AN ABSTRACT OF THE THESIS OF

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Title: Application of the Gamma Pathway Exemption Rule for Naturally Occurring Radioactive Materials in Industrial Waste Using ISOSHLD-II.

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Abstract Approved: _____ Dr. Jack Higginbotham

In recent years, a number of industries in Oregon have encountered situations where Naturally Occurring Radioactive Materials (NORM) are present in their waste, specifically uranium, radium and thorium. The law in Oregon prohibits the disposal of such waste at any sites in Oregon unless it was demonstrated that the gamma radiation exposure due to the NORM in the waste does not exceed 500 mrem (5 mSv) per year. To ensure that this dose limit is met for a member of the general public, standing on a semi-infinite plane of NORM waste, the maximum concentration of ^{226}Ra that can be present is 5 pCi/g. If the waste is contained in a standard box 1.5H x 1W x 2L feet (45.72 x 30.48 x 60.96 cm) or 55 gallon (0.242 m^3) steel drum, then the maximum dose rate at one foot (30.48 cm) from the surface of the container is 18 μR/hr. The Oregon Administrative Rules apply a Gamma Pathway Exemption Rule where the NORM concentration exceeds 5 pCi/g ^{226}Ra in the waste or the container geometry is not as the same as the one used in the regulations. An analysis on waste samples of some industrial companies in Oregon showed concentrations of uranium, radium and thorium in excess of allowed values. The concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra were found to be 15.51 pCi/g, 18.04 pCi/g, 7 pCi/g, 9 pCi/g respectively. These concentrations of NORM were

packaged in a container with the geometry of 5.4H x 8W x 20L feet (165.1 x 243.84 x 609.6 cm). This study is conducted to determine if applying the Gamma Pathway Exemption Rule for these concentrations of NORM contained in the new container will allow these materials to be exempt from the disposal prohibition law. To achieve this goal, the study followed the same methodology described in the regulations to verify if the waste will meet all the requirements of the Gamma Pathway Exemption Rule. The computer code (ISOSHLD-II) was used in this study to calculate the exemption level of 18 μR/hr dose rate from the box and the drum. The study considered two cases in the calculations: NORM in secular equilibrium and NORM in disequilibrium. The total dose rate from NORM in the new container was determined to be 2.44 μR/hr in case of secular equilibrium and 1.17 μR/hr in case of disequilibrium. Both dose rates are very low compared with the dose rate limit of 18 μR/hr. Thus the recommendation of this study is to exempt the waste from the disposal prohibition law and to allow it to be disposed at any site in Oregon.

Application of the Gamma Pathway Exemption Rule for Naturally Occurring Radioactive Materials in Industrial Waste Using ISOSHLD-II.

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بسم الله الرحمن الرحيم

IN THE NAME OF GOD(ALLAH), THE MOST BENEFICENT, THE MOST MERCIFUL

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All praise is due to Allah, the Lord of the worlds, whose blessings and beneficence are unceasing. O, Allah, All praise is due to you until you are pleased. O, Allah, make sincerity accompany my deeds; may thanking you for your gifts to my motto, and may fear of you be my security and belief. Remembering you is my pleasure. Peace and blessings be upon the one who was the most grateful to Allah, His Messenger Mohammad.

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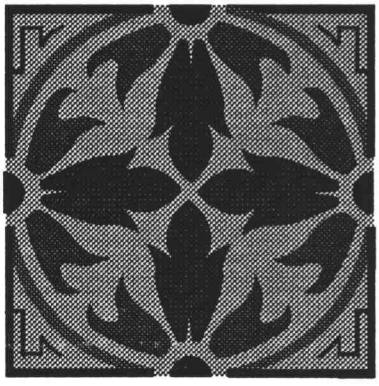

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Application of the Gamma Pathway Exemption Rule for Naturally Occurring Radioactive Materials in Industrial Waste Using ISOSHLD-II.

1. Introduction

Radiation can result from artificial and natural sources. Artificial sources(*some times called manmade sources*) include medical, dental X-ray and industrial radioactive tools. On the other hand, natural sources of radiation include radiation from outer space (cosmic rays), from naturally occurring radioactive materials found in the earth's crust and in living organisms. Some of these are ^{40}K, ^{14}C, ^{3}H, ^{238}U and ^{232}Th [1]. If body tissue or organs are exposed to excessive radiation, biological damage can occur, resulting in increasing the risk of cancer and birth defects in the individuals or in their descendants, or even death for extremely high doses. When radioactive materials, whether of natural or an artificial origin end up in forms or activity levels that are no longer useful to the licensee, they become radioactive waste.

The basic objective of the health physicist is to protect humans and the environment from unnecessary exposure to excessive levels of radiation. To keep the exposures from all kinds of sources as low as reasonably achievable, contact with these radioactive materials has to be minimized. To achieve this objective, the radioactive waste is packaged in a special-made containers and buried at disposal sites depending on the amount of activity and the concentration of the radioactive materials in the waste.

1.1 Disposal of radioactive materials in Oregon

In Oregon, it is prohibited by law to dispose any radioactive material by burial into any site in Oregon. The Oregon Administrative Rules OAR 345-50-006 states clearly this prohibition under the title **Disposal Prohibited**:

Except as provided in ORS 469.525 and OAR Chapter 345, Division 50, no discarded or unwanted radioactive material may be held or placed for more than seven days at any geographical site in Oregon except the site at which the radioactive material was used or generated pursuant to a license under ORS 453.635 or a site of a thermal power plant used for the temporary storage of radioactive material from that plant for which a site certificate has been issued by the Energy Facility Sitting Council.

The OAR 345-50-006 and ORS 469.525 are provided in Appendix A.

1.2 Naturally Occurring Radioactive Materials

In recent years, many industries have encountered situations where high concentrations of naturally occurring uranium, radium and thorium have existed within their consumer products and industrial waste. These Naturally Occurring Radioactive Materials, NORM, originate with ^{238}U, (half-life 4.5×10^{9} years) and with ^{232}Th (half-life 1.41×10^{10} years). Both radioactive series are found in the earth's crust and account for much of the radioactivity to which human and environment exposed. The progenies of ^{238}U and ^{232}Th are shown in Table 1-1 and Table 1-2 respectively. The isotope ^{226}Ra and its daughter products in the uranium series and the isotope ^{228}Ra and its daughter products in the thorium series are of special interest in our study. Both of these two isotopes are alpha particle emitters and they are present in various concentrations in all rocks and

Table 1-1. Uranium-238 Series

Isotope	Half-life	Radiation
^{238}U	4.47×10^{9} years	α,γ
^{234}Th	24 days	α,β,γ
^{234}Pa	1.2 min.	β,γ
^{234}U	2.5×10^{5} years	α,γ
^{230}Th	8.0×10^{4} years	α,γ
^{226}Ra	1622 years	α,γ
^{222}Rn	3.8 days	α,γ
^{218}Po	3.05 min.	α
^{214}Pb	26.8 min.	β,γ
^{218}At	1.5-2.0 sec.	α
^{214}Bi	19.7 min.	β,α
^{214}Po	1.64×10^{-4} sec.	α,γ
^{210}Tl	1.3 min.	β,γ
^{210}Pb	22 years	β,γ
^{210}Bi	5.0 days	β,α
^{210}Po	138 days	α,γ
^{206}Tl	4.2 min.	β
^{206}Pb	Stable	—

Table 1-2. Thorium-232 Series

Isotope	Half-life	Radiation
^{232}Th	1.41 x 10^{10} yr	α,γ
^{228}Ra	6.7 year	β
^{228}Ac	6.13 hr	β,γ
^{228}Th	1.9 year	α,γ
^{224}Ra	3.64 days	α,γ
^{220}Rn	55 sec.	α,γ
^{216}Po	0.16 sec.	α
^{212}Pb	10.6 hr	β,γ
^{212}Bi	60.5 min.	α,β,γ
^{212}Po	3.04x10^{-7} sec.	α
^{208}Tl	3.1 min.	β,γ
^{208}Pb	Stable	—

soils [2]. ^{226}Ra, which has a half-life of 1622 years is responsible for a major fraction of the dose received by humans from the naturally occurring radioactive materials. The biological hazard of ^{226}Ra to humans arises because it is a gamma ray emitter that contributes to the external whole body exposure. Also, it has a gaseous daughter element ^{222}Rn that can build up in closed places causing an elevated internal exposure. The ^{232}Th content of rocks is about four times that ^{238}U. Since the specific activity of the ^{232}Th is 0.11 pCi/g compared with 0.33 pCi/g for ^{238}U, the ratio of ^{226}Ra to ^{228}Ra is almost 1:1 [1]. Radium is usually found in gypsum rocks and very fine grained limestone, as many commercial products derived from these materials [2]. A study conducted by Oak Ridge National Laboratories (ORNL) showed that the average concentration of ^{226}Ra in the U.S. soil is approximately 1 pCi/g [3].

1.3 NORM Regulations

There is no federal statutes or regulations which specifically cover generation, storage, transport or disposal of NORM. In fact, the published regulations to guide the handling and the disposal of NORM-contaminated material are very few, except for NORM in uranium mill tailing which is well regulated by the Nuclear Regulatory Commission [2].

Furthermore, due to this absence of any federal guidelines for the NORM waste, some states have taken the task of creating NORM regulations and laws to be used in their domain, and some are prohibiting disposal until regulations are adopted. The State of Oregon has not yet adopted any laws regarding the NORM waste but it promulgated

regulations regarding the disposal of NORM since these materials are associated with many industrial processes in Oregon.

Although it is prohibited to dispose any radioactive waste in the State of Oregon, Naturally Occurring Radioactive Material is exempt from the provisions of OAR 345-50-006 **if** *"it can be demonstrated that accumulation of material will not result in exposure exceeding 500 millirem of external gamma radiation per year, nor in the release of effluents to air and water in annual average concentrations exceeding the values in Table 3.*", This is the Pathway Exemption Rule OAR 345-50-035. Table 3 and the Rule are reprinted in Appendix A. If the projected annual dose exceeds this limit, the material will be considered radioactive waste and must be disposed in a licensed radioactive waste disposal site. It is clear that the state limitations for NORM disposal follow the recommendations of the National Council on Radiation Protection and Measurements (NCRP). The recommendations state that the amount of the annual dose that will be received by individuals must not exceed the average annual effective dose equivalent of 500 mrem per year (5 mSv/yr)[4].

From the Pathway Exemption rule, there is no limitations on the amount of NORM that could be associated with the industrial waste. In other words, to be exempt from the OAR 345-50-006, A waste material that contains NORM must not result in a dose that exceeds 500 mrem per year (5 mSv) regardless of ^{238}U, ^{226}Ra and ^{232}Th concentrations.

To assure the compliance with the Pathway Exemption rule, the exposure dose from NORM is verified by applying the gamma pathway exemption Interpretive rule (OAR 345-50-036). This rule is used to determine whether a material contains NORM is a radioactive waste or not.

1.4 Gamma Pathway Exemption Interpretive Rule

The rule assumes that a person who spends 90 percent of the time in a house built on a homogeneous, semi-infinite plane of NORM will receive 500 mrem (5mSv) if the exposure dose is measured at three feet from the floor. Then by using a computer model, the corresponding NORM concentration is calculated. If NORM of this concentration is then packaged in one of two container geometries then the exposure rate at one foot from the side of the containers is found to be 18 μR/hr. These two containers are a standard 55 gallon (0.242 m^3) steel drum (Figure 1-1) and a box measuring 1.5H x 1W x 2L feet (45.72 x 30.48 x 60.96 cm) (Figure 1-2). So, if any waste material packaged in one of these container geometries gives a radiation level less than 18 μR/hr it will be exempt from Oregon law by the gamma pathway exemption rule.

The Interpretive Rule *(OAR 345-50-036)* states :

This rule shall be the basis for determining compliance with OAR 345-50-035 when considering external gamma radiation exposure. Disposal in Oregon of waste materials containing naturally-occurring radioactive materials (NORM) must not result in doses to individuals greater than 500 millirem per year. If doses exceed this limit, waste material is considered radioactive and must be disposed of in a licensed radioactive waste disposal site. The waste materials also must meet air and water (including radon and leaching) pathway exemptions in OAR 345-50-035. . .

. . . (4) The following readings correspond to a potential dose of 500 millirem per year for the respective container geometries. Long-lived radionuclides are assumed to be in a secular equilibrium. If measurements as described in section (3) of this rule produce readings below the following levels, the waste material shall be exempt based on the gamma pathway only:

(a) Standard 55-gallon steel drum: 18μR/hr (above background) at one foot.

(b) Box (1.5H x 1W x 2L feet): 18μR/hr (above background) at one foot.

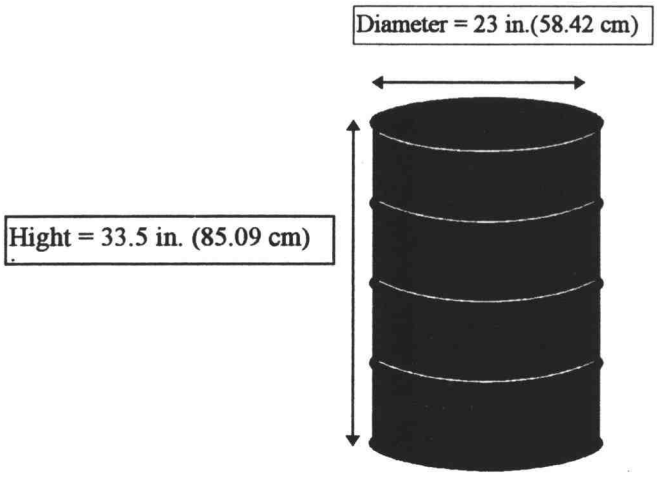

Fig. 1-1. A standard 55-gallon steel drum

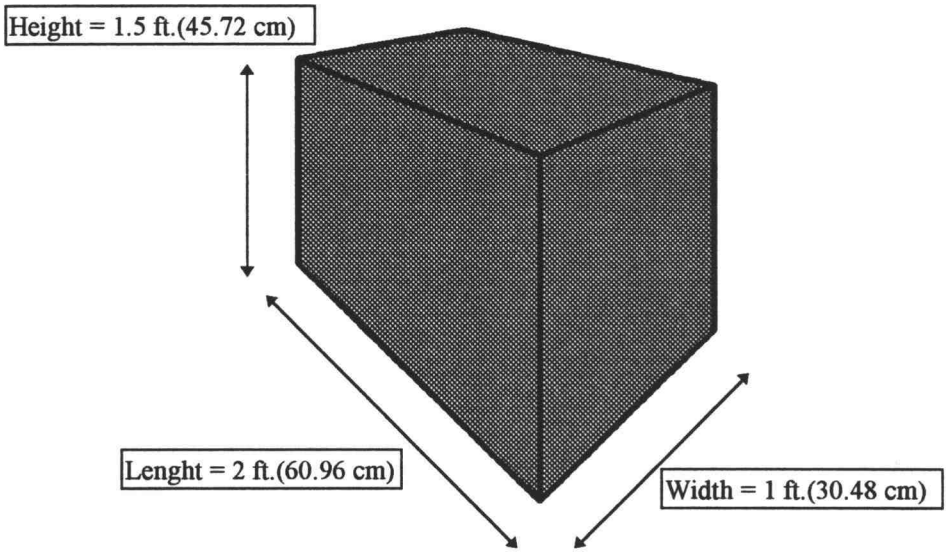

Figure 1-2. A standard box

It should be known that these two containers are not the only geometries that could be used for the approval of the gamma pathway exemption rule. Furthermore, the rule states clearly that the Oregon Department of Energy (ODOE) may approve any container type to be used under the exemption rule if :

(a) The exemption levels for the other container types are derived by the same computer model and assumptions used to calculate the exemption levels for the drum and the box in section (4) of this rule;
(b) Measurements are made in compliance with sections (2) and (3) of this rule;
(c) The contents of containers larger than a box or drum are uniformly mixed before readings are taken to determine compliance.

1.5 Purpose

The purpose of this work is to determine if industrial waste with high NORM concentrations will also be exempt from Oregon law by applying the pathway exemption rule, using the same methods and procedures referenced in the regulations. The main point of this study is to calculate the dose rate from various NORM concentrations packaged in a new container geometry using the same computer code that was used in the regulation to establish the dose rate limits for the standard box and the drum containers.

1.6 Objectives

The objectives of the study are as follows:

(1) To determine the compliance of the study's computer code results with that in the regulations.

(2) To calculate the gamma dose rate at one foot (30.48 cm) from NORM of concentrations higher than 5 pCi/g contained in a large box of different geometry using ISOSHLD-II computer code.

(3) To compare the results with the levels stated in the regulations .

2. Determination of Uranium and Thorium concentration in soil

The concentration of NORM in soil is determined by laboratory analysis of a sample of the soil, and is generally expressed in terms of picoCuries per gram (pCi/g). There are several ways to determine the concentration of uranium, thorium and their progeny in soil. The two most popular methods are the gamma ray spectroscopic analysis and the neutron activation analysis. These are analytical techniques which are used to determine the amount of a given isotope contained in some materials such as soil and industrial waste.

2.1 Gamma Spectroscopic Analysis

In gamma ray spectroscopic analysis, the emission rate of gamma rays from uranium and thorium progeny in a sample of unknown uranium and thorium concentrations are measured. The measured emission rate is compared with a measured rate from uranium and thorium progeny in a soil sample of known concentrations. To determine the uranium and thorium concentrations in the unknown sample , equation (1) is applied:

$$\text{Concentration (unknown)pCi/g} = \frac{\gamma \text{ emission rate (unknown) per Bq cm}^{-3} * \text{Concentration (known) pCi/g}}{\text{emission rate (known) per Bq cm}^{-3}} \quad (1)$$

The concentration of uranium and thorium in the unknown sample are equal to its gamma ray emission rate per Bq cm^{-3} multiplied by the concentration of the "known" sample and

divided by the "known" gamma ray emission rate per Bq cm^{-3}. This technique assumes that uranium and thorium progeny are in the same state of equilibrium in both the known and the unknown samples [5].

2.2 Neutron Activation Analysis

The neutron activation analysis is based on the principle that when a material is irradiated with neutrons, some of the nuclei present in the material will interact with the neutrons and be converted into radioisotopes with relatively short half lives. The concentrations of daughter radioisotopes are then measured using gamma ray spectroscopy. The most common and sensitive method of activation analysis is by activation with thermal neutrons in the high flux of a research reactor and measuring the radioactivity induced in the newly formed radionuclides from the stable isotopes present in the sample [4]. The number of activated atoms is proportional to the number of target atoms in the sample. Also, the rate of nuclear reaction in a given irradiated sample is proportional to the flux of the incident neutrons and the number of the target (whether it is uranium or thorium) nuclei. The nuclear activation of the analyzed sample is followed by the quantitative detection of the energy dependent gamma ray emissions. The basic steps for neutron activation analysis are shown in Fig. 2-1.

To determine the uranium concentration in an unknown sample, the disintegration rate of the activation product x* is first calculated using the expression:

$$D_{x^*} = N_x \sigma \phi (1 - e^{-\lambda_{x^*} t_i}) e^{-\lambda_{x^*} t_d} \qquad (2)$$

Where D_{x^*} is the disintegration rate of the product x* present at time t_d after the end of the bombardment, N_x is the number of uranium nuclei present initially, σ is the nuclear reaction cross section, ϕ is the flux of thermal neutrons, t_i is the length of the irradiation and λ_{x^*} is the decay constant of x* [6].

To determine the concentration of the uranium in the unknown sample, another sample of known uranium concentration and of the same physical and chemical characteristics of the unknown sample is activated under the same initial conditions. The induced gamma emission rate is measured by the same detector that has been used to measure the gamma emission rate of the unknown. The quantity or the concentration of the uranium in the unknown sample is then given by the expression :

$$\text{Uranium concentration (unknown)} = \text{U concentration (known)} * \frac{\gamma \text{ emission rate (unknown)}}{\gamma \text{ emission rate (known)}} \qquad (3)$$

Here in this method, the uranium and thorium concentrations are measured directly. Lazo and Roessler assumed that the neutron and gamma attenuation properties of the standard are the same as those of the unknown sample [5].

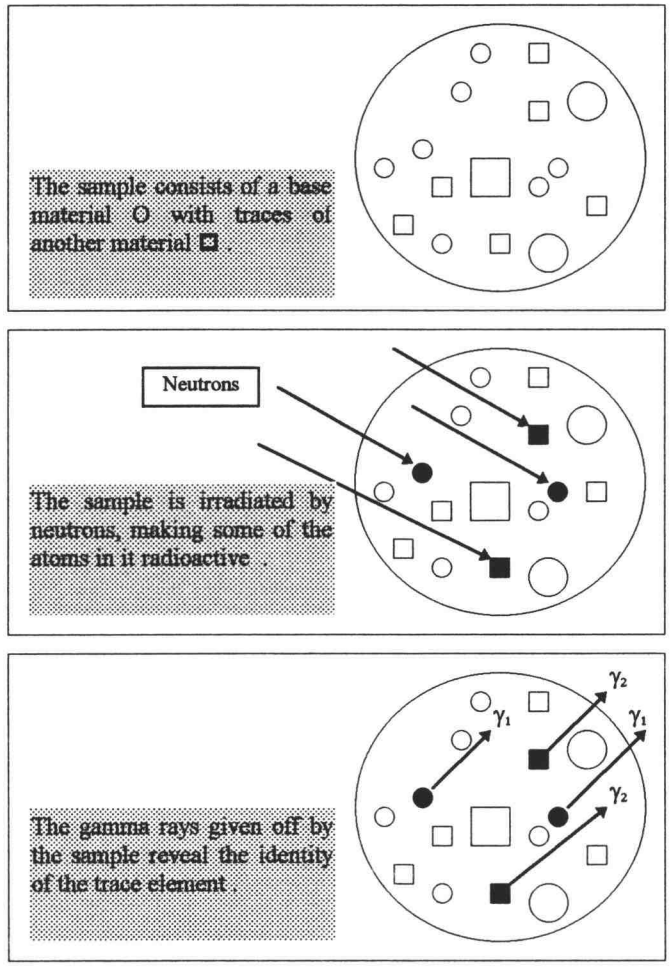

Figure 2-1. A schematic view of activation analysis. [7]

2.3 ^{238}U , ^{232}Th and ^{226}Ra concentrations in soil in the United States

A research team in Oak Ridge National Laboratories began in 1975 a background measurement program to determine the concentration of uranium, thorium and ^{226}Ra in surface soil nation wide [3]. These background concentrations across the U.S. have been measured by the remedial action survey and certification activities group of the health and safety research division at Oak Ridge National Laboratories.

Soil samples have been collected from 356 locations in 33 states including Oregon. For the determination of ^{238}U, ^{232}Th and ^{226}Ra the samples were taken from the top 6 cm of the soil from each location. For the determination of ^{238}U concentration, the neutron activation analysis method was used with the help of the Oak Ridge Research Reactor and subsequent counting of delayed neutrons in a high efficiency BF_3 counter. To determine the ^{232}Th and ^{226}Ra concentrations, the gamma spectroscopy analysis method was used by storing the analyzed samples for 30 days to allow build up of radon and its daughters. A germanium lithium drifted [Ge(Li)] detector was used because of its superior high resolution to detect and measure the gamma emission rate from the stored samples. The detector was calibrated using soil standards provided by New Brunswick laboratories. These soil standards contained certified concentrations of ^{238}U and ^{232}Th with associated daughters concentrations. It was assumed that the ^{238}U , ^{232}Th and their daughters are in secular equilibrium [3].

2.4 Results of the ORNL survey

The research team showed that the average concentrations in the U.S. for all three nuclides were 1.1, 0.98, and 1.0 pCi/g for ^{226}Ra, ^{232}Th and ^{238}U respectively[3]. Table 2-1 shows the background concentrations with comparison to the world average. The study showed that the U.S. average concentration of radium is almost the same as the concentration of uranium which implies that a radioactive equilibrium within the uranium decay series exists [3] .

Table 2-1. Background radionuclide concentrations in surface soil-world average

Radionuclide	U.S. average (pCi/g)	World average (pCi/g)
^{226}Ra	1.1	0.79
^{238}U	1.0	0.66
^{232}Th	0.98	0.65

3. Problem Description

3.1 The case

Many industrial companies in the United States perform analysis on their products waste before the disposal of the waste to ensure that hazardous materials are not contained in their waste material. One such company in Oregon sent samples of their waste products to an analytical laboratory to get information about the composition of the waste. The samples were fused Al_2O_3. The analysis showed that the naturally occurring radioactive materials uranium and thorium were present in the samples. The average concentration for uranium and thorium was found to be 46.5 ppm and 165 ppm respectively. The complete data analysis of these samples is given in Table 3-1.

It is better to convert the concentration unit from ppm to pCi/g by applying equation (4) as follows:

$$C_{pCi/g} = \frac{C(ppm) * N * \lambda * P(\%)}{M(g) * 3.7 * 10^{10} (dps)} \qquad (4)$$

Where $C_{pCi/g}$ is the concentration of the radioactive element in pCi per gram , C(ppm) the concentration of the same element in part per million, N Avogadro's number = 6.022×10^{23}, P(%) the abundance percent of the element and M(g) is the mass number. Thus, the concentration of the uranium in pCi per gram is equal to :

$$\text{The } ^{238}U \text{ concentration} = 46.5 * 10^{-6} * 6.022 * 10^{23} * 4.916 * 10^{-18} * 0.9927 / 238 * 3.7 * 10^{10}$$

$$= \mathbf{15.51\ pCi/g}$$

Using equation (4), the ^{232}Th concentration is **18.04 pCi/g** .

Table 3-1. Data analysis for the Al_2O_3 samples

Sample ID	*Test B2*	*Test 522*	*Avg. ppm*
Ba	62	63	
Bi	<1	<1	
Ce	270	330	
Cs	<1	<1	
Dy	14	19	
Er	10	12	
Eu	2.4	2.7	
Gd	13	13	
Hf	110	67	
Hg	<1	<1	
Ho	2.9	3.9	
La	83	100	
Lu	1.5	2.2	
Nd	76	77	
Pb	<1	2.0	
Sb	<1	<1	
Sn	14	18	
Ta	1.8	1.1	
Th	180	150	165
Tl	<1	<1	
Tm	1.4	2.2	
U	51	42	46.5
W	5.5	6.6	
Yb	11	13	

The above results reported as :
parts per million by weight

The samples were analyzed for the contents of ^{226}Ra and ^{228}Ra. The analysis showed a ^{226}Ra concentration of 7 ± 1 pCi/g and a ^{228}Ra concentration of 9 ± 1 pCi/g, as shown in Table 3-2. The disequilibrium in radium concentration could result from a redistribution of the parent isotopes of ^{226}Ra and ^{228}Ra during the treatment of the waste or during the manufacturing process. Secular equilibrium occurs when the numbers of atoms of each nuclide of a radioactive series that decays during a specific time interval nearly equals the number of decays of the parent nuclide in the series. This is due to the long half life of the parent. Thus the daughter has the same activity or concentration as that of the parent which is the highest activity in the progeny. The gamma pathway exemption rule assumed the long lived radionuclides (i.e. ^{238}U and ^{226}Ra) to be in secular equilibrium so that the measured radiation levels from the container are based on the highest activity of ^{226}Ra. In other words, the ^{226}Ra has its highest activity when it is in secular equilibrium with ^{238}U.

However, if the daughters of ^{238}U and ^{232}Th are in disequilibrium does the waste still meet the requirements of the gamma pathway exemption rule stated in the OAR 345-50-036 and how does one demonstrate this compliance?

Table 3-2. Concentration of NORM in Al_2O_3 samples

NORM	Concentration (pci/g)
^{238}U	15.51
^{232}Th	18.04
^{226}Ra	7 ± 1
^{228}Ra	9 ± 1

3.2 Methods

To ensure that the study is following the same methodology used in the regulation and to comply with section (5) of the gamma pathway exemption rule, the same calculations that have been used for the NORM of 5 pCi ^{226}Ra per gram contained in the 55-gallon steel drum (0.242 m^3) and 1.5H x 1W x 2L feet (45.72 x 30.48 x 60.96 cm) box have been repeated using the ISOSHLD-II Code. The study uses this code because it is the same code that has been used in the regulations to derive the exemption level of 18 μR/hr.

3.3 Computer Model

The computer software used in this work ISOSHLD-II. It is a point kernel code which was written at the Pacific National Laboratory (PNL) in 1966 and then modified to the ISOSHLD-II PC version in 1987 by Westinghouse Hanford Company (WHC) and compiled on the Lahey F77L compiler. The purpose of this computer code is to calculate decay gamma ray and bremsstrahlung doses exterior to a shield [8].

The ISOSHLD-II computer code has an isotope library that allows the user to select from 500 radioisotopes. Also it has a shield material library which contains 22 different shield materials to be used in the calculations. Also, the code allows the user to choose the source geometry from 12 different geometries (i.e. Point source, line source, cylindrical source, rectangular source... etc.) [8].

The code consists of the INPUT file which is necessary to execute ISOSHLD-II and the OUTPUT file which is the result of the dose calculations.

3.4 The INPUT file

The INPUT file is supplied by the user in a specific format and consists of the following:

1- *The Run Title* : Main run heading

2- *Case Title Line :* Which will be the heading for the final dose table.

3- *Namelist Lines* : Contain the values assigned to various program variables to control the computation such as the length of printout, source data, shielding material data, geometry, detector position, integration variables NTHETA, NPSI that determine how many intervals to slice the source into and DELR which is the thickness of the chunks in centimeters. It is important to note that all distances are measured in cm and the source concentration is assumed to have units of microcuries per cubic centimeter [8].

3.5 The OUTPUT file

The OUTPUT file is the final print out after running the code. It gives a summary about the source activity, the shield composition, energy groups, the total exposure dose rate in R/hr and the input file [8].

4. CALCULATIONS

4.1 Deriving the Exemption Level of 18 μR/hr

4.1.1 Standard Box

To derive the exemption level of 18 μR/hr it was assumed that a fused Al_2O_3 of density 3.967 g/cm^3 contains ^{226}Ra of a concentration of 5 pCi/g in a standard box. The source geometry, as shown in Fig. 1-2, is a 45.72 cm (height) by 60.96 cm (length) by 30.48 cm (width). The source strength is assumed to be uniformly distributed within the box, all daughters are assumed to be in secular equilibrium with ^{226}Ra. The strength of each isotope is 19.835 pCi/cm^3. A detector is placed in two points: one foot (30.48 cm) from the center of side A and one foot (30.48 cm) from the center of side B. The resulted two readings will be averaged to get the average dose rate one foot from the box. Table 4-1 shows the exposure rates and their average as calculated with ISOSHLD-II. From Table 4-1, the exposure dose rate at side A is 16.27 μR/hr. On the other hand, the exposure dose rate at side B is 19.84 μR/hr. The average of these two readings is 18 μR/hr.

4.1.2 Standard 55 gallon steel drum

Fused Al_2O_3 containing the 5 pCi/g of ^{226}Ra is packaged into a standard 55 gallon (0.242 m^3) steel drum. The source is now cylindrical in shape with height of 85.09 cm and a radius of 29.21 cm. The distance along the centerline from one end of the drum to

the detector is 42.54 cm. All isotopes are assumed to be in secular equilibrium. The strength of source and thus of each isotope is 19.835 pCi/cm^3 . The detector is placed one foot to the side of the drum. The input file and the output file are shown in Appendix C. The results of the ISOSHLD-II calculations are shown in Table 4-1 and the exposure rate due to 5 pCi/g of ^{226}Ra contained in the drum is 18 μR/hr.

Table 4-1. Exposure rates based on repeating the calculations in section(4) of the Exemption rule

Type of Container	^{226}Ra Concentration	At side (A) μR/hr	At side (B) μR/hr	Average μR/hr
Standard Box 45.72 cm (H) x 30.48 cm (W) x 60.96 cm (L)	5 pci/g	16.27 μR/hr	19.84 μR/hr	18 μR/hr
55-gallon steel drum (242 x 10^3 cm^3)	5 pci/g	18 μR/hr	18 μR/hr	18 μR/hr

The first objective has been achieved by ensuring that this study is following the same methodology that been used to calculate the exposure rates given in the OAR 345-50-036. Hence, the method used in this work can determine exposure rates "derived by the same computer model and assumptions used to calculate the exemption levels for the drum and the box in section (4)" of the rule.

4.2 Deriving Dose Rates From a New Container Geometry With Radium Concentration Higher Than 5 pCi/g

In this section, the task is to calculate the dose rate from NORM at concentrations higher than the 5 pCi/g used in the regulations and with the NORM packaged in a large container. The dimensions of the large container are 5.4H x 8W x 20L feet (165.1 x 243.84 x 609.6 cm) as shown in Fig. 4-1 and which are different than the drum or the box geometry. Another problem is that the ^{238}U is in disequilibrium with the ^{226}Ra, also the ^{232}Th is in disequilibrium with the ^{228}Ra and this will change one of the assumptions that was stated clearly in section (4) of the Gamma Exemption rule. Since for dose calculations from ^{238}U and ^{232}Th, we are concerned about the radium concentration and thus its activity, it is assumed that secular equilibrium exists between the ^{238}U and ^{226}Ra , ^{232}Th and ^{228}Ra to ensure that the radium activity is at its highest level and hence the resulting dose rate will be at the maximum.

Two kinds of calculation will be done to comply with the Gamma Pathway Exemption rule:

1- Deriving dose rate from NORM in the new geometry assuming secular equilibrium.

2- Deriving dose rate from NORM in the new geometry assuming disequilibrium.

For the first part, the study assumes that secular equilibrium exists between the ^{238}U and its daughters, and also between ^{232}Th and its daughters. For the second part, the study will calculate the dose rate from the new container due to ^{226}Ra and ^{228}Ra while neglecting their parents. The detector will be placed one foot from side B of the container. Although the highest dose rate is likely to be at the top and the bottom of the container, it is difficult to make the measurements at these two positions because of the size of the container and

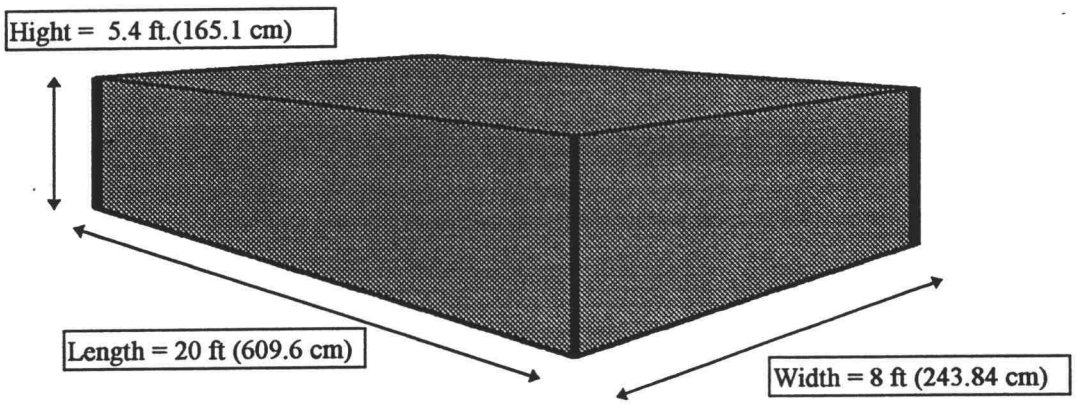

Fig. 4-1. The new container geometry of dimensions (5.4H x 8W x 20L feet) which is used with Al_2O_3 samples

it is not practicable to turn a container of this large size upside down to take the reading one foot from the bottom. However, the only positions for taking the readings are the sides of the container and it was found that dose rate at side B is higher than side A.

4.2.1 Dose rate from ^{238}U in large container (assuming secular equilibrium)

The fused Al_2O_3 is packaged in the container (Fig. 4-1). The ^{238}U concentration is 15.51 pCi/g and thus the strength of each isotope is 61.52 pCi/cm^3 . The distance from the bottom of the container to the detector (X parameter) is 274.32 cm , the height of the container (Y parameter) is 165.1 cm , the width of the container (SLTH parameter) is 609.8 cm and the depth of the container (T(1) parameter) is 243.84 cm. The detector is placed one foot from side B. The output file in Appendix D, shows a dose rate of 0.98 μR/hr.

4.2.2 Dose rate from ^{238}U in large container (assuming disequilibrium)

In this case, the ^{226}Ra and its daughters are of our concern. The concentration of ^{226}Ra was found to be 7±1 pCi/g and thus the source strength is 27.769 pCi/cm^3. The rest of the parameters(X,Y,SLTH,T(1)) are the same as in the equilibrium case. The detector position remains unchanged. The calculated dose rate as shown in the output file (Appendix E) is 0.43 μR/hr .

4.2.3 Dose rate from ^{232}Th in large container (assuming secular equilibrium)

The dose rate due to the ^{232}Th and its daughters is calculated using the same methods described above. The concentration of the ^{232}Th in the Al_2O_3 is 18.04 pCi/g and

thus the source strength is 71.56 pCi/cm^3. The ratio of gamma photon emissions of the ^{228}Ra and its daughters is 1:1 except for the ^{208}Tl where the ratio is 1:0.359 and thus the strength of the ^{208}Tl is 25.69 pCi/cm^3. All the parameters (X, Y, SLTH, T(1)) values are the same as used in the uranium cases. The detector is placed one foot from the center of side B of the container. The dose rate is expected to be higher than the one in the uranium case because the thorium concentration is higher. The output file in Appendix F shows a dose rate of 1.46 μR/hr.

4.2.4 Dose rate from a large container contains ^{232}Th (assuming disequilibrium)

For the ^{232}Th disequilibrium case, the concentration of ^{228}Ra was 9±1 pCi/g and thus a source strength of 35.703 pCi/cm^3 was used. The rest of the parameters (X,Y,SLTH,T(1)) are unchanged. The calculated dose rate as shown in the output file (Appendix G) is 0.74 μR/hr .

4.3 Total Dose rate from NORM in the large container

A. For the secular equilibrium case:

The total dose rate equals the dose rate from ^{238}U in case 4.2.1 plus the dose rate from ^{232}Th in case 4.2.3 which will give a total dose rate of **2.44 μR/hr .**

B. For the disequilibrium case:

The total dose rate equals the dose rate from ^{238}U in case 4.2.2 plus the dose rate from ^{232}Th in case 4.2.4 which will give a total dose rate of **1.17 μR/hr .**

5. Results

5.1 Discussion

All the calculation results are presented in Table 5-1 for the secular equilibrium case and in Table 5-2 for the disequilibrium case including the total exposure dose rates. The dose rate from the NORM in the new geometry container is less than the 18μR/hr dose rate limit enforced by the OAR 345-50-036. In the case of secular equilibrium, it is only 14% of the dose rate limit and for the disequilibrium case it is 7% of the dose rate limit.

It is true that the radium concentration is higher than that in the regulation, and if the calculation was based on the standard box we would expect to see a dose rate higher than 18 μR/hr, but the new container is larger in dimensions than the standard box and this is why the dose rate came less than 18 μR/hr. In fact, the dose rate depends on three important factors : the concentration of the NORM, the container geometry and shielding . The assumption that the radionuclides be in secular equilibrium does not have any obvious affect on the dose rate results as shown from Tables 5-1 and 5-2.

The disequilibrium between ^{238}U and ^{226}Ra ,^{232}Th and ^{228}Ra that occurs during some industrial operations can not be controlled. The research team of Oak Ridge National Laboratory observed a large deviations from equilibrium between uranium and radium compounds due to the different geochemical properties [3]. Although, the uranium and radium are found to be in secular equilibrium in the uranium ores, it does not necessarily

Table 5-1. Dose rates one foot (30.48 cm) from the new container geometry (Secular Equilibrium)

NORM	Concentration pCi/g	Dose Rate μR/hr	Total dose rate μR/hr
U-238	15.51	0.98	2.44
Th-232	18.04	1.46	

Table 5-2. Dose rates one foot (30.48 cm) from the new container geometry (Disequilibrium case)

NORM	Concentration pCi/g	Dose Rate μR/hr	Total dose rate μR/hr
Ra-226	7±1	0.43	1.17
Ra-228	9±1	0.74	

exist in other uranium and radium compounds [9]. Another study was done by a research group from the University of Florida in Gainesville on the phosphate rocks in Florida where uranium is known to be present in association with phosphate deposits. The study showed that uranium and radium are in a state of radioactive equilibrium in the phosphate ore. Once the phosphate ore is manufactured for industrial purposes, the equilibrium will be disrupted and a state of disequilibrium then exists between uranium and radium [10]. In other words, in the absence of chemical or physical separation processes, an equilibrium is reached between uranium and radium in nature. On the other hand , when dealing with an industrial waste which contain NORM, one should consider that these NORM are no longer in their natural state of equilibrium. This is because chemical and physical separation are common in industry and these processes could lead to the relative depletion of some nuclides from certain rocks and soils and the relative concentration of others causing the disruption of the equilibrium of the naturally occurring radioactive materials[11]. In general, any NORM present in an industrial waste would not necessary be in secular equilibrium and thus we conclude that the assumption of secular equilibrium for the NORM in the gamma pathway exemption rule is not valid for NORM in industrial wastes.

5.2 Conclusion and Recommendations

In this study we calculated the dose rate resulting from NORM in an industrial waste and applied the gamma pathway exemption rule. The study found that the dose rate from the large container that contained the waste is less than the dose rate limit of 18 μR/hr which is stated in the OAR 345-50-036. Furthermore, the study assured that the industrial waste meets all the requirements of the gamma pathway exemption rule except for the assumption that the NORM are in secular equilibrium. This is because the waste has been chemically processed and this process affects the natural distribution of the NORM in the waste. In fact the study showed that even in the case of secular equilibrium, the resulting dose rate due to the NORM in the waste is only 14% of the exempt dose rate level in the regulation. For this result, the waste should not be dealt with as a radioactive waste. Thereby, it should be considered as a normal waste and be exempt from the Oregon law by allowing the disposal of it in any site in Oregon.

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Appendices

Appendix A

Oregon Administrative Rules
Chapter 345, Division 50

DIVISION 50

RADIOACTIVE WASTE MATERIALS

Disposal Sites for Radioactive Materials
345-50-005 [NTEC 3, f. 5-19-72, ef. 6-1-72; Repealed by EFSC 9-1978, f. 12-28-78, ef. 3-1-79]

Disposal Prohibited
345-50-006 Except as provided in ORS 469.525 and OAR Chapter 345, Division 50, no discarded or unwanted radioactive material may be held or placed for more than seven days at any geographical site in Oregon except the site at which the radioactive material was used or generated pursuant to a license under ORS 453.635 or a site of a thermal power plant used for the temporary storage of radioactive material from that plant for which a site certificate has been issued by the Energy Facility Siting Council.

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79; EFSC 1-1979(Temp), f. & ef. 3-5-79; EFSC 9-1981, f. & ef. 12-28-81

[ED. NOTE: The text of Temporary Rules is not printed in the Oregon Administrative Rules Compilation. Copies may be obtained from the adopting agency or the Secretary of State.]

Purpose and Applicability
345-50-010 (1) Since virtually all materials contain some measure of radioactivity, it is the purpose of these rules to identify those materials which present such small health hazards that they are exempt from the provisions of ORS 469.525 (1981 Replacement Part) as incorporated in OAR 345-50-006 and may be disposed of within the state.

(2) It is also the purpose of these rules to establish standards for the siting of those waste disposal facilities which would only include wastes generated before June 1, 1981 through industrial or manufacturing processes which contain only naturally occurring radioactive isotopes. It is the purpose of these rules to implement the requirements of ORS 469.375, 469.470, 469.500 and 469.510 for such waste disposal facilities. These rules do not apply to uranium mine overburden or uranium mill tailings, mill wastes or mill by-product material which are subject to OAR Chapter 345, Divisions 92 and 95.

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79; EFSC 9-1981, f. & ef. 12-28-81

Exempt Quantities
345-50-020 Materials are exempt from provisions of ORS 469.525 provided that such materials contain radioactive material in individual quantities none of which exceeds that applicable quantity set forth in **Table 2** and provided that the number of individual quantities does not exceed 10.

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79

Exempt Concentrations
345-50-025 Materials are exempt from the provisions of ORS 469.525 provided that such materials contain radioactive materials in concentrations not in excess of those of **Table 1**.

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79; EFSC 5-1980, f. & ef. 4-25-80

Specific Exemptions
345-50-030 In addition to the exemptions under OAR 345-50-020 and 345-50-025, the following materials are exempt from the provisions of OAR 345-50-006 (or ORS 469.525):

(1) Radioactive material which has been incorporated into a consumer product manufacture under a license issued by the Nuclear Regulatory Commission, or an Agreement State and for which the agency licensing such manufacturer has determined that the possession, use, transfer, and disposal of such consumer product by all persons is exempt from regulatory requirements.

(2) Radium-bearing materials containing less than 5 picocuries of radium-226 per gram of solid, regardless of quantity.

(3) Radium-bearing material containing a total radium-226 activity of less than ten microcuries, regardless of concentration.

(4) Thorium-bearing materials containing less than 20 picocuries of radium-228 per gram of solid, providing that the radium-228 is present with the parent thorium-232, regardless of quantity.

(5) Thorium-bearing materials containing a total radium-228 activity of less than 100 microcuries, providing that the radium-228 is present with the parent thorium-232, regardless of concentration in the solid.

(6) Medical, industrial and research laboratory wastes contained in small, sealed, discrete containers in which the radioactive material is dissolved or dispersed in an organic colvent or biological fluid for the purpose of liquid scintillation counting and experimental animal carcasses which are disposed of or treated at a hazardous waste disposal facility licensed by the Department of Environmental Quality.

(7) Wastes generated before June 1, 1981 through industrial or manufacturing processes which contain only naturally occurring radioactive isotopes and for which a site certificate has been issued by the council in accordance with ORS 469.375 and OAR 345-50-040 through 345-50-130.

(8) Maintenance of radioactive coal ash at the site of a thermal power plant for which a site certificate has been issued.

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79; EFSC 9-1981, f. & ef. 12-28-81

Pathway Exemption
345-50-035 Naturally occurring radioactive materials shall be exempt from the provisions of OAR 345-50-006 (or ORS 469.525) if it can be demonstrated that accumulation of material will not result in exposures exceeding 500 millirem of external gamma radiation per year, nor in the release of effluents to air and water in annual average concentrations exceeding the values in **Table 3**. An evaluation of potential radiation exposures and effluent releases shall be performed using the following premises:

(1) The material shall be considered in the form

it exists when it is removed from the users' equipment, systems, or settling ponds prior to any dilution or remedial action designed to reduce radiation levels.

(2) No consideration shall be given to the ameliorating effects of land use restrictions, maintenance operations, or overburden at the disposal site.

(3) Accumulations of material over the reasonably projected period of waste generation shall be evaluated.

(4) External gamma radiation exposures shall be based on actual measurement and allowance may be made for the degree of equilibrium and for self-shielding.

(5) In computing radon concentrations in the air above a disposal site containing radium-226, the following additional premises shall be used:

(a) Any house built on ground contaminated with radium-226 is assumed to have an 8-foot high ceiling on the first floor, to have one complete air change per hour, and to have a foundation constructed so as to meet the Structural Specialty Code (State of Oregon Uniform Building Code) effective at the time of adoption of these rules. No consideration will be allowed for any special construction or treatments designed to reduce radon diffusion into the structure;

(b) The relation between radon-emanation rate and radium concentration will be based upon experimental measurements on material intended for disposal.

[Publications: The publication(s) referred to or incorporated by reference in this rule are available from the Energy Facility Siting Council.]

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 9-1978, f. 12-28-78, ef. 3-1-79

Gamma Pathway Exemption Interpretive Rule

345-50-036 This rule shall be the basis for determining compliance with OAR 345-50-035 when considering external gamma radiation exposure. Disposal in Oregon of waste materials containing naturally-occurring radioactive materials (NORM) must not result in doses to individuals greater than 500 millirem (mrem) per year. If doses exceed this limit, waste material is considered radioactive and must be disposed of in a licensed radioactive waste disposal site. The waste materials also must meet air and water (including radon and leaching) pathway exemptions in OAR 345-50-035. To determine compliance with the gamma pathway exemption in OAR 345-50-035, the following conditions apply:

(1) As used in this rule, "waste material" means the annual solid waste stream leaving a site for landfill disposal.

(2) Actual field gamma radiation exposures shall be measured. These exposure readings shall be compared with the levels given in section (4) of this rule to determine compliance. These levels correspond to a potential 500 mrem dose per year. They are based on the dose a person might receive being 90 percent of the time in a house built on a homogeneous, semi-infinite plane (slab) of NORM. This house has a two-inch wooden floor over a two-foot crawl space. Exposure is measured at three feet above the floor. Computer modeling was used to correlate the radiation levels measured in the house to radiation from NORM in two container geometries — A standard 55-gallon steel drum and a box measuring 1.5 x 1 x 2 feet (H x W x L).

(3) Readings shall be in microRoentgen per hour (uR/hr) using a detection system which is sensitive enough to determine compliance with the gamma radiation levels in section (4) of this rule. Systems shall be calibrated according to National Institute of Standards and Technology (NIST) procedures with an NIST-traceable source. Measurements shall be made at a distance of one foot from the waste container. The contents of the container shall be proportional in composition to the average waste material. The highest reading measured around the container shall be used.

(4) The following readings correspond to a potential dose of 500 millirem per year for the respective container geometries. Long-lived radionuclides are assumed to be in secular equilibrium. If measurements as described in section (3) of this rule produce readings below the following levels, the waste material shall be exempt based on the gamma pathway only:

(a) Standard 55-gallon steel drum: 18 uR/hr (above background) at one foot;

(b) Box (1.5H x 1W x 2L feet): 18 uR/hr (above background) at one foot.

(5) The Oregon Department of Energy may approve the use of exemption levels corresponding to container types other than those in section (4) of this rule to determine compliance provided that:

(a) The exemption levels for other container types are derived by the same computer model and assumptions used to calculate the exemption levels for the drum and the box in section (4) of this rule;

(b) Measurements are made in compliance with sections (2) and (3) of this rule;

(c) The contents of containers larger than a box or drum are uniformly mixed before readings are taken to determine compliance.

Stat. Auth.: ORS 469.300(19)(a), 469.490 & 469.500
Hist.: EFSC 2-1993, f. & cert. ef. 3-19-93, EFSC 3-1993, f. & cert. ef. 3-22-93

Standards for Waste Disposal Facilities

345-50-040 OAR 345-50-040 through 345-50-130 establish standards that applicants for site certificates for waste disposal facilities must meet. The Council will apply these standards in reaching a decision for or against issuance of a site certificate for the construction and operation of a waste disposal facility and "its related or supporting facilities" as defined in ORS 469.300. When the Council deems appropriate, it will adopt additional standards. Any additional standards will be adopted sufficiently in advance of the close of testimony at a hearing on a site certificate to allow parties to address the standard or if after the close of testimony in sufficient time to allow the parties an opportunity to supplement their testimony to offer evidence relating to the standard. These standards as well as other statutory and regulatory requirements of the EFSC and federal, state and local agencies may also be utilized in formulating site certificate conditions required by ORS 469.400(3).

Stat. Auth.: ORS Ch. 469
Hist.: EFSC 1-1981, f. & ef. 12-28-81

(2) Before resolving any conflicting conditions in site certificates under ORS 469.503 (1)(b) and (4), the council shall notify and consult with the agencies and local governments responsible for administering the statutes, administrative rules or substantive local criteria that result in the conflicting conditions regarding potential conflict resolution. [1993 c.569 §24 (469.501, 469.503, 469.505 and 469.507 enacted in lieu of 469.500 and 469.510)]

469.507 Monitoring environmental and ecological effects of construction and operation of energy facilities. (1) The Energy Facility Siting Council or its designee shall establish programs for monitoring the environmental and ecological effects of the construction and operation of energy facilities subject to site certificates to assure continued compliance with the terms and conditions of the certificate and health and safety standards adopted under ORS 469.501 and 469.503.

(2) The council or its designee shall perform the testing and sampling necessary for the monitoring program or require the operator of the plant to perform the necessary testing or sampling pursuant to guidelines established by the council or its designee. The council and director shall have access to operating logs, records and reprints of the certificate holder, including those required by federal agencies.

(3) The monitoring program may be conducted in cooperation with any federally operated program if the information available from the federal program is acceptable to the council, but no federal program shall be substituted totally for monitoring supervised by the council or its designee.

(4) The monitoring program shall include monitoring of the transportation process for all radioactive material removed from any nuclear fueled thermal power plant or nuclear installation. [1993 c.569 §25 (469.501, 469.503, 469.505 and 469.507 enacted in lieu of 469.500 and 469.510)]

469.510 [Formerly 453.515; 1977 c.794 §15; repealed by 1993 c.569 §21 (469.501, 469.503, 469.505 and 469.507 enacted in lieu of 469.500 and 469.510)]

469.520 Cooperation of state governmental bodies; adoption of rules by state agencies on energy facility development. (1) Each state agency and political subdivision in this state that is concerned with energy facilities shall inform the department promptly of its activities and programs relating to energy and radiation.

(2) Each state agency proposing to adopt, amend or rescind a rule relating to energy facility development first shall file a copy of its proposal with the council, which may order such changes as it considers necessary to conform to state policy as stated in ORS 469.010 and 469.310.

(3) The effective date of a rule relating to energy facility development, or an amendment or rescission thereof, shall not be sooner than 10 days subsequent to the filing of a copy of such proposal with the council. [Formerly 453.525]

(Plant Operations; Radioactive Wastes)

469.525 Radioactive waste disposal facilities prohibited; exceptions. Notwithstanding any other provision of this chapter, no waste disposal facility for any radioactive waste shall be established, operated or licensed within this state, except as follows:

(1) Wastes generated before June 1, 1981, through industrial or manufacturing processes which contain only naturally occurring radioactive isotopes which are disposed of at sites approved by the council in accordance with ORS 469.375.

(2) Medical, industrial and research laboratory wastes contained in small, sealed, discrete containers in which the radioactive material is dissolved or dispersed in an organic solvent or biological fluid for the purpose of liquid scintillation counting and experimental animal carcasses shall be disposed of or treated at a hazardous waste disposal facility licensed by the Department of Environmental Quality and in a manner consistent with rules adopted by the Department of Environmental Quality after consultation with and approval by the Health Division.

(3) Maintenance of radioactive coal ash at the site of a thermal power plant for which a site certificate has been issued pursuant to this chapter shall not constitute operation of a waste disposal facility so long as such coal ash is maintained in accordance with the terms of the site certificate as amended from time to time as necessary to protect the public health and safety. [Formerly 459.620; 1979 c.283 §2; 1981 c.537 §2]

469.530 Review and approval of security programs. The council and the director shall review and approve all security programs attendant to a nuclear-fueled thermal power plant, a nuclear installation and the transportation of radioactive material derived from or destined for a nuclear-fueled thermal power plant or a nuclear installation. The council shall provide reasonable public notice of a meeting of the council held for purposes of such review and approval. [Formerly 453.535; 1981 c.707 §3; 1989 c.5 §1]

469.533 Department rules for health protection and evacuation procedures in nuclear emergency. Notwithstanding ORS chapter 401, the Department of Energy in

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Table 3

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Actinium (89)	Ac-227	S	8×10^{-14}	2×10^{-4}
		I	9×10^{-13}	3×10^{-4}
	Ac-228	S	3×10^{-9}	9×10^{-5}
		I	6×10^{-10}	9×10^{-5}
Americium (95)	Am-241	S	2×10^{-13}	4×10^{-4}
		I	4×10^{-12}	3×10^{-3}
	Am-242m	S	2×10^{-13}	4×10^{-4}
		I	9×10^{-12}	9×10^{-3}
	Am-242	S	1×10^{-9}	1×10^{-4}
		I	2×10^{-9}	1×10^{-4}
	Am-243	S	2×10^{-13}	4×10^{-4}
		I	4×10^{-12}	3×10^{-3}
	Am-244	S	1×10^{-9}	5×10^{-3}
		I	8×10^{-9}	5×10^{-3}
Antimony (51)	Sb-122	S	6×10^{-9}	3×10^{-3}
		I	5×10^{-9}	3×10^{-3}
	Sb-124	S	5×10^{-9}	2×10^{-3}
		I	7×10^{-10}	2×10^{-3}
	Sb-125	S	2×10^{-8}	1×10^{-4}
		I	9×10^{-10}	1×10^{-4}
Argon (18)	Ar-37	Sub[2]	1×10^{-4}	------
	Ar-41	Sub	4×10^{-8}	------
Arsenic (33)	As-73	S	7×10^{-8}	5×10^{-4}
		I	1×10^{-8}	5×10^{-4}
	As-74	S	1×10^{-8}	5×10^{-5}
		I	4×10^{-9}	5×10^{-5}
	As-76	S	4×10^{-9}	2×10^{-5}
		I	3×10^{-9}	2×10^{-5}
	As-77	S	2×10^{-8}	8×10^{-5}
		I	1×10^{-8}	8×10^{-5}
Astatine (85)	At-211	S	2×10^{-10}	2×10^{-4}
		I	1×10^{-9}	7×10^{-5}

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Barium (56)	Ba-131	S	$4x10^{-8}$	$2x10^{-4}$
		I	$1x10^{-8}$	$2x10^{-4}$
	Ba-140	S	$4x10^{-9}$	$3x10^{-5}$
		I	$1x10^{-9}$	$2x10^{-5}$
Berkelium (97)	Bk-249	S	$3x10^{-11}$	$6x10^{-4}$
		I	$4x10^{-9}$	$6x10^{-4}$
	Bk-250	S	$5x10^{-9}$	$2x10^{-4}$
		I	$4x10^{-8}$	$2x10^{-4}$
Beryllium (4)	Be-7	S	$2x10^{-7}$	$2x10^{-3}$
		I	$4x10^{-8}$	$2x10^{-3}$
Bismuth (83)	Bi-206	S	$6x10^{-9}$	$4x10^{-5}$
		I	$5x10^{-9}$	$4x10^{-5}$
	Bi-207	S	$6x10^{-9}$	$6x10^{-5}$
		I	$5x10^{-10}$	$6x10^{-5}$
	Bi-210	S	$2x10^{-10}$	$4x10^{-5}$
		I	$2x10^{-10}$	$4x10^{-5}$
	Bi-212	S	$3x10^{-9}$	$4x10^{-4}$
		I	$7x10^{-9}$	$4x10^{-4}$
Bromine (35)	Br-82	S	$4x10^{-8}$	$3x10^{-4}$
		I	$6x10^{-9}$	$4x10^{-5}$
Cadmium (48)	Cd-109	S	$2x10^{-8}$	$2x10^{-4}$
		I	$3x10^{-9}$	$2x10^{-4}$
	Cd-115m	S	$1x10^{-9}$	$3x10^{-5}$
		I	$1x10^{-8}$	$3x10^{-5}$
	Cd-115	S	$8x10^{-9}$	$3x10^{-5}$
		I	$6x10^{-9}$	$4x10^{-5}$
Calcium (20)	Ca-45	S	$1x10^{-9}$	$9x10^{-5}$
		I	$4x10^{-9}$	$2x10^{-4}$
	Ca-47	S	$6x10^{-9}$	$5x10^{-5}$
		I	$6x10^{-9}$	$3x10^{-5}$
Californium (98)	Cf-249	S	$5x10^{-14}$	$4x10^{-6}$
		I	$3x10^{-12}$	$2x10^{-5}$
	Cf-250	S	$2x10^{-13}$	$1x10^{-5}$
		I	$3x10^{-12}$	$3x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Californium (98) (con't)	Cf-251	S	$6x10^{-14}$	$4x10^{-5}$
		I	$3x10^{-12}$	$3x10^{-5}$
	Cf-252	S	$2x10^{-13}$	$7x10^{-6}$
		I	$1x10^{-12}$	$7x10^{-6}$
	Cf-253	S	$3x10^{-11}$	$1x10^{-4}$
		I	$3x10^{-11}$	$1x10^{-4}$
	Cf-254	S	$2x10^{-13}$	$1x10^{-7}$
		I	$2x10^{-13}$	$1x10^{-7}$
Carbon (6)	C-14	S	$1x10^{-7}$	$8x10^{-4}$
	(CO_2)	Sub[2]	$1x10^{-6}$	------
Cerium (58)	Ce-141	S	$2x10^{-8}$	$9x10^{-3}$
		I	$5x10^{-9}$	$9x10^{-3}$
	Ce-143	S	$9x10^{-9}$	$4x10^{-3}$
		I	$7x10^{-9}$	$4x10^{-3}$
	Ce-144	S	$3x10^{-10}$	$1x10^{-5}$
		I	$2x10^{-10}$	$1x10^{-5}$
Cesium (55)	Cs-131	S	$4x10^{-7}$	$2x10^{-3}$
		I	$1x10^{-7}$	$9x10^{-4}$
	Cs-134m	S	$1x10^{-6}$	$6x10^{-3}$
		I	$2x10^{-7}$	$1x10^{-3}$
	Cs-134	S	$1x10^{-8}$	$9x10^{-6}$
		I	$4x10^{-10}$	$4x10^{-3}$
	Cs-135	S	$2x10^{-8}$	$1x10^{-4}$
		I	$3x10^{-9}$	$2x10^{-4}$
	Cs-136	S	$1x10^{-8}$	$9x10^{-5}$
		I	$6x10^{-9}$	$6x10^{-5}$
	Cs-137	S	$2x10^{-8}$	$2x10^{-5}$
		I	$5x10^{-10}$	$4x10^{-5}$
Chlorine (17)	Cl-36	S	$1x10^{-6}$	$8x10^{-5}$
		I	$8x10^{-10}$	$6x10^{-5}$
	Cl-38	S	$9x10^{-6}$	$4x10^{-4}$
		I	$7x10^{-6}$	$4x10^{-4}$
Chromium (24)	Cr-51	S	$4x10^{-7}$	$2x10^{-3}$
		I	$8x10^{-8}$	$2x10^{-3}$
Cobalt (27)	Co-57	S	$1x10^{-7}$	$5x10^{-4}$
		I	$6x10^{-9}$	$4x10^{-4}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Cobalt (27) (con't)	Co-58m	S	$6x10^{-7}$	$3x10^{-3}$
		I	$3x10^{-7}$	$2x10^{-3}$
	Co-58	S	$3x10^{-8}$	$1x10^{-4}$
		I	$2x10^{-8}$	$9x10^{-5}$
	Co-60	S	$1x10^{-8}$	$5x10^{-5}$
		I	$3x10^{-10}$	$3x10^{-5}$
Copper (29)	Cu-64	S	$7x10^{-8}$	$3x10^{-4}$
		I	$4x10^{-8}$	$2x10^{-4}$
Curium (96)	Cm-242	S	$4x10^{-12}$	$2x10^{-5}$
		I	$6x10^{-12}$	$2x10^{-5}$
	Cm-243	S	$2x10^{-13}$	$5x10^{-6}$
		I	$3x10^{-12}$	$2x10^{-5}$
	Cm-244	S	$3x10^{-13}$	$7x10^{-6}$
		I	$3x10^{-12}$	$3x10^{-5}$
	Cm-245	S	$2x10^{-13}$	$4x10^{-6}$
		I	$4x10^{-12}$	$3x10^{-5}$
	Cm-246	S	$2x10^{-13}$	$4x10^{-6}$
		I	$4x10^{-12}$	$3x10^{-5}$
	Cm-247	S	$2x10^{-13}$	$4x10^{-6}$
		I	$4x10^{-12}$	$2x10^{-5}$
	Cm-248	S	$2x10^{-14}$	$4x10^{-7}$
		I	$4x10^{-13}$	$1x10^{-6}$
	Cm-249	S	$4x10^{-7}$	$2x10^{-3}$
		I	$4x10^{-7}$	$2x10^{-3}$
Dysprosium (66)	Dy-165	S	$9x10^{-8}$	$4x10^{-4}$
		I	$7x10^{-8}$	$4x10^{-4}$
	Dy-166	S	$8x10^{-9}$	$4x10^{-5}$
		I	$7x10^{-9}$	$4x10^{-5}$
Einsteinium (99)	Es-253	S	$3x10^{-11}$	$2x10^{-5}$
		I	$2x10^{-11}$	$2x10^{-5}$
	Es-254m	S	$2x10^{-10}$	$2x10^{-5}$
		I	$2x10^{-10}$	$2x10^{-5}$
	Es-254	S	$6x10^{-13}$	$1x10^{-5}$
		I	$4x10^{-12}$	$1x10^{-5}$
	Es-255	S	$2x10^{-11}$	$3x10^{-5}$
		I	$1x10^{-11}$	$3x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Erbium (68)	Er-169	S	$2x10^{-6}$	$9x10^{-5}$
		I	$1x10^{-6}$	$9x10^{-5}$
	Er-171	S	$2x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
Europium (63)	Eu-152	S	$1x10^{-6}$	$6x10^{-5}$
	(Tr=9.2 hrs)		$1x10^{-6}$	$6x10^{-5}$
	Eu-152	S	$4x10^{-10}$	$8x10^{-5}$
	(Tr=13 yrs)		$6x10^{-10}$	$8x10^{-5}$
	Eu-154	S	$1x10^{-10}$	$2x10^{-5}$
		I	$2x10^{-10}$	$2x10^{-5}$
	Eu-155	S	$3x10^{-9}$	$2x10^{-4}$
		I	$3x10^{-9}$	$2x10^{-4}$
Fermium (100)	Fm-254	S	$2x10^{-9}$	$1x10^{-4}$
		I	$2x10^{-9}$	$1x10^{-4}$
	Fm-255	S	$6x10^{-10}$	$3x10^{-5}$
		I	$4x10^{-10}$	$3x10^{-5}$
	Fm-256	S	$1x10^{-10}$	$9x10^{-7}$
		I	$6x10^{-11}$	$9x10^{-7}$
Fluorine (9)	F-18	S	$2x10^{-7}$	$8x10^{-4}$
		I	$9x10^{-8}$	$5x10^{-4}$
Gadolinium (64)	Gd-153	S	$8x10^{-9}$	$2x10^{-4}$
		I	$3x10^{-9}$	$2x10^{-4}$
	Gd-159	S	$2x10^{-8}$	$8x10^{-5}$
		I	$1x10^{-8}$	$8x10^{-5}$
Gallium (31)	Ga-72	S	$8x10^{-9}$	$4x10^{-5}$
		I	$6x10^{-9}$	$4x10^{-5}$
Germanium (32)	Ge-71	S	$4x10^{-7}$	$2x10^{-3}$
		I	$2x10^{-7}$	$2x10^{-3}$
Gold (79)	Au-196	S	$4x10^{-6}$	$2x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
	Au-198	S	$1x10^{-6}$	$5x10^{-5}$
		I	$8x10^{-9}$	$5x10^{-5}$
	Au-199	S	$4x10^{-6}$	$2x10^{-4}$
		I	$3x10^{-6}$	$2x10^{-4}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Hafnium (72)	Hf-181	S	$1x10^{-9}$	$7x10^{-5}$
		I	$3x10^{-9}$	$7x10^{-5}$
Holmium (67)	Ho-166	S	$7x10^{-9}$	$3x10^{-5}$
		I	$6x10^{-9}$	$3x10^{-5}$
Hydrogen (1)	H-3	S	$2x10^{-7}$	$3x10^{-3}$
		I	$2x10^{-7}$	$3x10^{-3}$
		Sub[2]	$4x10^{-5}$	------
Indium (49)	In-113m	S	$3x10^{-7}$	$1x10^{-3}$
		I	$2x10^{-7}$	$1x10^{-3}$
	In-114m	S	$4x10^{-9}$	$2x10^{-5}$
		I	$7x10^{-10}$	$2x10^{-5}$
	In-115m	S	$8x10^{-8}$	$4x10^{-4}$
		I	$6x10^{-8}$	$4x10^{-4}$
	In-115	S	$9x10^{-9}$	$9x10^{-5}$
		I	$1x10^{-9}$	$9x10^{-5}$
Iodine (53)	I-125	S	$8x10^{-11}$	$2x10^{-7}$
		I	$6x10^{-9}$	$2x10^{-4}$
	I-126	S	$9x10^{-11}$	$3x10^{-7}$
		I	$1x10^{-8}$	$9x10^{-5}$
	I-129	S	$2x10^{-11}$	$6x10^{-8}$
		I	$2x10^{-9}$	$2x10^{-4}$
	I-131	S	$1x10^{-10}$	$3x10^{-7}$
		I	$1x10^{-9}$	$6x10^{-5}$
	I-132	S	$3x10^{-9}$	$8x10^{-6}$
		I	$3x10^{-8}$	$2x10^{-4}$
	I-133	S	$4x10^{-10}$	$1x10^{-6}$
		I	$7x10^{-9}$	$4x10^{-5}$
	I-134	S	$6x10^{-9}$	$2x10^{-5}$
		I	$1x10^{-7}$	$6x10^{-4}$
	I-135	S	$1x10^{-9}$	$4x10^{-6}$
		I	$1x10^{-8}$	$7x10^{-5}$
Iridium (77)	Ir-190	S	$4x10^{-8}$	$2x10^{-4}$
		I	$1x10^{-8}$	$2x10^{-4}$
	Ir-192	S	$4x10^{-9}$	$4x10^{-5}$
		I	$9x10^{-10}$	$4x10^{-5}$
	Ir-194	S	$8x10^{-8}$	$3x10^{-5}$
		I	$5x10^{-8}$	$3x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Iron (26)	Fe-55	S	$3x10^{-8}$	$8x10^{-4}$
		I	$3x10^{-8}$	$2x10^{-3}$
	Fe-59	S	$5x10^{-9}$	$6x10^{-5}$
		I	$2x10^{-9}$	$5x10^{-5}$
Krypton (36)	Kr-85m	Sub[2]	$1x10^{-7}$	------
	Kr-85	Sub	$3x10^{-7}$	------
	Kr-87	Sub	$2x10^{-8}$	------
	Kr-88	Sub	$2x10^{-8}$	------
Lanthanum (57)	La-140	S	$5x10^{-9}$	$2x10^{-5}$
		I	$4x10^{-9}$	$2x10^{-5}$
Lead (82)	Pb-203	S	$9x10^{-8}$	$4x10^{-4}$
		I	$6x10^{-8}$	$4x10^{-4}$
	Pb-210	S	$4x10^{-12}$	$1x10^{-7}$
		I	$8x10^{-12}$	$2x10^{-6}$
	Pb-212	S	$6x10^{-10}$	$2x10^{-5}$
		I	$7x10^{-10}$	$2x10^{-5}$
Lutetium (71)	Lu-177	S	$2x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
Manganese (25)	Mn-52	S	$7x10^{-9}$	$3x10^{-5}$
		I	$5x10^{-9}$	$3x10^{-5}$
	Mn-54	S	$1x10^{-8}$	$1x10^{-4}$
		I	$1x10^{-9}$	$1x10^{-4}$
	Mn-56	S	$3x10^{-8}$	$1x10^{-4}$
		I	$2x10^{-8}$	$1x10^{-4}$
Mercury (80)	Hg-197m	S	$3x10^{-6}$	$2x10^{-4}$
		I	$3x10^{-6}$	$2x10^{-4}$
	Hg-197	S	$4x10^{-6}$	$3x10^{-4}$
		I	$9x10^{-6}$	$5x10^{-4}$
	Hg-203	S	$2x10^{-9}$	$2x10^{-5}$
		I	$4x10^{-9}$	$1x10^{-4}$
Molybdenum (42)	Mo-99	S	$3x10^{-6}$	$2x10^{-4}$
		I	$7x10^{-9}$	$4x10^{-5}$
Neodymium (60)	Nd-144	S	$3x10^{-12}$	$7x10^{-5}$
		I	$1x10^{-11}$	$8x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Neodymium (60) (con't)	Nd-147	S	$1x10^{-6}$	$6x10^{-5}$
		I	$8x10^{-6}$	$6x10^{-5}$
	Nd-149	S	$6x10^{-6}$	$3x10^{-4}$
		I	$5x10^{-6}$	$3x10^{-4}$
Neptunium (93)	Np-237	S	$1x10^{-13}$	$3x10^{-6}$
		I	$4x10^{-12}$	$3x10^{-5}$
	Np-239	S	$3x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
Nickel (28)	Ni-59	S	$2x10^{-6}$	$2x10^{-4}$
		I	$3x10^{-6}$	$2x10^{-3}$
	Ni-63	S	$2x10^{-7}$	$3x10^{-5}$
		I	$1x10^{-6}$	$7x10^{-4}$
	Ni-65	S	$3x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
Niobium (41)	Nb-93m	S	$4x10^{-6}$	$4x10^{-4}$
		I	$5x10^{-7}$	$4x10^{-4}$
	Nb-95	S	$2x10^{-6}$	$1x10^{-4}$
		I	$3x10^{-6}$	$1x10^{-4}$
	Nb-97	S	$2x10^{-7}$	$9x10^{-4}$
		I	$2x10^{-7}$	$9x10^{-4}$
Osmium (76)	Os-185	S	$2x10^{-6}$	$7x10^{-5}$
		I	$2x10^{-6}$	$7x10^{-5}$
	Os-191m	S	$6x10^{-7}$	$3x10^{-3}$
		I	$3x10^{-7}$	$2x10^{-3}$
	Os-191	S	$4x10^{-6}$	$2x10^{-4}$
		I	$1x10^{-6}$	$2x10^{-4}$
	Os-193	S	$1x10^{-6}$	$6x10^{-5}$
		I	$9x10^{-7}$	$5x10^{-5}$
Palladium (46)	Pd-103	S	$5x10^{-6}$	$3x10^{-4}$
		I	$3x10^{-6}$	$3x10^{-4}$
	Pd-109	S	$2x10^{-6}$	$9x10^{-5}$
		I	$1x10^{-6}$	$7x10^{-5}$
Phosphorus (15)	P-32	S	$2x10^{-6}$	$2x10^{-5}$
		I	$3x10^{-7}$	$2x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Platinum (78)	Pt-191	S	$3x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
	Pt-193m	S	$2x10^{-7}$	$1x10^{-3}$
		I	$2x10^{-7}$	$1x10^{-3}$
	Pt-193	S	$4x10^{-6}$	$9x10^{-4}$
		I	$1x10^{-6}$	$2x10^{-3}$
	Pt-197m	S	$2x10^{-7}$	$1x10^{-3}$
		I	$2x10^{-7}$	$9x10^{-4}$
	Pt-197	S	$3x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
Plutonium (94)	Pu-238	S	$7x10^{-14}$	$5x10^{-6}$
		I	$1x10^{-12}$	$3x10^{-5}$
	Pu-239	S	$6x10^{-14}$	$5x10^{-6}$
		I	$1x10^{-12}$	$3x10^{-5}$
	Pu-240	S	$6x10^{-14}$	$5x10^{-6}$
		I	$1x10^{-12}$	$3x10^{-5}$
	Pu-241	S	$3x10^{-12}$	$2x10^{-4}$
		I	$1x10^{-9}$	$1x10^{-5}$
	Pu-242	S	$6x10^{-14}$	$5x10^{-6}$
		I	$1x10^{-12}$	$3x10^{-5}$
	Pu-243	S	$6x10^{-6}$	$3x10^{-4}$
		I	$8x10^{-9}$	$3x10^{-4}$
	Pu-244	S	$6x10^{-14}$	$4x10^{-6}$
		I	$1x10^{-12}$	$1x10^{-5}$
Polonium (84)	Po-210	S	$2x10^{-11}$	$7x10^{-7}$
		I	$7x10^{-12}$	$3x10^{-6}$
Potassium (19)	K-42	S	$7x10^{-6}$	$3x10^{-4}$
		I	$4x10^{-9}$	$2x10^{-5}$
Praseodymium (59)	Pr-142	S	$7x10^{-9}$	$3x10^{-5}$
		I	$5x10^{-9}$	$3x10^{-5}$
	Pr-143	S	$1x10^{-6}$	$5x10^{-5}$
		I	$6x10^{-9}$	$5x10^{-5}$
Promethium (61)	Pm-147	S	$2x10^{-9}$	$2x10^{-4}$
		I	$3x10^{-9}$	$2x10^{-4}$
	Pm-149	S	$1x10^{-6}$	$4x10^{-5}$
		I	$8x10^{-9}$	$4x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Protactinium (91)	Pa-230	S	$6x10^{-11}$	$2x10^{-4}$
		I	$3x10^{-11}$	$2x10^{-4}$
	Pa-231	S	$4x10^{-14}$	$9x10^{-7}$
		I	$4x10^{-12}$	$2x10^{-5}$
	Pa-233	S	$2x10^{-8}$	$1x10^{-4}$
		I	$6x10^{-9}$	$1x10^{-4}$
Radium (88)	Ra-223	S	$6x10^{-11}$	$7x10^{-7}$
		I	$8x10^{-12}$	$4x10^{-6}$
	Ra-224	S	$2x10^{-10}$	$2x10^{-6}$
		I	$2x10^{-11}$	$5x10^{-6}$
	Ra-226	S	$3x10^{-12}$	$3x10^{-8}$
		I	$2x10^{-12}$	$3x10^{-5}$
	Ra-228	S	$2x10^{-12}$	$3x10^{-8}$
		I	$1x10^{-12}$	$3x10^{-5}$
Radon (86)	Rn-220	S	$1x10^{-6}$	------
	Rn-222[3]	S	$3x10^{-9}$	------
Rhenium (75)	Re-183	S	$9x10^{-8}$	$6x10^{-4}$
		I	$5x10^{-9}$	$3x10^{-4}$
	Re-186	S	$2x10^{-8}$	$9x10^{-5}$
		I	$8x10^{-9}$	$5x10^{-5}$
	Re-187	S	$3x10^{-7}$	$3x10^{-3}$
		I	$2x10^{-8}$	$2x10^{-3}$
	Re-188	S	$1x10^{-8}$	$6x10^{-5}$
		I	$6x10^{-9}$	$3x10^{-5}$
Rhodium (45)	Rh-103m	S	$3x10^{-6}$	$1x10^{-2}$
		I	$2x10^{-6}$	$1x10^{-2}$
	Rh-105	S	$3x10^{-8}$	$1x10^{-4}$
		I	$2x10^{-8}$	$1x10^{-4}$
Rubidium (37)	Rb-86	S	$1x10^{-8}$	$7x10^{-5}$
		I	$2x10^{-9}$	$2x10^{-5}$
	Rb-87	S	$2x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-8}$	$2x10^{-4}$
Ruthenium (44)	Ru-97	S	$8x10^{-8}$	$4x10^{-4}$
		I	$6x10^{-8}$	$3x10^{-4}$
	Ru-103	S	$2x10^{-8}$	$8x10^{-5}$
		I	$3x10^{-9}$	$8x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Ruthenium (44) (con't)	Ru-105	S	$2x10^{-6}$	$1x10^{-4}$
		I	$2x10^{-6}$	$1x10^{-4}$
	Ru-106	S	$3x10^{-9}$	$1x10^{-5}$
		I	$2x10^{-10}$	$1x10^{-5}$
Samarium (62)	Sm-147	S	$2x10^{-12}$	$6x10^{-5}$
		I	$9x10^{-12}$	$7x10^{-5}$
	Sm-151	S	$2x10^{-9}$	$4x10^{-4}$
		I	$5x10^{-9}$	$4x10^{-4}$
	Sm-153	S	$2x10^{-8}$	$8x10^{-3}$
		I	$1x10^{-8}$	$8x10^{-3}$
Scandium (21)	Sc-46	S	$8x10^{-9}$	$4x10^{-5}$
		I	$8x10^{-10}$	$4x10^{-5}$
	Sc-47	S	$2x10^{-8}$	$9x10^{-5}$
		I	$2x10^{-8}$	$9x10^{-5}$
	Sc-48	S	$6x10^{-9}$	$3x10^{-5}$
		I	$5x10^{-9}$	$3x10^{-5}$
Selenium (34)	Se-75	S	$4x10^{-6}$	$3x10^{-4}$
		I	$4x10^{-9}$	$3x10^{-4}$
Silicon (14)	Si-31	S	$2x10^{-7}$	$9x10^{-4}$
		I	$3x10^{-8}$	$2x10^{-4}$
Silver (47)	Ag-105	S	$2x10^{-8}$	$1x10^{-4}$
		I	$3x10^{-9}$	$1x10^{-4}$
	Ag-110m	S	$7x10^{-9}$	$3x10^{-5}$
		I	$3x10^{-10}$	$3x10^{-5}$
	Ag-111	S	$1x10^{-8}$	$4x10^{-5}$
		I	$8x10^{-9}$	$4x10^{-5}$
Sodium (11)	Na-22	S	$6x10^{-9}$	$4x10^{-5}$
		I	$3x10^{-10}$	$3x10^{-5}$
	Na-24	S	$4x10^{-8}$	$2x10^{-4}$
		I	$5x10^{-9}$	$3x10^{-5}$
Strontium (38)	Sr-85m	S	$1x10^{-6}$	$7x10^{-3}$
		I	$1x10^{-6}$	$7x10^{-3}$
	Sr-85	S	$8x10^{-9}$	$1x10^{-4}$
		I	$4x10^{-9}$	$2x10^{-4}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Strontium (38) (con't)	Sr-89	S	$3x10^{-10}$	$3x10^{-6}$
		I	$1x10^{-9}$	$3x10^{-5}$
	Sr-90	S	$3x10^{-11}$	$3x10^{-7}$
		I	$2x10^{-10}$	$4x10^{-6}$
	Sr-91	S	$2x10^{-8}$	$7x10^{-6}$
		I	$9x10^{-9}$	$5x10^{-5}$
	Sr-92	S	$2x10^{-8}$	$7x10^{-6}$
		I	$1x10^{-8}$	$6x10^{-5}$
Sulfur (16)	S-35	S	$9x10^{-9}$	$6x10^{-5}$
		I	$9x10^{-9}$	$3x10^{-4}$
Tantalum (73)	Ta-182	S	$1x10^{-9}$	$4x10^{-5}$
		I	$7x10^{-10}$	$4x10^{-5}$
Technetium (43)	Tc-96m	S	$3x10^{-6}$	$1x10^{-3}$
		I	$1x10^{-6}$	$1x10^{-2}$
	Tc-96	S	$2x10^{-6}$	$1x10^{-4}$
		I	$8x10^{-9}$	$5x10^{-5}$
	Tc-97m	S	$8x10^{-6}$	$4x10^{-4}$
		I	$5x10^{-9}$	$2x10^{-4}$
	Tc-97	S	$4x10^{-7}$	$2x10^{-3}$
		I	$1x10^{-6}$	$8x10^{-4}$
	Tc-99m	S	$1x10^{-4}$	$6x10^{-3}$
		I	$5x10^{-7}$	$3x10^{-3}$
	Tc-99	S	$7x10^{-6}$	$3x10^{-4}$
		I	$2x10^{-9}$	$2x10^{-4}$
Tellurium (52)	Te-125m	S	$1x10^{-6}$	$2x10^{-4}$
		I	$4x10^{-9}$	$1x10^{-4}$
	Te-127m	S	$5x10^{-9}$	$6x10^{-5}$
		I	$1x10^{-9}$	$5x10^{-5}$
	Te-127	S	$6x10^{-6}$	$3x10^{-4}$
		I	$3x10^{-6}$	$2x10^{-4}$
	Te-129m	S	$3x10^{-9}$	$3x10^{-5}$
		I	$1x10^{-9}$	$2x10^{-5}$
	Te-129	S	$2x10^{-7}$	$8x10^{-4}$
		I	$1x10^{-7}$	$8x10^{-4}$
	Te-131m	S	$1x10^{-6}$	$6x10^{-5}$
		I	$6x10^{-9}$	$4x10^{-5}$
	Te-132	S	$7x10^{-9}$	$3x10^{-5}$
		I	$4x10^{-9}$	$2x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Terbium (65)	Tb-160	S	$3x10^{-9}$	$4x10^{-5}$
		I	$1x10^{-9}$	$4x10^{-5}$
Thallium (81)	Tl-200	S	$9x10^{-8}$	$4x10^{-4}$
		I	$4x10^{-8}$	$2x10^{-4}$
	Tl-201	S	$7x10^{-8}$	$3x10^{-4}$
		I	$3x10^{-8}$	$2x10^{-4}$
	Tl-202	S	$3x10^{-8}$	$1x10^{-4}$
		I	$8x10^{-9}$	$7x10^{-5}$
	Tl-204	S	$2x10^{-8}$	$1x10^{-4}$
		I	$9x10^{-10}$	$6x10^{-5}$
Thorium (90)	Th-227	S	$1x10^{-11}$	$2x10^{-5}$
		I	$6x10^{-12}$	$2x10^{-5}$
	Th-228	S	$3x10^{-13}$	$7x10^{-6}$
		I	$2x10^{-13}$	$1x10^{-5}$
	Th-230	S	$8x10^{-14}$	$2x10^{-6}$
		I	$3x10^{-13}$	$3x10^{-5}$
	Th-231	S	$5x10^{-8}$	$2x10^{-4}$
		I	$4x10^{-8}$	$2x10^{-4}$
	Th-232	S	$1x10^{-12}$	$2x10^{-6}$
		I	$1x10^{-12}$	$4x10^{-5}$
	Th-natur.	S	$2x10^{-12}$	$2x10^{-6}$
		I	$2x10^{-12}$	$2x10^{-5}$
	Th-234	S	$2x10^{-9}$	$2x10^{-5}$
		I	$1x10^{-9}$	$2x10^{-5}$
Thulium (69)	Tm-170	S	$1x10^{-9}$	$5x10^{-5}$
		I	$1x10^{-9}$	$5x10^{-5}$
	Tm-171	S	$4x10^{-9}$	$5x10^{-4}$
		I	$8x10^{-9}$	$5x10^{-4}$
Tin (50)	Sn-113	S	$1x10^{-8}$	$9x10^{-5}$
		I	$2x10^{-9}$	$8x10^{-5}$
	Sn-125	S	$4x10^{-9}$	$2x10^{-5}$
		I	$3x10^{-9}$	$2x10^{-5}$
Tungsten (74)	W-181	S	$8x10^{-8}$	$4x10^{-4}$
		I	$4x10^{-9}$	$3x10^{-4}$
	W-185	S	$3x10^{-8}$	$1x10^{-4}$
		I	$4x10^{-9}$	$1x10^{-4}$
	W-187	S	$2x10^{-8}$	$7x10^{-5}$
		I	$1x10^{-8}$	$6x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Uranium (92)	U-230	S	$1x10^{-11}$	$5x10^{-6}$
		I	$4x10^{-12}$	$5x10^{-6}$
	U-232	S	$3x10^{-12}$	$3x10^{-6}$
		I	$9x10^{-13}$	$3x10^{-6}$
	U-233	S	$2x10^{-11}$	$3x10^{-5}$
		I	$4x10^{-12}$	$3x10^{-5}$
	U-234	S[4]	$2x10^{-11}$	$3x10^{-5}$
		I	$4x10^{-12}$	$3x10^{-5}$
	U-235	S[4]	$2x10^{-11}$	$3x10^{-5}$
		I	$4x10^{-12}$	$3x10^{-5}$
	U-236	S	$2x10^{-11}$	$3x10^{-5}$
		I	$4x10^{-12}$	$3x10^{-5}$
	U-238	S[4]	$3x10^{-12}$	$4x10^{-5}$
		I	$5x10^{-12}$	$4x10^{-5}$
	U-240	S	$8x10^{-9}$	$3x10^{-3}$
		I	$6x10^{-9}$	$3x10^{-3}$
	U-natural	S[4]	$5x10^{-12}$	$3x10^{-5}$
		I	$5x10^{-12}$	$3x10^{-5}$
Vanadium (23)	V-48	S	$6x10^{-9}$	$3x10^{-5}$
		I	$2x10^{-9}$	$3x10^{-5}$
Xenon (54)	Xe-131m	Sub[2]	$4x10^{-7}$	------
	Xe-133m	Sub	$3x10^{-7}$	------
	Xe-133	Sub	$3x10^{-7}$	------
	Xe-135	Sub	$1x10^{-7}$	------
Ytterbium (70)	Yb-175	S	$2x10^{-8}$	$1x10^{-4}$
		I	$2x10^{-8}$	$1x10^{-4}$
Yttrium (39)	Y-90	S	$4x10^{-9}$	$2x10^{-5}$
		I	$3x10^{-9}$	$2x10^{-5}$
	Y-91m	S	$8x10^{-7}$	$3x10^{-3}$
		I	$6x10^{-7}$	$3x10^{-3}$
	Y-91	S	$1x10^{-9}$	$3x10^{-5}$
		I	$1x10^{-9}$	$3x10^{-5}$
	Y-92	S	$1x10^{-8}$	$6x10^{-5}$
		I	$1x10^{-8}$	$6x10^{-5}$
	Y-93	S	$6x10^{-9}$	$3x10^{-5}$
		I	$5x10^{-9}$	$3x10^{-5}$

Element (Atomic Number)	Isotope[1]		Air (μCi/ml)	Water (μCi/ml)
Zinc (30)	Zn-65	S	$4x10^{-9}$	$1x10^{-4}$
		I	$2x10^{-9}$	$2x10^{-4}$
	Zn-69m	S	$1x10^{-8}$	$7x10^{-5}$
		I	$1x10^{-8}$	$6x10^{-3}$
	Zn-69	S	$2x10^{-7}$	$2x10^{-3}$
		I	$3x10^{-7}$	$2x10^{-3}$
Zirconium (40)	Zr-93	S	$4x10^{-9}$	$8x10^{-4}$
		I	$1x10^{-8}$	$8x10^{-4}$
	Zr-95	S	$4x10^{-9}$	$6x10^{-5}$
		I	$1x10^{-8}$	$6x10^{-3}$
	Zr-97	S	$4x10^{-9}$	$2x10^{-5}$
		I	$3x10^{-9}$	$2x10^{-3}$
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life less than two hours.		Sub[2]	$3x10^{-8}$	------
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life greater than two hours.			$1x10^{-10}$	$3x10^{-6}$
Any single radionuclide not listed above, which decays by alpha emission or spontaneous fission.			$2x10^{-14}$	$3x10^{-6}$

[1] Soluble (S); Insoluble (I).

[2] "Sub" means that values given are for submersion in a semispherical infinite cloud of airborne material.

[3] These radon concentrations are appropriate for protection from radon-222 combined with its short-lived daughters. Alternatively, this value may be replaced by one-thirtieth (1/30) of a "working level". (A working level is defined as any combination of short-lived radon-222 daughters, polonium-218, lead-214, bismuth-214 and polonium-214, in one liter of air, without regard to the degree of equilibrium, that will result in the ultimate emission of 1.3×10^5 MeV of alpha particle energy.)

[4] For soluble mixtures of U-238, U-234 and U-235 in air, chemical toxicity may be the limiting factor. If the percent by weight (enrichment) of U-235 is less than 5, the concentration value is 0.007 milligrams uranium per cubic meter of air. The specific activity for natural uranium is 6.77×10^{-7} curies per gram uranium. The specific activity for other mixtures of U-238, U-235 and U-234, if not known, shall be:

$SA = 3.6 \times 10^{-7}$ curies/gram U	U-depleted
$SA = (0.4 + 0.38\ E + 0.0034\ E^2)\ 10^{-6}$	$E \geq 0.72$

where E is the percentage by weight of U-235, expressed as percent.

Note: In any case where there is a mixture in air or water of more than one radionuclide, the limiting values for purposes of this Appendix should be determined as follows:

1. If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows: Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radio-nuclides in the mixture may not exceed "1" (i.e., "unity").

Example: If radionuclides a, b and c are present in concentrations C_a, C_b and C_c and if the applicable maximum permissible concentrations (MPC's) are MPC_a, MPC_b and MPC_c respectively, then the concentrations shall be limited so that the following relationship exists:

$$\frac{C_a}{MPC_a} + \frac{C_b}{MPC_b} + \frac{C_c}{MPC_c} < 1$$

2. If either the identity or the concentration of any radionuclide in the mixture is not known, the limiting values for purposes of Appendix B shall be:

a. For purposes of Table 3, Col. 1..... 2×10^{-14}

b. For purposes of Table 3, Col. 2..... 3×10^{-8}

3. If any of the conditions specified below are met, the corresponding values specified below may be used in lieu of those specified in paragraph 2 above.

a. If the identity of each radionuclide in the mixture is known but the concentration of one or more of the radionuclides in the mixture is not known, the concentration limit for the mixture is the limit specified in Appendix B for the radionuclide in the mixture having the lowest concentration limit; or

b. If the identity of each radionuclide in the mixture is not known, but it is known that certain radionuclides specified in Appendix B are not present in the mixture, the concentration limit for the mixture is the lowest concentration limit specified in Appendix B for any radionuclide which is not known to be absent from the mixture; or

Element (Atomic Number)	Isotope[1]	Air (μCi/ml)	Water (μCi/ml)
If it is known that Sr-90, I-125, I-126, I-129, I-131, I-133, Pb-210, Po-210, At-211, Ra-223, Ra-224, Ra-226, Ac-227, Ra-228, Th-230, Pa-231, Th-232, Th-nat, Cm-248, Cf-254, and Fm-256 are not present----------		------	3×10^{-6}
If it is known that Sr-90, I-125, I-126, I-129, I-131, I-133, Pb-210, Po-210, Ra-223, Ra-226, Ra-228, Pa-231, Th-nat, Cm-248, CF-254 and Fm-256 are not present---		-----	2×10^{-6}
If it is known that Sr-90, I-129 I-125, I-126, I-131, Pb-210, Ra-226, Ra-228, Cm-248 and Cf-254 are not present-----		------	6×10^{-7}
If it is known that I-129, Ra-226,and Ra-228 are not present----------		------	1×10^{-7}
If it is known that alpha-emitters and Sr-90, I-129, Pb-210, Ac-227, Ra-228, Pa-230, Pu-241, and Bk-249 are not present----------		1×10^{-10}	------
If it is known that alpha-emitters and Pb-210, Ac-227, Ra-228 and Pu-241 are not present--------		1×10^{-11}	------
If it known that alpha-emitters and Ac-227 are not present----------		1×10^{-12}	------

Element (Atomic Number)	Isotope[1]	Air (μCi/ml)	Water (μCi/ml)
If it is known that Ac-227, Th-230, Pa-231, Pu-238, Pu-239, Pu-240, Pu-242, Pu-244, Cm-248, Cf-249 and Cf-251 are not present----------		$1x10^{-13}$	------

4. If a mixture of radionuclides consists of uranium and its daughters in ore dust prior to chemical separation of the uranium from the ore, the values specified below may be used for uranium and its daughters through radium-226, instead of those from paragraph 1, 2 or 3 above.

For purposes of Table 3, Column 1, 3×10^{-12} μCi/ml gross alpha activity; 2×10^{-12} μCi/ml natural uranium; or 3 micrograms per cubic meter of air natural uranium.

5. For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_a) to the concentration limit for that radionuclide specified in Table 3 (MPC_a) does not exceed 1/10, (i.e., $C_a/MPC_a \leq 1/10$) and (b) the sum of such ratios for all radionuclides considered as not present in the mixture does not exceed 1/4, (i.e., $C_a/MPC_a + C_b/MPC_b + \ldots\ldots \leq 1/4$).

Note: To convert μCi/ml to SI units of megabecquerels per liter multiply the above values by 37.

Example: Zirconium (40), Zr-97, S, Column 1-Air, $1x10^{-7}$ μCi/ml multiplied by 37 is equivalent to 37×10^{-7} MBq/l.

Appendix B

Dose rates from a standard box as calculated by ISOSHLD-II

Detector at one foot from the center of face A and face B of the box

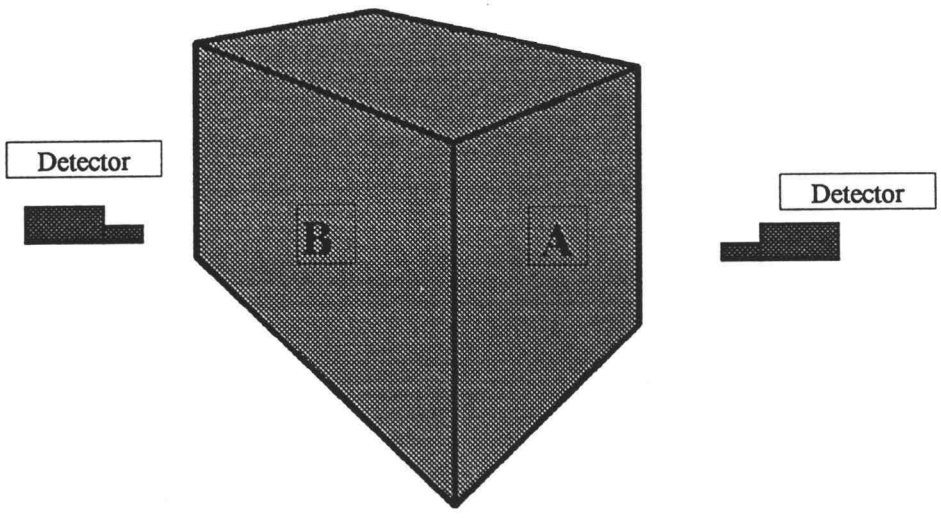

Figure B-1. Standard box

Start run at 10:46:22 05/09/95

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Dose rates from a box contains Ra-226 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
BI-210	1.98E-05	1.984E-05
PO-210	1.98E-05	1.984E-05
RA-226	1.98E-05	1.984E-05
PB-210	1.98E-05	1.984E-05
PB-214	1.98E-05	1.984E-05
BI-214	1.98E-05	1.984E-05
PO-214	1.98E-05	1.984E-05
RN-222	1.98E-05	1.984E-05

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5

Group	Linear Attenuation Coefficients (last region is air)					
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00

15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

STANDARD BOX (1.5'H x 1'W x 2'L) , detector at 1 foot from side A

Source Slab Thickness = 6.096E+01 cm
Shields Slab Height = 4.572E+01 cm
Distance to Detector, X = 9.144E+01 cm
Volume = 8.495E+04 cc
Width = 3.048E+01 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.032E+00 cm
Total Intervals: 3.630E+03

Shield Thickness, cm 6.096E+01
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.954E+04	2.954E+04	2.913E-04	2.398E-08
2	2.500E-02	1.487E+04	1.487E+04	2.779E-04	4.807E-09
3	3.500E-02	1.034E+04	1.034E+04	3.693E-04	2.345E-09
4	4.500E-02	7.675E+03	3.776E+04	5.216E-03	1.711E-08
5	5.500E-02	5.991E+03	1.406E+04	3.093E-03	7.083E-09
6	6.500E-02	4.797E+03	4.797E+03	1.890E-03	3.575E-09
7	7.500E-02	3.675E+03	3.675E+03	1.957E-03	3.354E-09
8	8.500E-02	2.777E+03	2.777E+03	1.937E-03	3.132E-09
9	9.500E-02	2.337E+03	2.337E+03	2.002E-03	3.209E-09
10	1.500E-01	1.089E+04	3.496E+04	2.271E-02	3.924E-08
11	2.500E-01	3.328E+03	1.990E+05	2.247E-01	4.404E-07
12	3.500E-01	1.631E+03	2.739E+05	5.436E-01	1.120E-06
13	4.750E-01	1.099E+03	1.613E+03	4.860E-03	9.915E-09
14	6.500E-01	5.995E+02	3.507E+05	1.623E+00	3.376E-06
15	8.250E-01	2.148E+02	5.313E+04	3.060E-01	6.120E-07
16	1.000E+00	1.520E+02	2.364E+04	1.776E-01	3.428E-07
17	1.225E+00	9.155E+01	1.770E+05	1.670E+00	3.073E-06
18	1.475E+00	4.527E+01	7.417E+04	8.677E-01	1.527E-06
19	1.700E+00	1.851E+01	1.483E+05	2.038E+00	3.485E-06
20	1.900E+00	1.009E+01	1.542E+04	2.433E-01	4.038E-07
21	2.100E+00	5.249E+00	8.812E+03	1.559E-01	2.495E-07
22	2.300E+00	2.474E+00	3.670E+04	7.359E-01	1.133E-06
23	2.500E+00	9.933E-01	1.174E+04	2.596E-01	3.946E-07
24	2.700E+00	3.093E-01	3.093E-01	7.425E-06	1.099E-11
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		1.001E+05	1.529E+06	8.890E+00	1.627E-05

Note that 1.627E-05 R/hr = 1.166E-12 amp/kg

Detector at 1' from side B

Source Slab Shields Slab Distance to Detector, X = 7.620E+01 cm
Volume = 8.495E+04 cc
Thickness = 4.572E+01 cm Height = 6.096E+01 cm Width = 3.048E+01 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.078E+00 cm
Total Intervals: 2.662E+03

Shield Thickness, cm 4.572E+01
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.954E+04	2.954E+04	3.629E-04	2.987E-08
2	2.500E-02	1.487E+04	1.487E+04	3.479E-04	6.019E-09
3	3.500E-02	1.034E+04	1.034E+04	4.400E-04	2.794E-09
4	4.500E-02	7.675E+03	3.776E+04	6.025E-03	1.976E-08
5	5.500E-02	5.991E+03	1.406E+04	3.585E-03	8.211E-09
6	6.500E-02	4.797E+03	4.797E+03	2.303E-03	4.354E-09
7	7.500E-02	3.675E+03	3.675E+03	2.357E-03	4.039E-09
8	8.500E-02	2.777E+03	2.777E+03	2.322E-03	3.755E-09
9	9.500E-02	2.337E+03	2.337E+03	2.413E-03	3.868E-09
10	1.500E-01	1.089E+04	3.496E+04	2.725E-02	4.709E-08
11	2.500E-01	3.328E+03	1.990E+05	2.699E-01	5.289E-07
12	3.500E-01	1.631E+03	2.739E+05	6.560E-01	1.351E-06
13	4.750E-01	1.099E+03	1.613E+03	5.880E-03	1.199E-08
14	6.500E-01	5.995E+02	3.507E+05	1.969E+00	4.095E-06
15	8.250E-01	2.148E+02	5.313E+04	3.716E-01	7.431E-07
16	1.000E+00	1.520E+02	2.364E+04	2.160E-01	4.169E-07
17	1.225E+00	9.155E+01	1.770E+05	2.034E+00	3.742E-06
18	1.475E+00	4.527E+01	7.417E+04	1.058E+00	1.862E-06
19	1.700E+00	1.851E+01	1.483E+05	2.488E+00	4.254E-06
20	1.900E+00	1.009E+01	1.542E+04	2.972E-01	4.933E-07
21	2.100E+00	5.249E+00	8.812E+03	1.906E-01	3.050E-07
22	2.300E+00	2.474E+00	3.670E+04	9.004E-01	1.387E-06
23	2.500E+00	9.933E-01	1.174E+04	3.177E-01	4.829E-07
24	2.700E+00	3.093E-01	3.093E-01	9.090E-06	1.345E-11
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		1.001E+05	1.529E+06	1.082E+01	1.980E-05

Note that 1.980E-05 R/hr = 1.419E-12 amp/kg

***> This is the end

Finish run at 10:46:25 05/09/95

Contents of Input file, radbox

0 2Dose rates from a box contains Ra-226 and its daughters
STANDARD BOX (1.5'H x 1'W x 2'L) , detector at 1 foot from side A

```
&INPUT NEXT=1, IGEOM=10, X=91.44, Y=45.72, SLTH=30.48, ISPEC=3,
NSHLD=1, T(1)=60.96, NPSI=10, NTHETA=10, DELR=2,
WEIGHT(485)=19.835E-06, WEIGHT(514)=19.835E-06, WEIGHT(510)=19.835E-06,
WEIGHT(511)=19.835E-06, WEIGHT(512)=19.835E-06, WEIGHT(508)=19.835E-06,
WEIGHT(483)=19.835E-06,WEIGHT(484)=19.835E-06, JBUF=1 &
1A1O    7   3.967
Detector at 1' from side B
&INPUT NEXT= 4, X= 76.2, Y=60.96, T(1)=45.72  &
This is the end
&INPUT NEXT=6 &
```

Appendix C

Dose Rate from a 55 gallon steel drum as calculated by

ISOSHLD II

Detector at one foot from the side of the drum

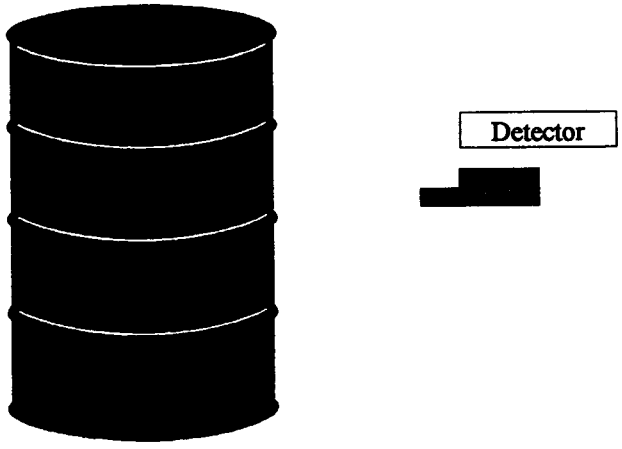

Figure C-1. Standard 55 gallon steel drum

Start run at 10:48:09 05/09/95

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Dose rate from steel drum contains Ra-226 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
BI-210	1.98E-05	1.984E-05
PO-210	1.98E-05	1.984E-05
RA-226	1.98E-05	1.984E-05
PB-210	1.98E-05	1.984E-05
PB-214	1.98E-05	1.984E-05
BI-214	1.98E-05	1.984E-05
PO-214	1.98E-05	1.984E-05
RN-222	1.98E-05	1.984E-05

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5

Group	Linear Attenuation Coefficients (last region is air)					
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00

15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

55-gallon steel drum (Hight=33.5" , Diameter=23") , detector at 1 foot

Source Shields Distance to Detector, X = 4.254E+01 cm
Cylindrical Cylindrical Volume = 2.281E+05 cc
Source Length = 8.509E+01 cm Distance Along Cylinder, Y = 4.254E+01 cm
Integration Specs: NTHETA = 7 NPSI = 7 DELR = 2.086E+00 cm
Total Intervals: 6.860E+02

Shield Thickness, cm 2.921E+01
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.954E+04	2.954E+04	2.553E-04	2.101E-08
2	2.500E-02	1.487E+04	1.487E+04	2.317E-04	4.009E-09
3	3.500E-02	1.034E+04	1.034E+04	3.379E-04	2.145E-09
4	4.500E-02	7.675E+03	3.776E+04	5.085E-03	1.668E-08
5	5.500E-02	5.991E+03	1.406E+04	3.009E-03	6.891E-09
6	6.500E-02	4.797E+03	4.797E+03	1.822E-03	3.445E-09
7	7.500E-02	3.675E+03	3.675E+03	1.956E-03	3.353E-09
8	8.500E-02	2.777E+03	2.777E+03	1.956E-03	3.162E-09
9	9.500E-02	2.337E+03	2.337E+03	2.031E-03	3.256E-09
10	1.500E-01	1.089E+04	3.496E+04	2.245E-02	3.880E-08
11	2.500E-01	3.328E+03	1.990E+05	2.232E-01	4.375E-07
12	3.500E-01	1.631E+03	2.739E+05	5.575E-01	1.148E-06
13	4.750E-01	1.099E+03	1.613E+03	5.082E-03	1.037E-08
14	6.500E-01	5.995E+02	3.507E+05	1.736E+00	3.611E-06
15	8.250E-01	2.148E+02	5.313E+04	3.303E-01	6.606E-07
16	1.000E+00	1.520E+02	2.364E+04	1.946E-01	3.757E-07
17	1.225E+00	9.155E+01	1.770E+05	1.856E+00	3.415E-06
18	1.475E+00	4.527E+01	7.417E+04	9.783E-01	1.722E-06
19	1.700E+00	1.851E+01	1.483E+05	2.319E+00	3.966E-06
20	1.900E+00	1.009E+01	1.542E+04	2.796E-01	4.641E-07
21	2.100E+00	5.249E+00	8.812E+03	1.806E-01	2.890E-07
22	2.300E+00	2.474E+00	3.670E+04	8.616E-01	1.327E-06
23	2.500E+00	9.933E-01	1.174E+04	3.057E-01	4.647E-07
24	2.700E+00	3.093E-01	3.093E-01	8.775E-06	1.299E-11
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		1.001E+05	1.529E+06	9.867E+00	1.799E-05

Note that 1.799E-05 R/hr = 1.290E-12 amp/kg

```
***>  This is the end

 Finish run at  10:48:10  05/09/95

 Contents of Input file, raddrum

0         2Dose rate from steel drum contains Ra-226 and its daughters
55-gallon steel drum (Hight=33.5" , Diameter=23") , detector at 1 foot f
&INPUT NEXT=1, IGEOM=7, SLTH=85.09, X=42.54, Y=42.54,  ISPEC=3,
NSHLD=1, T(1)=29.21, NPSI=7, NTHETA=7, DELR=2,
WEIGHT(485)=19.835E-06, WEIGHT(514)=19.835E-06, WEIGHT(510)=19.835E-06,
WEIGHT(511)=19.835E-06, WEIGHT(512)=19.835E-06, WEIGHT(508)=19.835E-06,
WEIGHT(483)=19.835E-06,WEIGHT(484)=19.835E-06, JBUF=1 &
1A1O    7   3.967
This is the end
&INPUT NEXT=6 &
```

Appendix D

Dose rate from a new container geometry assuming ^{238}U is in ***Secular Equilibrium*** *with its daughters* as calculated by ISOSHLD II

Detector is placed one foot from the center of face B

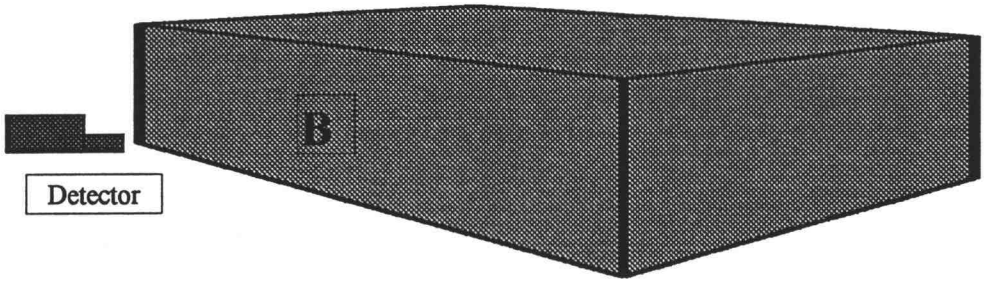

Figure D-1. A new container geometry

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Dose rate from a container contains U-238 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
BI-210	6.15E-05	6.152E-05
PO-210	6.15E-05	6.152E-05
RA-226	6.15E-05	6.152E-05
PB-210	6.15E-05	6.152E-05
PB-214	6.15E-05	6.152E-05
BI-214	6.15E-05	6.152E-05
PO-214	6.15E-05	6.152E-05
RN-222	6.15E-05	6.152E-05
TH-230	6.15E-05	6.152E-05
U -234	6.15E-05	6.152E-05
U -238	6.15E-05	6.152E-05
TH-234	6.15E-05	6.152E-05
PA-234M	6.15E-05	6.152E-05

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5

Group	Linear Attenuation Coefficients (last region is air)					
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00

10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B

Source Slab Shields Slab — Distance to Detector, X = 2.743E+02 cm
Volume = 2.455E+07 cc
Thickness = 2.438E+02 cm Height = 1.651E+02 cm Width = 6.098E+02 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.015E+00 cm
Total Intervals: 1.464E+04

Shield Thickness, cm 2.438E+02
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	1.617E+05	7.353E+05	1.672E-04	1.376E-08
2	2.500E-02	8.305E+04	8.305E+04	4.157E-05	7.192E-10
3	3.500E-02	5.473E+04	5.473E+04	4.205E-05	2.670E-10
4	4.500E-02	4.003E+04	1.334E+05	2.377E-04	7.797E-10
5	5.500E-02	3.009E+04	5.784E+04	1.586E-04	3.631E-10
6	6.500E-02	2.497E+04	1.206E+05	7.305E-04	1.381E-09
7	7.500E-02	2.071E+04	2.071E+04	1.766E-04	3.026E-10
8	8.500E-02	1.715E+04	1.715E+04	1.931E-04	3.122E-10
9	9.500E-02	1.501E+04	1.379E+05	1.939E-03	3.109E-09
10	1.500E-01	6.995E+04	1.455E+05	1.528E-03	2.640E-09
11	2.500E-01	2.223E+04	6.304E+05	1.158E-02	2.270E-08
12	3.500E-01	1.088E+04	8.554E+05	2.886E-02	5.945E-08
13	4.750E-01	7.721E+03	9.641E+03	5.064E-04	1.033E-09
14	6.500E-01	4.343E+03	1.092E+06	9.068E-02	1.886E-07
15	8.250E-01	1.566E+03	1.718E+05	1.801E-02	3.602E-08
16	1.000E+00	1.060E+03	8.763E+04	1.220E-02	2.354E-08
17	1.225E+00	5.726E+02	5.515E+05	9.819E-02	1.807E-07
18	1.475E+00	2.317E+02	2.307E+05	5.184E-02	9.124E-08
19	1.700E+00	7.770E+01	4.652E+05	1.243E-01	2.125E-07
20	1.900E+00	3.543E+01	5.410E+04	1.679E-02	2.788E-08
21	2.100E+00	1.659E+01	2.733E+04	9.616E-03	1.539E-08
22	2.300E+00	7.675E+00	1.138E+05	4.599E-02	7.083E-08
23	2.500E+00	3.081E+00	3.642E+04	1.635E-02	2.485E-08

24	2.700E+00	9.593E-01	9.593E-01	4.699E-07	6.955E-13
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		5.662E+05	5.832E+06	5.301E-01	9.783E-07

Note that 9.783E-07 R/hr = 7.012E-14 amp/kg

***> The U238 was assumed to be in secular equilibrium with its daughters.

Finish run at 17:08:28 06/06/95

Contents of Input file, usebox

```
0          2Dose rate from a container contains U-238 and its daughters
Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B
&INPUT NEXT=1, IGEOM=10, X=274.32, Y=165.1, SLTH=609.8, ISPEC=3,
NSHLD=1, T(1)=243.84, NPSI=10, NTHETA=10, DELR=2,
WEIGHT(526)=61.52E-06, WEIGHT(530)=61.52E-06, WEIGHT(533)=61.52E-06,
WEIGHT(520)=61.52E-06, WEIGHT(518)=61.52E-06, WEIGHT(485)=61.52E-06,
WEIGHT(514)=61.52E-06, WEIGHT(510)=61.52E-06, WEIGHT(511)=61.52E-06,
WEIGHT(512)=61.52E-06, WEIGHT(508)=61.52E-06, WEIGHT(483)=61.52E-06,
WEIGHT(484)=61.52E-06, JBUF=1 &
1A1O     7    3.967
The U238 was assumed to be in secular equilibrium with its daughters.
&INPUT NEXT=6 &
```

Appendix E

Dose rate from a new container geometry assuming ^{238}U is in ***Disequilibrium*** *with its daughters* as calculated by ISOSHLD II

Detector is placed one foot from the center of face B

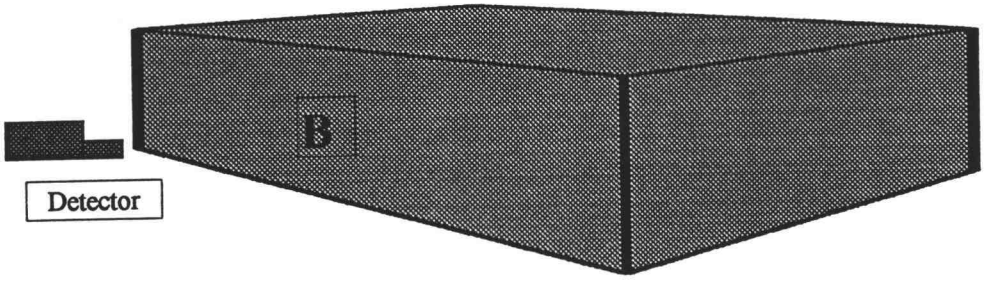

Figure E-1. A new container geometry

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Dose rate from container contains Ra-226 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
BI-210	2.78E-05	2.777E-05
PO-210	2.78E-05	2.777E-05
RA-226	2.78E-05	2.777E-05
PB-210	2.78E-05	2.777E-05
PB-214	2.78E-05	2.777E-05
BI-214	2.78E-05	2.777E-05
PO-214	2.78E-05	2.777E-05
RN-222	2.78E-05	2.777E-05

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5

Group	Linear Attenuation Coefficients (last region is air)					
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00

15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B

Source Shields Distance to Detector, X = 2.743E+02 cm
Slab Slab Volume = 2.455E+07 cc
Thickness = 2.438E+02 cm Height = 1.651E+02 cm Width = 6.098E+02 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.015E+00 cm
Total Intervals: 1.464E+04

Shield Thickness, cm 2.438E+02
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	4.135E+04	4.135E+04	9.405E-06	7.740E-10
2	2.500E-02	2.082E+04	2.082E+04	1.042E-05	1.803E-10
3	3.500E-02	1.448E+04	1.448E+04	1.112E-05	7.063E-11
4	4.500E-02	1.074E+04	5.287E+04	9.424E-05	3.091E-10
5	5.500E-02	8.387E+03	1.969E+04	5.398E-05	1.236E-10
6	6.500E-02	6.715E+03	6.715E+03	4.068E-05	7.693E-11
7	7.500E-02	5.145E+03	5.145E+03	4.387E-05	7.519E-11
8	8.500E-02	3.888E+03	3.888E+03	4.378E-05	7.079E-11
9	9.500E-02	3.272E+03	3.272E+03	4.601E-05	7.376E-11
10	1.500E-01	1.524E+04	4.894E+04	5.139E-04	8.879E-10
11	2.500E-01	4.660E+03	2.786E+05	5.119E-03	1.003E-08
12	3.500E-01	2.283E+03	3.835E+05	1.294E-02	2.665E-08
13	4.750E-01	1.539E+03	2.258E+03	1.186E-04	2.420E-10
14	6.500E-01	8.393E+02	4.909E+05	4.076E-02	8.479E-08
15	8.250E-01	3.007E+02	7.438E+04	7.797E-03	1.559E-08
16	1.000E+00	2.128E+02	3.309E+04	4.606E-03	8.891E-09
17	1.225E+00	1.282E+02	2.477E+05	4.411E-02	8.116E-08
18	1.475E+00	6.338E+01	1.038E+05	2.333E-02	4.107E-08
19	1.700E+00	2.592E+01	2.076E+05	5.545E-02	9.482E-08
20	1.900E+00	1.413E+01	2.159E+04	6.702E-03	1.113E-08
21	2.100E+00	7.349E+00	1.234E+04	4.340E-03	6.945E-09
22	2.300E+00	3.464E+00	5.138E+04	2.076E-02	3.197E-08
23	2.500E+00	1.391E+00	1.644E+04	7.380E-03	1.122E-08
24	2.700E+00	4.330E-01	4.330E-01	2.121E-07	3.139E-13
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		1.401E+05	2.141E+06	2.343E-01	4.272E-07

Note that 4.272E-07 R/hr = 3.061E-14 amp/kg

```
***>  This calculation based on a disequilibrium between U238 and Ra226

 Finish run at  17:12:02  06/06/95

 Contents of Input file, ra226box

0         2Dose rate from container contains Ra-226 and its daughters
Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B
&INPUT NEXT=1, IGEOM=10, X=274.32, Y=165.1, SLTH=609.8, ISPEC=3,
NSHLD=1, T(1)=243.84, NPSI=10, NTHETA=10, DELR=2,
WEIGHT(485)=27.769E-06, WEIGHT(514)=27.769E-06, WEIGHT(510)=27.769E-06,
WEIGHT(511)=27.769E-06, WEIGHT(512)=27.769E-06, WEIGHT(508)=27.769E-06,
WEIGHT(483)=27.769E-06,WEIGHT(484)=27.769E-06, JBUF=1 &
1A1O    7   3.967
This calculation based on a disequilibrium between U238 and Ra226
&INPUT NEXT=6 &
```

Appendix F

Dose rate from a new container geometry assuming ^{232}Th is in ***Secular Equilibrium*** *with its daughters* as calculated by ISOSHLD II

Detector is placed one foot from the center of face B

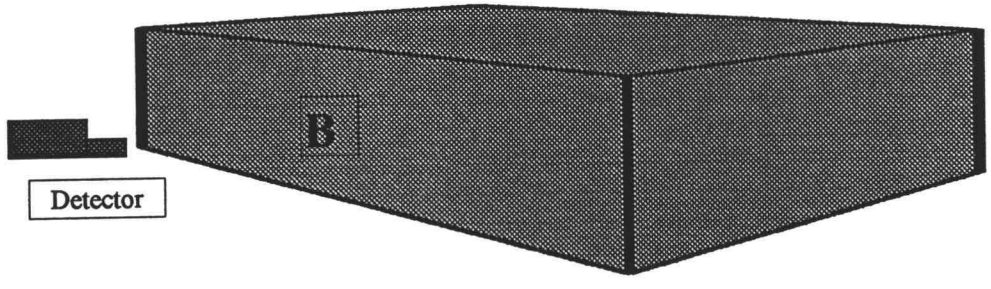

Figure F-1. A new container geometry

Start run at 09:37:22 05/25/95

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Fused Al2O3 contains Th232 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
RA-228	7.16E-05	7.156E-05
RA-224	7.16E-05	7.156E-05
RN-220	7.16E-05	7.156E-05
PB-212	7.16E-05	7.156E-05
BI-212	7.16E-05	7.156E-05
TL-208	2.57E-05	2.569E-05
AC-228	7.16E-05	7.156E-05

Shield Composition, g/cc

	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5

Linear Attenuation Coefficients (last region is air)

Group						
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B

Source Slab Thickness = 2.438E+02 cm
Shields Slab Height = 1.651E+02 cm
Distance to Detector, X = 2.743E+02 cm
Volume = 2.455E+07 cc
Width = 6.098E+02 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.015E+00 cm
Total Intervals: 1.464E+04

Shield Thickness, cm 2.438E+02
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	2.776E+05	8.074E+05	1.836E-04	1.511E-08
2	2.500E-02	1.209E+05	1.209E+05	6.052E-05	1.047E-09
3	3.500E-02	6.905E+04	6.905E+04	5.306E-05	3.369E-10
4	4.500E-02	4.384E+04	4.384E+04	7.814E-05	2.563E-10
5	5.500E-02	3.093E+04	3.093E+04	8.481E-05	1.942E-10
6	6.500E-02	2.408E+04	2.408E+04	1.459E-04	2.758E-10
7	7.500E-02	1.912E+04	1.912E+04	1.630E-04	2.794E-10
8	8.500E-02	1.543E+04	1.543E+04	1.737E-04	2.809E-10
9	9.500E-02	1.293E+04	1.293E+04	1.819E-04	2.915E-10
10	1.500E-01	4.757E+04	4.757E+04	4.994E-04	8.630E-10
11	2.500E-01	1.552E+04	1.547E+06	2.843E-02	5.572E-08
12	3.500E-01	7.284E+03	5.156E+05	1.740E-02	3.584E-08
13	4.750E-01	5.077E+03	3.340E+05	1.755E-02	3.580E-08
14	6.500E-01	2.765E+03	9.976E+05	8.284E-02	1.723E-07
15	8.250E-01	9.262E+02	2.659E+05	2.787E-02	5.575E-08
16	1.000E+00	5.770E+02	1.396E+06	1.943E-01	3.750E-07
17	1.225E+00	2.628E+02	2.628E+02	4.679E-05	8.609E-11
18	1.475E+00	7.511E+01	7.511E+01	1.688E-05	2.971E-11
19	1.700E+00	1.518E+01	3.973E+04	1.061E-02	1.815E-08
20	1.900E+00	2.871E+00	2.871E+00	8.913E-07	1.480E-12
21	2.100E+00	1.495E-01	1.495E-01	5.259E-08	8.414E-14
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	9.485E+05	4.647E-01	6.877E-07
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		6.939E+05	7.236E+06	8.454E-01	1.455E-06

Note that 1.455E-06 R/hr = 1.043E-13 amp/kg

```
***>  The Th232 was assumed to be in a secular equilibrium with its daughter


 Finish run at  17:13:49  06/06/95

 Contents of Input file, thsebox

0         2Fused Al2O3 contains Th232 and its daughters
Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B
&INPUT NEXT=1, IGEOM=10, X=274.32, Y=165.1, SLTH=609.8, ISPEC=3,
NSHLD=1, T(1)=243.84, NPSI=10, NTHETA=10, DELR=2,
WEIGHT(488)=71.56E-06, WEIGHT(537)=71.56E-06, WEIGHT(522)=71.56E-06,
WEIGHT(523)=71.56E-06, WEIGHT(524)=71.56E-06, WEIGHT(525)=71.56E-06,
WEIGHT(536)=25.69E-06, JBUF=1 &
1A1O     7    3.967
The Th232 was assumed to be in a secular equilibrium with its daughters.
&INPUT NEXT=6 &
```

Appendix G

Dose rate from a new container geometry assuming ^{232}Th is in ***Disequilibrium*** *with its daughters* as calculated by ISOSHLD II

Detector is placed one foot from the center of face B

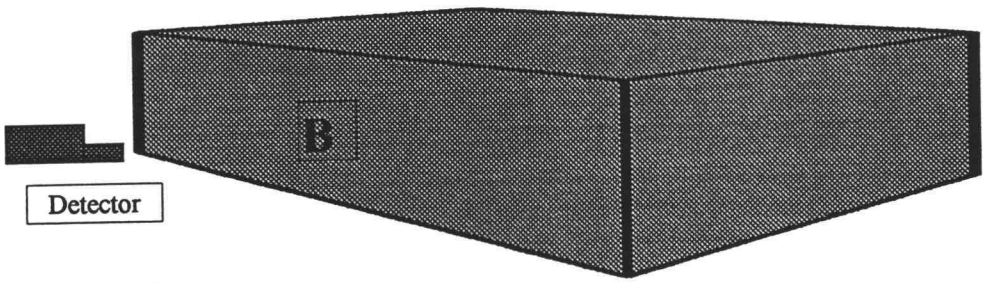

Figure G-1. A new container geometry

ISOSHLD-II (RIBD removed)

IBM PC/AT Version 1.5, August 1987
Radiological Analysis
Westinghouse Hanford Company
Richland, WA 99352

Dose rate from a container contains Ra228 and its daughters

Table of Source Activity:

Scale Factor = 1.000E+00

Isotope Name	Curies	Adjusted Curies
RA-228	3.57E-05	3.570E-05
RA-224	3.57E-05	3.570E-05
RN-220	3.57E-05	3.570E-05
PB-212	3.57E-05	3.570E-05
BI-212	3.57E-05	3.570E-05
TL-208	1.32E-05	1.317E-05
AC-228	3.57E-05	3.570E-05

Shield Composition, g/cc

Group	Shield 1	Shield 2	Shield 3	Shield 4	Shield 5
	Linear Attenuation Coefficients (last region is air)				
1	7.104E+01	4.424E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2	8.370E+00	6.542E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3	3.019E+00	3.504E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4	1.609E+00	2.715E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5	1.410E+00	2.405E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
6	9.156E-01	2.247E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7	7.946E-01	2.137E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8	7.093E-01	2.049E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9	6.597E-01	1.985E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
10	5.316E-01	1.725E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
11	5.078E-01	1.474E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
12	3.927E-01	1.312E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
13	3.443E-01	1.183E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
14	2.995E-01	1.118E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
15	2.682E-01	8.986E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

16	2.440E-01	8.210E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
17	2.194E-01	7.408E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
18	1.976E-01	6.658E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
19	1.853E-01	6.180E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
20	1.738E-01	5.818E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
21	1.642E-01	5.495E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
22	1.547E-01	5.262E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	1.488E-01	5.004E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	1.448E-01	4.784E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
25	1.416E-01	4.383E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B

Source Shields Distance to Detector, X = 2.743E+02 cm
Slab Slab Volume = 2.455E+07 cc
Thickness = 2.438E+02 cm Height = 1.651E+02 cm Width = 6.098E+02 cm
Integration Specs: NTHETA = 11 NPSI = 11 DELR = 2.015E+00 cm
Total Intervals: 1.464E+04

Shield Thickness, cm 2.438E+02
Taylor Buildup Data for Shield 1 with Effective Atomic Number 13.0

Group	Average Energy, Mev	Bremsstr. photons/sec	Source Total photons/sec	Energy Flux Mev/sq.cm/sec	Dose Rate R/hr
1	1.500E-02	1.387E+05	4.031E+05	9.167E-05	7.544E-09
2	2.500E-02	6.045E+04	6.045E+04	3.026E-05	5.234E-10
3	3.500E-02	3.453E+04	3.453E+04	2.653E-05	1.685E-10
4	4.500E-02	2.193E+04	2.193E+04	3.909E-05	1.282E-10
5	5.500E-02	1.548E+04	1.548E+04	4.245E-05	9.722E-11
6	6.500E-02	1.206E+04	1.206E+04	7.305E-05	1.381E-10
7	7.500E-02	9.577E+03	9.577E+03	8.166E-05	1.400E-10
8	8.500E-02	7.731E+03	7.731E+03	8.705E-05	1.408E-10
9	9.500E-02	6.479E+03	6.479E+03	9.110E-05	1.460E-10
10	1.500E-01	2.382E+04	2.382E+04	2.501E-04	4.322E-10
11	2.500E-01	7.775E+03	7.728E+05	1.420E-02	2.783E-08
12	3.500E-01	3.649E+03	2.573E+05	8.680E-03	1.788E-08
13	4.750E-01	2.543E+03	1.695E+05	8.905E-03	1.817E-08
14	6.500E-01	1.384E+03	5.091E+05	4.227E-02	8.793E-08
15	8.250E-01	4.635E+02	1.343E+05	1.407E-02	2.815E-08
16	1.000E+00	2.885E+02	6.965E+05	9.695E-02	1.871E-07
17	1.225E+00	1.313E+02	1.313E+02	2.337E-05	4.301E-11
18	1.475E+00	3.749E+01	3.749E+01	8.426E-06	1.483E-11
19	1.700E+00	7.576E+00	1.982E+04	5.295E-03	9.055E-09
20	1.900E+00	1.433E+00	1.433E+00	4.447E-07	7.382E-13
21	2.100E+00	7.457E-02	7.457E-02	2.706E-08	4.329E-14
22	2.300E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
23	2.500E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
24	2.700E+00	0.000E+00	4.864E+05	2.383E-01	3.527E-07
25	3.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTALS		3.471E+05	3.641E+06	4.295E-01	7.383E-07

Note that 7.383E-07 R/hr = 5.291E-14 amp/kg

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***>  This calculation is based on a disequilibrium between Th232 and Ra228


 Finish run at  17:15:22  06/06/95

 Contents of Input file, ra228box

0         2Dose rate from a container contains Ra228 and its daughters
Waste Container (65"H x 8'W x 20'L) , detector at 1 foot from side B
&INPUT NEXT=1, IGEOM=10, X=274.32, Y=165.1, SLTH=609.8, ISPEC=3,
NSHLD=1, T(1)=243.84, NPSI=10, NTHETA=10, DELR=2,
WEIGHT(488)=35.703E-06, WEIGHT(537)=35.703E-06, WEIGHT(522)=35.703E-06,
WEIGHT(523)=35.703E-06, WEIGHT(524)=35.703E-06, WEIGHT(525)=35.703E-06,
WEIGHT(536)=13.174E-06, JBUF=1 &
1A1O     7    3.967
This calculation is based on a disequilibrium between Th232 and Ra228
&INPUT NEXT=6 &
```