U-235 | 26 | 71 | 110 | 200 | 430 | 650 | 890 | 930 |
| CLASS Y U-235 | 560 | 2100 | 2200 | 2200 | 2300 | 2400 | 2600 | 3100 |
| CLASS Y ZN-65 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 |
| CLASS Y ZR-95 | < 1 | < 1 | < 1 | < 1 | 2 | 2 | 6 | 55 |
| CLASS D ZR-95 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 3 | 26 |
| CLASS W ZR-95 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 8 | 70 |

Table 15. Summary of missed 12-month dose 1-day fecal samples.

| Nuclide | Missed 12-Month Effective Dose Equivalent in mrem at Indicated Day After Intake | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 7 days | 15 days | 30 days | 60 days | 90 days | 180 days | 365 days |
| CLASS W AM-241 | < 1 | < 1 | 2 | 2 | 3 | 5 | 16 | 150 |
| CLASS W CF-252 | < 1 | < 1 | 4 | 4 | 7 | 11 | 38 | 420 |
| CLASS Y CF-252 | < 1 | < 1 | 39 | 47 | 50 | 53 | 65 | 95 |
| CLASS W CM-242 | < 1 | < 1 | < 1 | 2 | 3 | 4 | 22 | 460 |
| CLASS W CM-244 | < 1 | < 1 | 2 | 2 | 3 | 5 | 17 | 160 |
| CLASS W NP-237 | < 1 | < 1 | < 1 | 2 | 3 | 4 | 14 | 180 |
| CLASS W PU-238 | < 1 | < 1 | 2 | 2 | 3 | 5 | 16 | 150 |
| CLASS Y PU-238 | < 1 | < 1 | 20 | 24 | 25 | 26 | 29 | 38 |
| CLASS W PU-239 | < 1 | < 1 | < 1 | 2 | 3 | 4 | 14 | 140 |
| CLASS Y PU-239 | < 1 | < 1 | 18 | 22 | 23 | 24 | 27 | 34 |
| CLASS Y SR-89 | < 1 | < 1 | 6 | 9 | 15 | 23 | 90 | 1500 |
| CLASS Y SR-90 | < 1 | < 1 | 40 | 49 | 51 | 53 | 60 | 79 |
| CLASS W TH-228 | < 1 | < 1 | 9 | 11 | 17 | 27 | 100 | 1600 |
| CLASS Y TH-228 | < 1 | 2 | 100 | 120 | 130 | 140 | 180 | 270 |
| CLASS W TH-232 | < 1 | < 1 | < 1 | 2 | 3 | 4 | 14 | 180 |
| CLASS Y TH-232 | < 1 | < 1 | 16 | 19 | 20 | 20 | 23 | 30 |
| CLASS Y U-234 | < 1 | < 1 | 17 | 20 | 21 | 22 | 25 | 32 |
| CLASS W U-234 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 84 |
| CLASS W U-235 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 77 |
| CLASS Y U-235 | < 1 | < 1 | 16 | 19 | 20 | 20 | 23 | 30 |
| CLASS Y U-236 | < 1 | < 1 | 16 | 20 | 20 | 21 | 24 | 31 |
| CLASS W U-236 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 79 |
| CLASS Y U-238 | < 1 | < 1 | 15 | 18 | 19 | 20 | 22 | 29 |
| CLASS W U-238 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 | 6 | 74 |

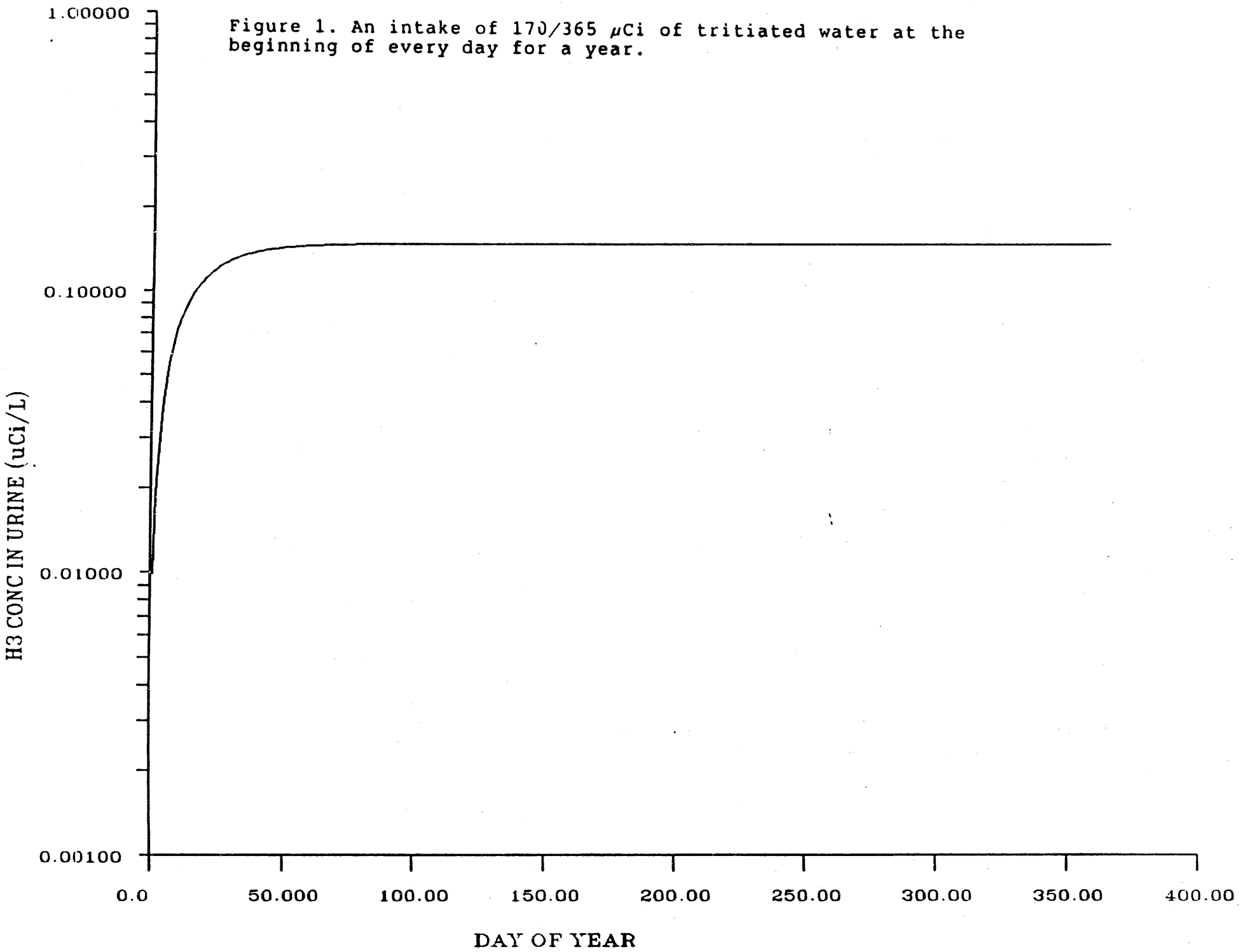



Figure 1. An intake of 170/365 μCi of tritiated water at the beginning of every day for a year.

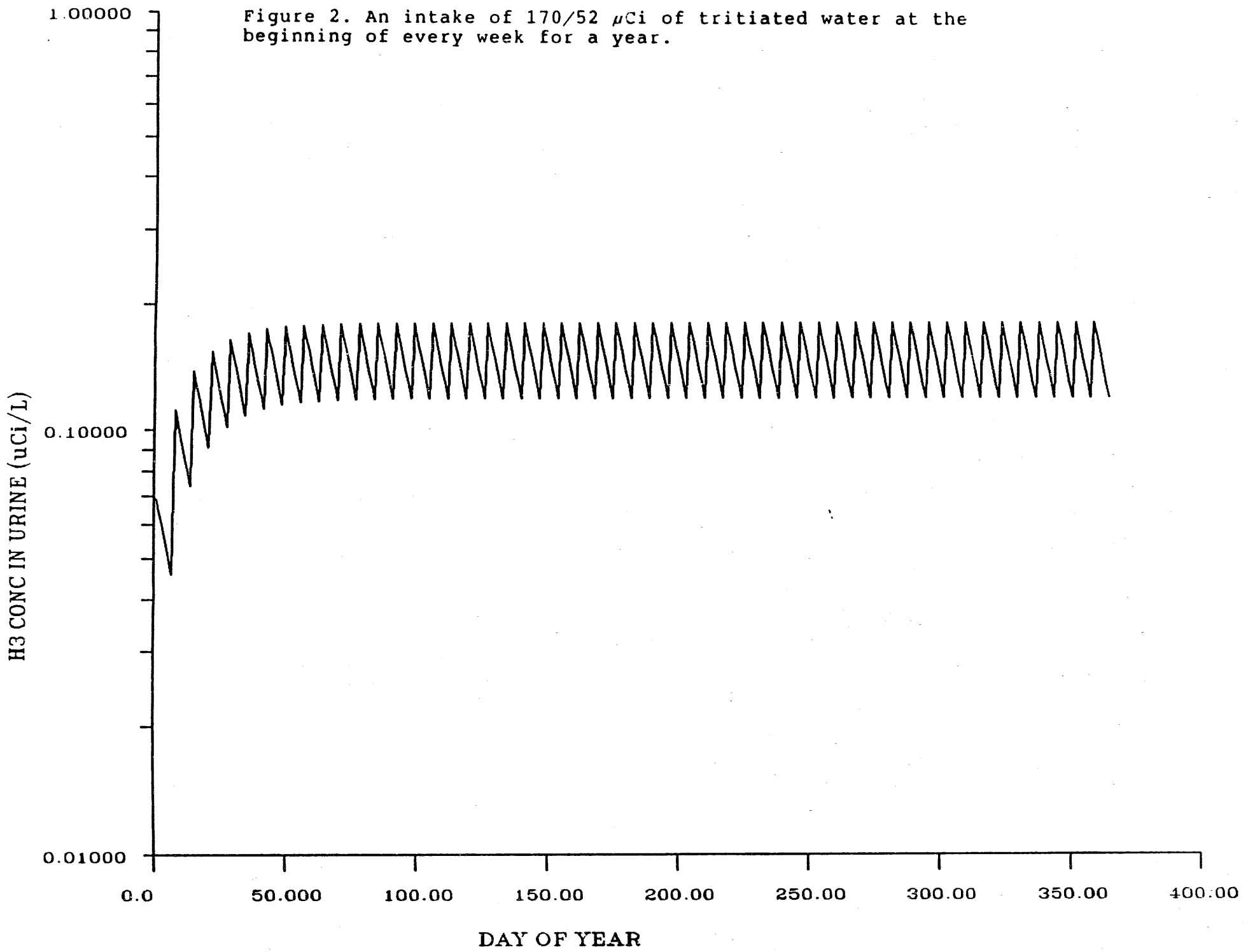
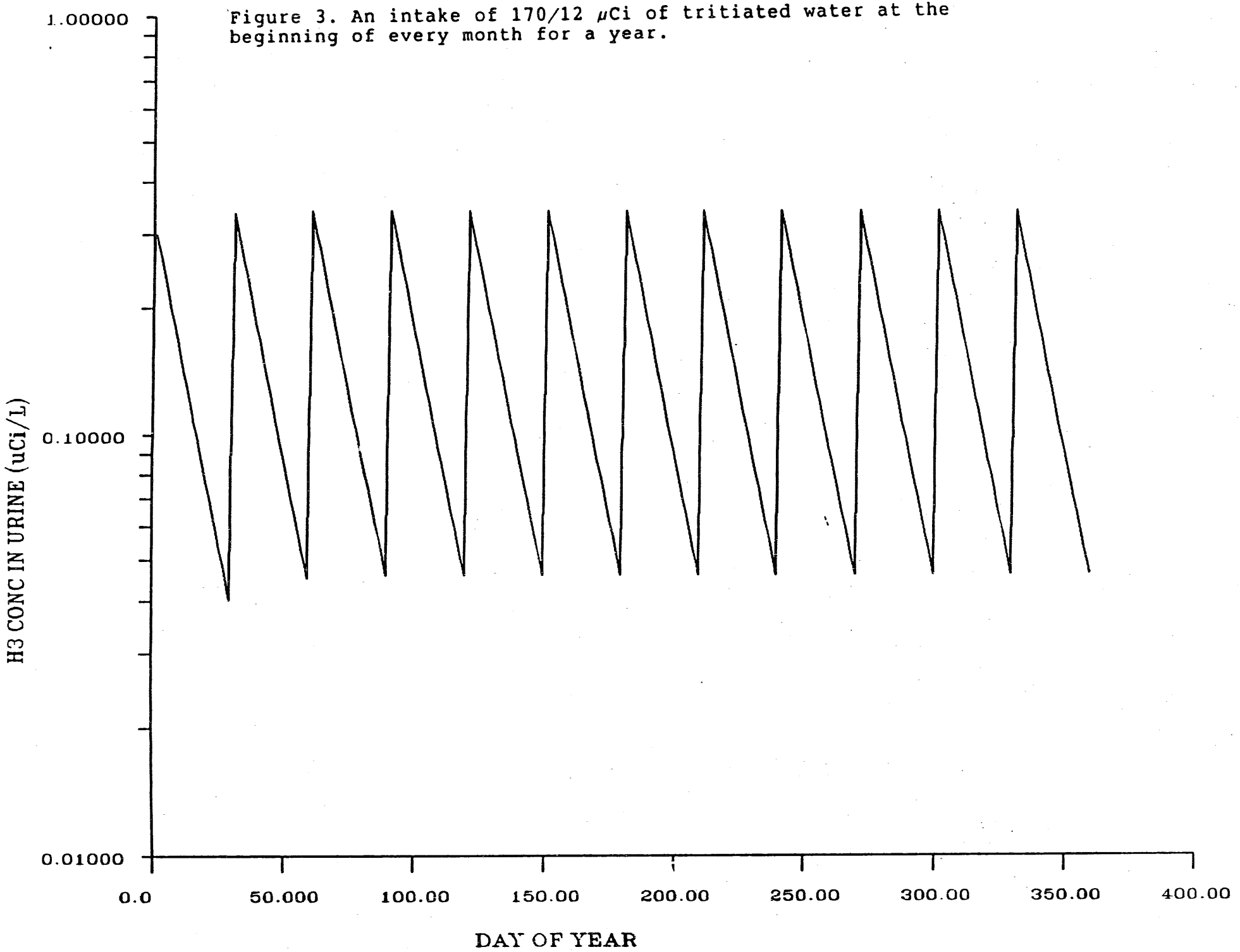



Figure 2. An intake of 170/52 $\mu$Ci of tritiated water at the beginning of every week for a year.

Figure 3. An intake of 170/12 μCi of tritiated water at the beginning of every month for a year.



# END

# DATE FILMED

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