Technical Basis for Beta Skin Dose Calculations at the Y-12 Plant

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CONTENTS

LIST OF TABLES	iv
ABSTRACT	v
INTRODUCTION	1
REQUIREMENTS FOR SKIN DOSE CALCULATION	1
VARSKIN COMPUTER CODE PARAMETERS	3
RADIONUCLIDE SELECTION	4
AREA DETERMINATION	5
SOURCE STRENGTH	6
EXPOSURE TIME	7
SKIN THICKNESS	8
SUMMARY OF Y-12 PLANT SPECIFIC ASSUMPTIONS	10
RADIONUCLIDES	10
SKIN THICKNESS	10
CONTAMINATED AREA	10
SOURCE STRENGTH	11
EXPOSURE TIME	12
DERIVATION OF TRIGGER LEVELS FOR SKIN DOSE ASSESSMENT	12
DEPLETED-URANIUM CONTAMINATION MEASURED WITH A GM SURVEY INSTRUMENT	12
DEPLETED-URANIUM CONTAMINATION MEASURED WITH A GAS PROPORTIONAL COUNTER SURVEY INSTRUMENT	13
ENRICHED-URANIUM CONTAMINATION	15
REFERENCES	18
APPENDIX: SAMPLE VARSKIN DATA FILE	19

LIST OF TABLES

<i>Table</i>	<i>Title</i>	<i>Page</i>
1	Recording requirements for nonuniform exposure of the skin	2
2	Decay data for beta-emitting radionuclides present in enriched and depleted uranium	4
3	Relative skin dose conversion factors for uranium daughters	4
4	Effects of contamination size on skin dose	5
5	Effects of contamination amount on skin dose	6
6	Effects of exposure duration on skin dose	7
7	Epidermal thickness for main body sites for males and females of ages 15 to 89 years	8
8	Typical density thicknesses of company-issued clothing	9
9	Guidelines for estimating the size of contaminated skin with a 20-cm ² GM survey instrument	10
10	Guidelines for estimating the size of contaminated skin with a 100-cm ² gas proportional counter survey instrument	11

ABSTRACT

This report describes the methods for determining shallow dose equivalent to workers at the Oak Ridge Y-12 Plant from skin contamination detected by survey instrumentation. Included is a discussion of how the computer code VARSKIN is used to calculate beta skin dose and how the code input parameters affect skin dose calculation results. A summary of Y-12 Plant specific assumptions used in performing VARSKIN calculations is presented. Derivations of contamination levels that trigger the need for skin dose assessment are given for both enriched and depleted uranium with the use of Y-12 Plant site-specific survey instruments. Department of Energy recording requirements for nonuniform exposure of the skin are illustrated with sample calculations.

INTRODUCTION

The purpose of this document is to describe the methodology for calculating beta skin dose to workers at the Oak Ridge Y-12 Plant. Skin dose, or dose equivalent, from radioactive contamination on the surface of the skin at a depth of 70 μm must be inferred from calculations. The computer code VARSKIN MOD 1 (ref. 1) is used to perform these calculations. This document reviews the input parameters necessary to calculate skin dose equivalent and provides the technical basis for all associated assumptions. Recommendations for practical levels of skin contamination at which dose assessment is initiated are also included.

REQUIREMENTS FOR SKIN DOSE CALCULATION

The *U.S. Department of Energy Radiological Control Manual*² (referred to as the *DOE RadCon Manual*), Department of Energy (DOE) Notice N 5480.6, Article 541.5, requires that levels of skin contamination that trigger the need for dose assessment be established at levels not exceeding 100 mrem. At the Y-12 Plant, skin dose is assessed if the potential dose is 100 mrem or greater (which is 0.2% of the annual limit). A level of 1000 mrem was proposed in a draft revision to DOE Order 5480.11 (ref. 3), dated March 13, 1990, for reporting purposes, but this value has not been incorporated into official DOE orders. Currently, 10 *CFR* Pt. 835 (ref. 4) and DOE Order 5480.11 do not mention trigger levels for skin dose calculations.

Nonuniform exposures of the skin from X rays, beta radiation, and radioactive materials on the skin, including hot particles, shall be assessed and recorded as specified in the following documents:

1. DOE N 5480.6, *U.S. Department of Energy Radiological Control Manual*, Appendix 2C.
2. DOE Order 5480.11, "Radiation Protection for Occupational Workers," 9f2.
3. 10 *CFR* Pt. 835, "Radiation Protection for Occupational Workers," Sect. 205.

The regulatory requirements for recording skin dose are listed in Table 1.

Table 1. Recording requirements for nonuniform exposure of the skin

Area of skin irradiated	(1) Method of averaging, (2) adding to other doses received, and (3) recording nonuniform skin dose
$\geq 100 \text{ cm}^2$	<p>(1) Averaged over the 100 cm^2 of skin receiving the maximum dose</p> <p>(2) Added to any uniform dose equivalent also received by the skin</p> <p>(3) Recorded as the annual extremity or skin (shallow) dose equivalent (H)</p>
$< 100 \text{ cm}^2$	<p>(1) Averaged over the 1 cm^2 of skin receiving the maximum dose (D), reduced by the fraction (f) that is the irradiated area in square centimeters divided by 100 cm^2 (i.e., $H = f D$)</p> <p>(2) Added to any uniform dose equivalent also received by the skin</p> <p>(3) Recorded as the annual extremity or skin (shallow) dose equivalent</p>
$< 10 \text{ cm}^2$	<p>(1) Averaged over the 1 cm^2 of skin receiving the maximum dose</p> <p>(2) Not added to any other dose equivalent, extremity, or shallow dose equivalent (skin) recorded for the annual dose equivalent</p> <p>(3) Recorded in a person's radiation dose record as a special entry</p>

For example, if a person has contamination covering a 25-cm^2 area of the skin and the maximum dose to a 1-cm^2 area of that skin is reported by VARSKIN to be 50 mrem, the following dose would be reported:

$$H = f D , \quad (1)$$

where

H = reported skin (shallow) dose equivalent,

f = irradiated area in square centimeters divided by 100 cm^2 ,

D = average dose to a 1-cm^2 area of skin receiving the maximum dose.

Therefore,

$$\begin{aligned}
 \text{Skin dose } H \text{ (mrem)} &= \frac{25 \text{ cm}^2}{100 \text{ cm}^2} 50 \text{ mrem} \\
 &= 12.5 \text{ mrem} .
 \end{aligned} \quad (2)$$

In addition, the DOE RadCon Manual lists the following requirements:

Article 541.7: Personnel with skin contamination for which dose assessment was not performed should be informed of the nature of the contamination and an upper estimate of the potential dose (such as less than 10 mrem) as soon as practicable, preferably prior to the end of the work day.

Article 541.8: An assessment of skin exposure requires time to conduct a detailed evaluation. Assessments shall be conducted ... and, promptly after completion, the results should be explained to the persons affected.

VARSKIN COMPUTER CODE PARAMETERS

VARSKIN is a computer code developed to estimate the radiation dose to the skin resulting from the spectrum of beta energies emitted from various radioactive contaminants on the skin. VARSKIN utilizes a method based on tables of absorbed energy distributions around point sources in water that were developed by M. J. Berger.⁵ The code has a library of 83 radioisotopes and allows dose computation at a specified depth from a source ranging in size from a point source to a 100-cm² disk.

The basic formula for skin dose calculation is

$$\text{Dose equivalent} = \text{activity} \times \text{time} \times \text{dose conversion factor} . \quad (3)$$

To calculate skin dose, the VARSKIN code requires the following information:

1. Radionuclide(s).
2. Skin thickness (0.007 cm is the VARSKIN default).
3. Size of the contaminated area in square centimeters.
4. Source strength (input as either a total microcurie amount or a concentration in microcuries per square centimeter).
5. Exposure time (the amount of time the contamination was present on the skin).

After a dose calculation, VARSKIN stores pertinent information in a text data file that can be used to document dose assessments. The Appendix is a sample VARSKIN data file.

RADIONUCLIDE SELECTION

The first step in determining skin dose by using the VARSKIN code is to select the appropriate radionuclides that contribute to skin dose. At the Y-12 Plant, depleted uranium is approximately 99.8% ^{238}U and only 0.2% ^{235}U , and enriched uranium is approximately 93% ^{235}U , 6% ^{238}U , and 1% ^{234}U . Because of the isotopic percentages, skin dose from depleted-uranium contamination will consider ^{238}U progeny, and skin dose from enriched-uranium contamination will consider ^{235}U and ^{238}U progeny. For the purpose of this document, all beta doses from ^{238}U are assumed to come from $^{234\text{m}}\text{Pa}$ and ^{234}Th . All beta doses from ^{235}U are assumed to come from ^{231}Th .

The beta emitters of interest from depleted uranium are ^{234}Th and $^{234\text{m}}\text{Pa}$ resulting from ^{238}U decay. Thorium-231 results from ^{235}U decay and is the primary source of beta dose for enriched uranium. Table 2 lists the parent radionuclides, maximum beta energies, and beta intensities for the beta-emitting radionuclides of interest. The primary skin dose hazard at the Y-12 Plant is from depleted uranium.

Table 2. Decay data for beta-emitting radionuclides present in enriched and depleted uranium

Parent radionuclide	Beta-emitting radionuclide	Maximum beta energy (MeV)	Beta intensity (%)
^{238}U	$^{234\text{m}}\text{Pa}$	2.29	98
	^{234}Th	0.123	21
		0.193	79
^{235}U	^{231}Th	0.305	40

Dose conversion factors are used to convert the activity levels of radionuclides on the skin to dose equivalent. Table 3 lists dose conversion factors calculated with VARSKIN for uranium progeny radionuclides. To illustrate the relative dose contribution, the dose conversion factors are calculated by using a 1-cm² contaminated area, a 10,000 disintegrations per minute (dpm) source strength, and a 1-h exposure duration.

Table 3. Relative skin dose conversion factors for uranium daughters

Radionuclide	Skin dose (mrem/h per 10,000 dpm/1 cm ²)
$^{234\text{m}}\text{Pa}$	36
^{234}Th	4
^{231}Th	9

As can be seen from Table 3, ^{234m}Pa contributes nine times the dose as an equal concentration of ^{234}Th . Although ^{231}Th contributes 2.25 times the dose per unit exposure that ^{234}Th contributes, the activity of ^{231}Th in depleted uranium is approximately only 1/78 that of ^{234}Th or ^{234m}Pa . This ratio demonstrates the insignificance of including ^{231}Th in beta skin dose calculations for depleted uranium. Furthermore, enriched-uranium contamination is not a very significant source of skin dose.

AREA DETERMINATION

The second step in calculating skin dose is to input the size of the contaminated area. The Health Physics technician should make every effort to determine the actual area of the contaminated skin. Table 4 demonstrates how the size of the contaminated area affects the dose calculation for equal quantities of radioactivity. The data presented in Table 4 were obtained by using a 1-h exposure time and a 0.007-cm skin thickness.

Table 4. Effects of contamination size on skin dose

Radionuclide	Contamination amount (μCi)	Contamination area (cm^2)	Dose to affected skin ^a (mrem)	Reported skin dose ^b (mrem)
^{234m}Pa	0.25	1	324	2020
^{234m}Pa	0.25	5	151	458
^{234m}Pa	0.25	10	98	23
^{234m}Pa	0.25	20	58	23
^{234m}Pa	0.25	25	50	23
^{234m}Pa	0.25	50	29	23
^{234m}Pa	0.25	75	21	23
^{234m}Pa	0.25	100 ^c	17	22
^{234m}Pa	0.25	150	12	15
^{234m}Pa	0.25	200	9	12

^aVARSKIN reports an area of skin where all cell damage occurs. "Dose to affected skin" is the skin dose averaged over this area.

^b"Reported skin dose" refers to the skin dose required to be reported to comply with DOE Order 5480.11 and DOE N 5480.6 (see p. 2).

^cCurrent default area in use for calculations for 1990–1993.

As can be seen in Table 4, the dose to the affected skin area decreases as the radioactivity is distributed over larger areas. Currently at the Y-12 Plant, all skin contamination measurements are normalized to a 100-cm² area, with no determination of the actual size of contamination. International Commission on Radiological Protection Publication 26 (ref. 6)

states that, for routine purposes, it is adequate to regard the contamination as being averaged over areas of 100 cm². However, to calculate and report skin dose properly, the actual size of the contaminated area should be determined.

To measure beta/gamma skin contamination, the Y-12 Plant uses Geiger-Müller (GM) counters that have a 20-cm² detector surface area and gas proportional counters that have a 100-cm² detector surface area. In some instances, it may be difficult to accurately determine the size of a contaminated area when the area is less than the size of the detector surface area. In this case, the area of skin contamination should be assumed to be the size of the surface area of the detector. Nevertheless, every effort should be made to determine the actual size of the contaminated area.

SOURCE STRENGTH

Once the size of the contaminated area is known, either the total amount of radioactivity present or the concentration of radioactivity must be ascertained. To be conservative, the maximum contamination level obtained with a field instrument should be used. Unless information indicates otherwise, this maximum contamination level is assumed to be uniformly distributed and representative of the contamination levels of the entire affected area. Table 5 presents VARSKIN data obtained by varying contamination amounts distributed over a 20-cm² area. VARSKIN allows the user to input either total activity (i.e., µCi) or activity per unit area (i.e., µCi/cm²).

Table 5. Effects of contamination amount on skin dose

Radionuclide	Contamination amount (µCi/cm ²)	Contamination area (cm ²)	Dose to affected skin ^a (mrem)	Reported skin dose ^b (mrem)
^{234m} Pa	0.001	20	5	1
^{234m} Pa	0.002	20	9	2
^{234m} Pa	0.005	20	23	5
^{234m} Pa	0.0075	20	35	7
^{234m} Pa	0.010	20	47	9
^{234m} Pa	0.015	20	70	14
^{234m} Pa	0.020	20	94	19

^aVARSKIN reports an area of skin where all cell damage occurs. "Dose to affected skin" is the skin dose averaged over this area.

^b"Reported skin dose" refers to the skin dose required to be reported to comply with DOE Order 5480.11 and DOE N 5480.6

As Table 5 demonstrates, the skin dose increases linearly with contamination amount when all other variables are constant. This is true for both the affected-skin calculations (column 4) and the reported-dose calculations (column 5).

EXPOSURE TIME

The next variable required for skin dose calculation is the duration of exposure, or the time the radioactive contamination was in contact with the skin. This information may be available from the contaminated worker. If the time at which the skin actually became contaminated is unknown, the Health Physics technician should assume that the contamination has been present on the skin since the person last began working with radioactive material (or entered a contaminated area) or since the last time a personnel contamination survey was conducted (either by Health Physics personnel or upon egress from a contaminated area). After each successive washing and resurvey, a separate dose calculation should be performed for each activity duration as appropriate. Judgment should be used in determining the appropriate exposure duration and whether additional dose calculations are needed. To perform this calculation, the technician must record the time of each survey and each decontamination effort.

Table 6 demonstrates how exposure duration affects skin dose calculation. The data for Table 6 were obtained by assuming a 0.01- $\mu\text{Ci}/\text{cm}^2$ contamination concentration uniformly distributed over a 20- cm^2 area for various exposure durations and a 0.007-cm skin thickness.

Table 6. Effects of exposure duration on skin dose

Radionuclide	Contamination amount ($\mu\text{Ci}/\text{cm}^2$)	Contamination area (cm^2)	Exposure duration (min)	Dose to affected skin ^a (mrem)	Reported skin dose ^b (mrem)
^{234m}Pa	0.010	20	15	12	4.6
^{234m}Pa	0.010	20	30	23	9.2
^{234m}Pa	0.010	20	45	35	13.8
^{234m}Pa	0.010	20	60	47	18.4
^{234m}Pa	0.010	20	90	70	27.6
^{234m}Pa	0.010	20	120	94	36.8
^{234m}Pa	0.010	20	180	140	55.2

^aVARSKIN reports an area of skin where all cell damage occurs. "Dose to affected skin" is the skin dose averaged over this area.

^b"Reported skin dose" refers to the skin dose required to be reported to comply with DOE Order 5480.11 and DOE N 5480.6.

As demonstrated in Table 6, the skin dose is directly proportional to exposure duration when all other variables are constant.

SKIN THICKNESS

The VARSKIN default skin thickness of 0.007 cm should be used for routine dose assessments. Table 7 lists some alternate skin thicknesses provided by the International Commission on Radiological Protection⁷ that can be substituted when appropriate.

Table 7. Epidermal thickness for main body sites for males and females of ages 15 to 89 years

Body site	Mean $\pm$ standard deviation for epidermal thickness (cm)
Head	0.0050 $\pm$ 0.0022
Trunk	0.0043 $\pm$ 0.0013
Arms and legs	0.0060 $\pm$ 0.0002
Back of hands	0.0085 $\pm$ 0.0026
Wrists	0.0080 $\pm$ 0.0002
Fingers	0.0220 $\pm$ 0.0120
Fingertips	0.0370 $\pm$ 0.0112

As stated, the default input for skin thickness is 0.007 cm. For situations involving contamination on clothing, several things must be considered in skin dose calculation. Because many of the ^{234m}Pa and ²³⁴Th betas will be attenuated by clothing, this must be taken into account during dose assessment. One method of doing this is to increase the default skin thickness in VARSKIN to include clothing attenuation. However, this method is not justified if the contamination has penetrated or absorbed into the clothing and could be in contact with the skin. The best method is to measure the contamination levels on the inside of the clothing that contacts the skin. This directly accounts for clothing attenuation and allows the use of the VARSKIN default skin thickness. If clothing contamination exceeds regulatory contamination limits, the clothing must be removed for disposal; the appropriate inner surfaces can then be surveyed.

If the contamination has not penetrated/absorbed into the clothing facing the skin, the skin thickness can be increased to account for the beta attenuation of the clothing. To include the thickness of clothing in the skin thickness parameter, the following equations can be used:

$$\begin{aligned} \text{Equivalent skin thickness (cm)} &= \text{equivalent skin thickness from clothing (cm)} \\ &+ \text{VARSKIN default skin thickness (cm)} , \end{aligned} \quad (4)$$

and

$$\begin{aligned} \text{Equivalent skin thickness from clothing (cm)} &= \text{VARSKIN default skin thickness (cm)} \\ &\times \frac{\text{clothing density thickness (mg/cm}^2\text{)}}{\text{default skin density thickness (mg/cm}^2\text{)}} . \end{aligned} \quad (5)$$

The resulting equation is

$$\text{Equivalent skin thickness (cm)} = 0.007 \text{ cm} \frac{\text{clothing density thickness (mg/cm}^2\text{)}}{7 \text{ mg/cm}^2} + 0.007 \text{ cm} , \quad (6)$$

where a 0.007-cm skin thickness is assumed.

For other skin thicknesses, the following equation is used:

$$\text{Equivalent skin thickness (cm)} = A \text{ cm} \frac{\text{clothing density thickness (mg/cm}^2\text{)}}{B \text{ mg/cm}^2} + A \text{ cm} , \quad (7)$$

where A is skin thickness in centimeters and B equals 1000 times the skin thickness in centimeters (density of skin $\approx 1000 \text{ mg/cm}^3$).

Table 8 lists some known values for clothing density thickness.⁸

Table 8. Typical density thicknesses of company-issued clothing

Item	Density thickness (mg/cm ²)	Comments
Men's pants	30	New
	27	Washed many times
Men's shirt	21	
Women's blouse	13	

SUMMARY OF Y-12 PLANT SPECIFIC ASSUMPTIONS

To estimate a conservative skin dose from beta/gamma skin contamination at the Y-12 Plant, the assumptions given in this section should be incorporated into routine VARSKIN calculations.

RADIONUCLIDES

The beta skin dose from depleted uranium should consider only the contributions from ^{234m}Pa and ^{234}Th in secular equilibrium.

SKIN THICKNESS

The VARSKIN default skin thickness of 0.007 cm should be used for situations in which the skin thickness is unknown. When appropriate, the skin thickness values given in Table 7 may be used.

CONTAMINATED AREA

If possible, the actual size of the contaminated area should be determined. If the exact size of the contaminated area cannot be accurately determined, the guidelines outlined in Table 9 should be used for measurement with Y-12 GM survey instruments (i.e., GM counters with associated electronic equipment).

Table 9. Guidelines for estimating the size of contaminated skin
with a 20-cm² GM survey instrument

Contaminated area	Guidelines for estimating contaminated area
Smaller than the size of the probe ($< 20 \text{ cm}^2$)	Assume that the contaminated area of the skin is 20 cm^2
Larger than the size of the probe ($>20 \text{ cm}^2$)	Assume that the contaminated area of the skin is 100 cm^2
Larger than 100 cm^2	Estimate the contaminated area of the skin as closely as possible

If a gas proportional counter with a 100-cm² detector surface area is used to determine the size of the contaminated area, the guidelines outlined in Table 10 should be used.

**Table 10. Guidelines for estimating the size of contaminated skin
with a 100-cm² gas proportional counter survey instrument**

Contaminated area	Guidelines for estimating contaminated area
Smaller than the size of the probe ($<100\text{ cm}^2$)	Assume that the contaminated area of the skin is 100 cm^2
Larger than the size of the probe ($>100\text{ cm}^2$)	Estimate the contaminated area of the skin as closely as possible

SOURCE STRENGTH

When the Health Physics technician is reporting the contamination source strength, the maximum disintegration rate obtained from the survey instrument should be given. This number will be the maximum net counts per minute (cpm) seen with the survey instrument during survey of the skin, divided by the instrument detection efficiency. If the technician normalizes the activity to 100 cm^2 , this information must then be provided to the dosimetrist, along with the size of the contaminated area.

For the GM survey instruments at the Y-12 Plant, a 16.7% efficiency is assumed. To obtain the disintegration rate from the instrument count rate, the count rate should be multiplied by 6 ($1 \div 0.167$) and the result reported in disintegrations per minute. Because the Y-12 Plant's GM counters have a window with a 1.7-mg/cm^2 density thickness as well as a plastic "alpha discriminator" with approximately a 7-mg/cm^2 density thickness, the beta emissions from ^{234}Th cannot penetrate into the active area of the detector. Therefore, the disintegration rate obtained from the GM counter is the disintegration rate for $^{234\text{m}}\text{Pa}$ only.

The gas proportional counters in use at Y-12 have a window density thickness of only 0.9 mg/cm^2 (an alpha efficiency of approximately 20% and a ^{90}Sr beta efficiency of approximately 44%). This window density thickness will allow entry and detection of both the ^{234}Th betas and the $^{234\text{m}}\text{Pa}$ beta. Therefore, the disintegration rate obtained from the gas proportional counter is the sum of the disintegration rates of both ^{234}Th and $^{234\text{m}}\text{Pa}$. As can be seen, it is important to note the type of instrument used to measure the level of skin contamination. (Gas proportional counters measure either alpha radiations only or alpha and beta radiations together. The beta activity must be obtained by subtracting the disintegration rate at the "alpha" operating voltage from the disintegration rate obtained at the "alpha + beta" operating voltage.)

EXPOSURE TIME

The exposure time should be recorded by using conservative but reasonable estimates. As previously stated, if the time at which the skin became contaminated is unknown, the technician should assume that the contamination has been present on the skin since the person last began working with radioactive material (or entered a contaminated area) or since the last time a personnel contamination survey was conducted (either by Health Physics personnel or upon egress from a contaminated area). Judgment should be used in determining the appropriate exposure duration. After each successive decontamination effort, the remaining contamination level, as well as the exposure duration at that level, must be recorded. This is best achieved by recording the time of each survey and each decontamination effort.

DERIVATION OF TRIGGER LEVELS FOR SKIN DOSE ASSESSMENT

DEPLETED-URANIUM CONTAMINATION MEASURED WITH A GM SURVEY INSTRUMENT

The DOE RadCon Manual, Article 541.5 (ref. 2), states that the levels of skin contamination that trigger the need for dose assessments should be established for site-specific radionuclides and that these trigger levels should not exceed 100 mrem. In order to establish these trigger levels, several assumptions must be made. The following tabulation lists assumptions that will be used to determine the 100-mrem skin-dose-assessment trigger level for depleted-uranium skin contamination measured with a GM survey instrument at the Y-12 Plant:

Radionuclide	^{234m}Pa and ^{234}Th (in equilibrium) (Note: Only ^{234m}Pa betas are detected with the Y-12 Plant GM survey instrument.)
Skin thickness	0.007 cm
Size of contaminated area	20 cm ²
Exposure time	2 h
VARSKIN dose conversion factors for a 20-cm ² contaminated area with the dose averaged over a 1-cm ² area	^{234m}Pa : 21 mrem/h per 100,000 dpm ^{234}Th : 2 mrem/h per 100,000 dpm

Hence, for equal amounts of activity covering 20 cm², the dose resulting from the ^{234m}Pa beta is 10.25 times that of the ²³⁴Th betas. Therefore, if ^{234m}Pa and ²³⁴Th are present in equal amounts and deliver a combined dose of 100 mrem, the contribution from the ^{234m}Pa beta must be approximately 91 mrem and that from the ²³⁴Th betas about 9 mrem. To incorporate the reporting requirements of DOE Order 5480.11 and DOE N 5480.6 into the trigger level for a 20-cm² contaminated area, the dose averaged over the 1 cm² of skin receiving the maximum dose must be reduced by the fraction (f) that is the size of the contaminated area divided by 100 cm². Therefore,

$$\text{Reported dose of 91 mrem of } ^{234m}\text{Pa} = \text{dose averaged over 1 cm}^2 \frac{20 \text{ cm}^2}{100 \text{ cm}^2}, \quad (8)$$

and

$$\text{Dose averaged over 1 cm}^2 = \frac{\text{reported dose of 91 mrem}}{0.2} = 455 \text{ mrem}. \quad (9)$$

The contamination trigger level corresponding to a 455-mrem ^{234m}Pa skin dose averaged over a 1-cm² area (20-cm² contaminated skin area) is

$$\begin{aligned} \text{Trigger level} &= \frac{\text{dose averaged over 1 cm}^2 \text{ of skin}}{\text{exposure duration (h)} \times \text{dose conversion factor (mrem/h per 100,000 dpm)}} \\ &= \frac{455 \text{ mrem}}{2 \text{ h} \frac{21 \text{ mrem/h}}{100,000 \text{ dpm}}} \\ &= 1,083,333 \text{ dpm}. \end{aligned} \quad (10)$$

With the use of the previously defined assumptions, the contamination level that will correspond to a 100-mrem skin dose, reported with a GM survey instrument, is 1,083,333 dpm of ^{234m}Pa beta activity.

DEPLETED-URANIUM CONTAMINATION MEASURED WITH A GAS PROPORTIONAL COUNTER SURVEY INSTRUMENT

A list of assumptions that will be used to determine the 100-mrem skin-dose-assessment trigger level for depleted-uranium skin contamination measured with a gas proportional counter at the Y-12 Plant follows.

Radionuclide	^{234m}Pa and ^{234}Th (in equilibrium) (Note: Both ^{234m}Pa betas and ^{234}Th betas are detected with the Y-12 Plant gas proportional counter survey instrument.)
Skin thickness	0.007 cm
Size of contaminated area	100 cm ²
Exposure time	2 h
VARSKIN dose conversion factors for a 100-cm ² contaminated area with the dose averaged over a 1-cm ² area	^{234m}Pa : 41 mrem/h per 1,000,000 dpm ^{234}Th : 4 mrem/h per 1,000,000 dpm $^{234m}\text{Pa} + ^{234}\text{Th}$: 45 mrem/h per 2,000,000 dpm

To incorporate the reporting requirements of DOE Order 5480.11 and DOE N 5480.6 into the trigger level for a 100-cm² contaminated area, the dose averaged over the 1 cm² of skin receiving the maximum dose must be reported. Therefore,

$$\text{Dose averaged over 1 cm}^2 = 100 \text{ mrem} . \quad (11)$$

The contamination trigger level corresponding to a 100-mrem $^{234m}\text{Pa} + ^{234}\text{Th}$ skin dose averaged over a 1-cm² area (100-cm² contaminated skin area) is

$$\begin{aligned}
 \text{Trigger level} &= \frac{\text{dose averaged over 1 cm}^2 \text{ of skin}}{\text{exposure duration (h)} \times \text{dose conversion factor (mrem/h per 2,000,000 dpm)}} \\
 &= \frac{100 \text{ mrem}}{2 \text{ h} \frac{45 \text{ mrem/h}}{2,000,000 \text{ dpm}}} \\
 &\approx 2,220,000 \text{ dpm} .
 \end{aligned} \quad (12)$$

With the use of the previously defined assumptions, the contamination level that will correspond to a 100-mrem skin dose, reported with a gas proportional counter survey instrument, is approximately 2,220,000 dpm of beta activity.

ENRICHED-URANIUM CONTAMINATION

Because the primary hazard from enriched uranium (EU) is alpha radioactivity, the resulting beta skin dose is negligible. For EU process areas, not exceeding the alpha personnel contamination limits ensures that the beta personnel contamination limits have not been exceeded. Thus, the need to routinely survey EU workers for beta contamination is eliminated. Therefore, the levels of skin contamination that trigger the need for beta dose assessments for EU contamination must be based on alpha contamination levels. A list of assumptions that will be used to determine the 100-mrem skin-dose-assessment trigger level for EU skin contamination at the Y-12 Plant follows:

Radionuclides	^{234m}Pa and ^{234}Th (in equilibrium with ^{238}U) ^{231}Th (in equilibrium with ^{235}U)
Skin thickness	0.007 cm
Size of contaminated area	20 cm ²
Exposure time	2 h
EU isotopic abundances	93% ^{235}U , 6% ^{238}U , 1% ^{234}U
^{234m}Pa	21 mrem/h per 100,000 dpm
^{234}Th	2 mrem/h per 100,000 dpm
^{238}U	23 mrem/h per 100,000 dpm (from ^{234m}Pa + ^{234}Th betas)
^{231}Th	5 mrem/h per 100,000 dpm
^{235}U	5 mrem/h per 100,000 dpm (^{231}Th betas)
Specific activity of ^{238}U	0.333 $\mu\text{Ci/g} \approx 7.39 \times 10^5$ dpm/g
Specific activity of ^{235}U	2.14 $\mu\text{Ci/g} \approx 4.75 \times 10^6$ dpm/g

The alpha specific activity of EU (93% ^{235}U) is

$$\text{Alpha specific activity} = (0.4 + 0.38 E + 0.0034 E^2) 10^{-6} \text{ Ci/g} , \quad (13)$$

where $E = \text{wt } \% {}^{235}\text{U}$. [Equation (13) was taken from the *Health Physics Manual of Good Practices for Uranium Facilities*.⁹]

The specific activity of EU is 65.1 $\mu\text{Ci/g}$ ($\approx 1.45 \times 10^8 \text{ dpm/g}$). The ${}^{235}\text{U}$ alpha activity component in EU is calculated by

$$\begin{aligned}
 \frac{\text{dpm } {}^{235}\text{U}}{\text{dpm EU}} &= \frac{\text{specific activity of } {}^{235}\text{U}}{\text{specific activity of EU}} \frac{\text{g of } {}^{235}\text{U}}{\text{g of EU}} \\
 &\approx \frac{4.75 \times 10^6 \frac{\text{dpm } {}^{235}\text{U}}{\text{g of } {}^{235}\text{U}}}{1.45 \times 10^8 \frac{\text{dpm EU}}{\text{g of EU}}} \frac{93 \text{ g of } {}^{235}\text{U}}{100 \text{ g of EU}} \\
 &\approx 0.030 \frac{\text{dpm } {}^{235}\text{U}}{\text{dpm EU}} \\
 &\approx 3.0 \times 10^3 \frac{\text{dpm } {}^{235}\text{U}}{100,000 \text{ dpm EU}} .
 \end{aligned} \tag{14}$$

Likewise, for ${}^{238}\text{U}$,

$$\begin{aligned}
 \frac{\text{dpm } {}^{238}\text{U}}{\text{dpm EU}} &\approx \frac{7.39 \times 10^5 \frac{\text{dpm } {}^{238}\text{U}}{\text{g of } {}^{238}\text{U}}}{1.45 \times 10^8 \frac{\text{dpm EU}}{\text{g of EU}}} \frac{6 \text{ g of } {}^{238}\text{U}}{100 \text{ g of EU}} \\
 &\approx 3.06 \times 10^{-4} \frac{\text{dpm } {}^{238}\text{U}}{\text{dpm EU}} \\
 &\approx 30.6 \frac{\text{dpm } {}^{238}\text{U}}{100,000 \text{ dpm EU}} .
 \end{aligned} \tag{15}$$

Therefore, the beta skin dose conversion factor for EU is

$$\begin{aligned}
 \frac{\beta \text{ mrem/h}}{100,000 \text{ dpm EU}} &\approx \left[\left(3 \times 10^3 \frac{\text{dpm } {}^{235}\text{U}}{100,000 \text{ dpm EU}} \right) \left(5 \frac{\text{mrem/h}}{100,000 \text{ dpm } {}^{235}\text{U}} \right) \right] \\
 &\quad + \left[\left(30.6 \frac{\text{dpm } {}^{238}\text{U}}{100,000 \text{ dpm EU}} \right) \left(23 \frac{\text{mrem/h}}{100,000 \text{ dpm } {}^{238}\text{U}} \right) \right] \\
 &\approx 0.157 \frac{\text{mrem/h}}{100,000 \text{ dpm EU}} .
 \end{aligned} \tag{16}$$

To incorporate the reporting requirements of DOE Order 5480.11 and DOE N 5480.6 into the trigger level for a 20-cm² contaminated area, the dose averaged over the 1 cm² of skin receiving the maximum dose must be reduced by the fraction (*f*) that is the size of the contaminated area divided by 100 cm². Therefore,

$$\text{Reported dose of 100 mrem} = \text{dose averaged over 1 cm}^2 \frac{20 \text{ cm}^2}{100 \text{ cm}^2}, \quad (17)$$

and

$$\text{Dose averaged over 1 cm}^2 = \frac{\text{reported dose of 100 mrem}}{0.2} = 500 \text{ mrem}. \quad (18)$$

The alpha contamination trigger level corresponding to a 500-mrem beta skin dose averaged over a 1-cm² area (20-cm² contaminated skin area) is

$$\begin{aligned} \text{Trigger level} &= \frac{\text{dose averaged over 1 cm}^2 \text{ of skin}}{\text{exposure duration (h)} \times \text{dose conversion factor (mrem/h per 100,000 dpm)}} \\ &\approx \frac{500 \text{ mrem}}{2 \text{ h} \frac{0.157 \text{ mrem/h}}{100,000 \text{ dpm}}} \\ &= 159,236,000 \text{ dpm}. \end{aligned} \quad (19)$$

With the use of the previously defined assumptions, the EU alpha contamination level that will correspond to a 100-mrem beta skin dose is approximately 159,236,000 dpm.

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APPENDIX

SAMPLE VARSKIN DATA FILE

Program VARSKIN

MOD 1

Disc Source with Radius = .56420 cm
Skin Thickness = .00700 cm

SOURCE

Radionuclide : Pa-234M
Average Beta Energy (MeV) : .864
X-90 Distance (cm) : .5178
Srce Strength, microCi/cm2 : 4.50E-03

Irradiation time = 3600. sec.

All cell damage occurs in an area with radius = 1.496 cm

Beta Dose averaged over an area of Skin
at the Basal Layer:

Radius (cm)	Area (cm2)	Beta Dose (rem)
-----	-----	-----
.5642	1.0000	.036
1.4962	7.0329	.006

Calculated Beta Doses at Points
on the Skin Basal Layer:

Horizontal Distance (cm)	Beta Dose (rem)
.0000	.041
.0451	.041
.0901	.041
.1724	.041
.2468	.040
.3134	.040
.3722	.039
.4231	.037
.4662	.034
.5015	.034
.5289	.032
.5485	.027
.5603	.022
.5642	.019
.5707	.015
.5901	.009
.6225	.005
.6678	.003
.7260	.002
.7972	.001
.8813	.000
.9784	.000
1.0885	.000
1.2114	.000
1.3474	.000
1.4962	.000

Program VARSKIN
MOD 1

Disc Source with Radius = .56420 cm
Skin Thickness = .00700 cm

SOURCE

Radionuclide : Th-234
Average Beta Energy (MeV) : .043
X-90 Distance (cm) : .0094
Srce Strength, microCi/cm2 : 4.50E-03

Irradiation time = 3600. sec.

All cell damage occurs in an area with radius = .580 cm

Beta Dose averaged over an area of Skin
at the Basal Layer:

Radius (cm)	Area (cm2)	Beta Dose (rem)
-----	-----	-----
.5642	1.0000	.004
.5796	1.0554	.004

Calculated Beta Doses at Points
on the Skin Basal Layer:

Horizontal Distance (cm)	Beta Dose (rem)
.0000	.004
.5488	.004
.5513	.004
.5535	.004
.5555	.004
.5574	.004
.5590	.003
.5603	.003
.5615	.003
.5625	.003
.5632	.002
.5638	.002
.5641	.002
.5642	.002
.5643	.002
.5646	.002
.5652	.002
.5659	.001
.5669	.001
.5681	.001
.5694	.001
.5710	.000
.5729	.000
.5749	.000
.5771	.000
.5796	.000

Program VARSKIN
MOD 1

Disc Source with Radius = .56420 cm
Skin Thickness = .00700 cm

SOURCE

Radionuclide : Th-231
Average Beta Energy (MeV) : .065
X-90 Distance (cm) : .0267
Srce Strength, microCi/cm2 : 4.50E-03

Irradiation time = 3600. sec.

All cell damage occurs in an area with radius = .612 cm

Beta Dose averaged over an area of Skin
at the Basal Layer:

Radius (cm)	Area (cm2)	Beta Dose (rem)
-----	-----	-----
.5642	1.0000	.009
.6117	1.1757	.008

Calculated Beta Doses at Points
on the Skin Basal Layer:

Horizontal Distance (cm)	Beta Dose (rem)
.0000	.010
.5167	.010
.5242	.010
.5312	.010
.5375	.010
.5431	.009
.5480	.009
.5523	.009
.5559	.008
.5589	.008
.5612	.006
.5629	.006
.5639	.005
.5642	.005
.5645	.005
.5655	.004
.5672	.003
.5695	.002
.5725	.001
.5761	.001
.5804	.000
.5853	.000
.5909	.000
.5972	.000
.6042	.000
.6117	.000

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