Sandia National Laboratories

National Nuclear Security Administration

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An Updated Comprehensive Risk Analysis for Radioisotopes of Concern

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WHAT was the background?

Understanding GTRI…

"Global Threat Reduction Initiative"

- **Multi-agency Program:**

Under directives of the U.S. Department of Energy (DOE) and the National Nuclear Security Administration (NNSA)

- **GTRI Mission:**

To reduce and protect vulnerable nuclear and radiological materials located at civilian sites worldwide, preventing the unauthorized acquisition of nuclear and radiological materials for possible use in weapons of mass destruction/disruption (WMDs) as well as other acts of terrorism.

WHAT was the background?

Understanding GTRI…

"Global Threat Reduction Initiative"

- **Three Sub-Programs of GTRI:**

1. Convert (HEU to LEU Worldwide)
2. Remove (HEU and High Activity Sources)
3. Protect (Physical Protection Systems Internationally and Domestically)

WHAT was the background?

This Work Directly falls within the "Protection Program"

To provide support for the on-going protection of materials of concern.

The Goal?

Developed an updated global survey of radioactive source production evaluated using the 5-Point downselection methodology to identify new possible radioisotopes of concern for use in dose projection modeling using standard EPA TEDE PAG levels versus 10 CFR 20 worker dose limits to guide the implementation of protective actions in an emergency scenario, such as relocation.

HOW was this achieved?

In FOUR Sub-Sections:

1. Completion of the Global Source Production Survey
2. Update to the Radiological Source Down-Selection Methodology
3. Characterization of the determined radioisotopes of concern using Dose Projection Modeling software known as “Turbo FRMAC” (*Federal Radiological Monitoring and Assessment Center*) using 4 calculation methodologies
4. Comparison of data collected from Dose Projection Models from all four calculation methodologies to analyze the effectiveness of current relocation policy guidance.

SECTION 1: Global Source Survey

WHERE are all the sources?

And **WHAT** are they?

SECTION 1: Global Source Survey

What was done in the PAST

What has been done in the PRESENT

SECTION 1: Global Source Survey

2008

Sandia Report for unlimited release :

SAND2008-8252, "Survey of Radioactive Sources and Commerce"

(Gorenz and Rhodes 2008)

Globally Identified…

- *6 Major Manufacturers and Suppliers*
- *15 Secondary Manufacturers and Suppliers*
- *11 Original Equipment Manufacturers*

PAST

SECTION 1: Global Source Survey

2008 *Issues…*

FOCUS & SCOPE

MISSION &

¿INCONCLUSIVE DATA?

PAST

SECTION 1: Global Source Survey

CURRENT <u>Updated "Global Source Survey"</u>

An attempt to more completely identify…

- *All sites of interest per country*

(Government Agencies, Universities, Companies)

- *Facilities within each site*

(Reactors, Cyclotrons, Accelerators identified as source producers)

- *Sources manufactured within these facilities*
- *Significant site sources*

(HEU / Pu-239 powered reactors, Co-60 /Cs-137 fueled sterilization plants)

- *Major distributors*

(Those known to handle most global source inventory)

PRESENT

SECTION 1: Global Source Survey

Governmental Departments
(Ex. Energy, Defense,etc.)

Regulatory Institutions
(Ex. NRC,etc.)

Research Sites
- Academic Institutions
- Weapons/Defense Research
- Medical Research Institutions, etc.

Industrial Sites
- Radiopharmaceutical Plants
- Sealed Source Plants for Medical/Industrial
- Irradiation Plants for Food and/or Medical
- Technology Plants - Electronics
- Weaponry Component Plants, etc.
- Key Global Source Distributors

Reactors | **Accelerators** | **Cyclotrons**

Additional Facilities
- Fuel Storage and/or Source Storage
- Fuel Reprocessing and/or Separation

Identification of Site Sources → **Identification of Manufactured Sources**

PRESENT

SECTION 1: Global Source Survey

The Outcome…

- Determination of the market sectors that drive radioisotope source production, use and distribution
- Determined Support of 5 Industries within 2 Market Sectors:

1. Government Sector
   a. Research and Development
   b. Defense
2. Government Sector
   a. Industrial
   b. Medical
   c. Power

PRESENT

SECTION 1: Global Source Survey

The Outcome…

1. **Government Sector (Research & Development and Defense)**

- Production within 51 countries on all continents
- Completed Government Source Producers Guide

- 127 sites and source producing facilities were identified
-149 unique radioisotopes produced across these site facilities identified

PRESENT

SECTION 1: Global Source Survey

Sample – Government Source Producers from R&D and Defense

COUNTRY	FACILITY	LOCATION	UNIT	RADIOISOTOPE	QUANTITIES Up To (per SOURCE Unless Specified)
Algeria	Nuclear Research Center of Birine Commisariat A L'Energie Atomique	Birine, Algeria	ES-SALAM	Various Radioisotopes	NK
	Centre de Dévélopement des Techniques Nucléaires	Argel, Algeria	NUR	Various Radioisotopes	2,100 GBq Annual Total
Argentina	Atomic Cneter of the National Atomic Energy Commission, Comision Nacional de Energia Atomica (CNEA)	Buenos Aires, Argentina	RA-1	Cr-51 Ir-192 Sm-153 I-131 Mo-99	851,000 GBq Annual Total
	Ezeiza Atomic Center (EAC), Comision Nacional de Energia Atomica (CNEA)	Buenos Aires, Argentina	RA-3	Co-60 Mo-99	14,000 Ci/Source NK
	INVAP, Comision Nacional de Energia Atomica (CNEA)	Bariloche, Argentina	RA-6	Au-198 Br-82 I-131 Ir-192 Mo-99 Sm-153	2,0000 GBq Annual Total
	Pilcaniyeu Technology Center, Comision Nacional de Energia Atomica (CNEA)	Rio Nigro, Argentina	RA-8	Ar-41 Au-198 Br-82	NK NK NK

SECTION 1: Global Source Survey

The Outcome…

1. **Government Sector (Research & Development and Defense)**

➢ Unique radioisotopes and a simplified marker for availability in the market for each determined by analysis of the complete Government Source Production Guide

"Government Source Availability" table created with each unique radioisotope produced in these sectors represented, along with the maximum source activity and frequency of occurrence for each radioisotope indicated.

PRESENT

SECTION 1: Global Source Survey

The Outcome…

1. Government Sector (Research & Development and Defense)

Sample of "Government Source Availability"

RADIOISOTOPE	QUANTITIES UP TO (per SOURCE Unless Specified)	OCCURRENCE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE Unless Specified)	OCCURRENCE
Ir-192	> 1000 Ci	42	Au-198	100's mCi	16
I-131	4,000 Ci (Weekly)	38	Lu-177	80 Ci	15
Co-60	14,000 Ci	33	Na-24	100's mCi	15
Mo-99	2500 Ci (Weekly)	27	Ar-41	100's mCi	13
Tc-99	100's mCi	25	Ho-166	10,000 Ci	13
Sm-153	< 8.6 Ci	23	Cr-51	mCi	12
HEU*	N/A	20	Br-82	100's mCi	11
Pu-239	~ 61.3 mCi	20	Re-186	10,000 Ci	9
P-32	< 10 mCi	19	P-33	> 4300 Ci	8
I-125	1200 mCi	18	Y-90	NK	8

PRESENT

SECTION 1: Global Source Survey

The Outcome…

1. **Government Sector (Research & Development and Defense)**

➢ Higher levels of occurrence in the Government Source Availability Table were analyzed as higher availabilities of a radioisotope within the sector.

"Government Sources by Availability" was then created from those sources of highest availability (indicated by an occurrence of 5 or greater in the Government Source Availability Table), or those with an "Availability Score" correspondingly assigned from these occurrence levels from "1 to 33," with "1" being the number one, most readily available radioisotope found in the survey.

PRESENT

SECTION 1: Global Source Survey

The Outcome…

1. Government Sector (Research & Development and Defense)

Sample of "Government Sources By Availability"

AVAILABILITY SCORE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE Unless Specified)	OCCURRENCE
1	Ir-192	> 1000 Ci	42
2	I-131	4,000 Ci (Weekly)	38
3	Co-60	14,000 Ci	33
4	Mo-99	2500 Ci (Weekly)	27
5	Tc-99	100's mCi	25
6	Sm-153	< 8.6 Ci	23
7	HEU*	N/A	20
8	Pu-239	~ 61.3 mCi	20
9	P-32	< 10 mCi	19
10	I-125	1200 mCi	18
11	Au-198	100's mCi	16
12	Lu-177	80 Ci	15
13	Na-24	100's mCi	15
14	Ar-41	100's mCi	13
15	Ho-166	10,000 Ci	13
16	Cr-51	mCi	12
17	Br-82	100's mCi	11

AVAILABILITY SCORE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE Unless Specified)	OCCURRENCE
18	Re-186	10,000 Ci	9
19	P-33	> 4300 Ci	8
20	Y-90	NK	8
21	Fe-59	>1 mCi	7
22	Sb-124	NK	7
23	Xe-133	NK	7
24	Re-188	5 mCi	6
25	Sc-46	mCi	6
26	W-188	5 Ci	6
27	Cs-137	40 Ci	5
28	Hg-203	mCi	5
29	La-140	NK	5
30	Mn-56	100's mCi	5
31	S-35	5 mCi	5
32	Se-75	1 mCi	5
33	Sr-89	NK	5

"NK" is used to indicate where source activities are "Not Known."

* In use in reactor

SECTION 1: Global Source Survey

The Outcome…

2. **Commercial Sector (Medical, Industrial, Power)**

➢ Completed Commercial Sector – Over 500 corporations documented

➢ Used MAJOR corporations only for analysis; indicated by inclusion in International Source Suppliers and Producers Association (ISSPA) - **said to represent more than 95% of all commercial radioactive source producers globally (ISSPA 2012).**

SECTION 1: Global Source Survey

Sample – Commercial Source Producers from Industrial, Medical & Power

COUNTRY	COMPANY	LOCATION	RADIOISOTOPE	QUANTITIES Up To (per SOURCE Unless Specified)
Argentina	Dioxitek - Comision Nacional de Energia Atomica	Cordoba / Buenos Aires, Argentina	Co-60 UO_2	NK NK
	INVAP	Bariloche, Argentina	Co-60 Cr-51 I-125 I-131 Ir-192 Mo-99 Tc-99m	NK NK NK NK NK NK NK
Belgium	Institute for Radioelements (IRE)	Fleurus, Belgium	I-131 Mo-99 Y-90	> 4.3 Ci 0.5 Ci > 1.5 Ci
	Institute for Radioelements Environmental & Lifestyle Technologies (IRE ELiT)	Fleurus, Belgium	Re-188 W-188 Y-90	1.5 Ci 1.5 Ci > 1.5 Ci
Canada	CANBERRA (Sourced from Eckert & Ziegler, Isotrak and LEA, AREVA subsidiary)	USA France UK Canada Belgium Netherlands Luxemborg	Ba-133 Cd-109 Co-57 Co-60 Cs-137 Eu-152 Mn-54	10 uCi 10 uCi 25 uCi 1 uCi 10 uCi 0.1 uCi 10 uCi

SECTION 1: Global Source Survey

The Outcome…

2. Commercial Sector (Industry, Medical and Power)

- Same availability rankings used by "occurrence" (as in Government sector) to indicate those radioisotopes of highest availability
- 144 unique radioisotope cut down to 32 based on occurrence of 5 or more

Top Commercial Sources by Availability Table created with each unique radioisotope produced in these sectors represented, and maximum source activity and frequency of occurrence for each radioisotope indicated.

SECTION 1: Global Source Survey

The Outcome…

2. Commercial Sector (Industrial, Medical, Power)

Sample of "Top Commercial Sources By Availability"

AVAILABILITY SCORE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE)	OCCURRENCE
1	Co-60	14,250 Ci	28
2	Cs-137	2.2 kCi	17
3	I-125	250 Ci	16
4	I-131	30 Ci	13
5	Ir-192	500 Ci	12
6	Co-57	100 mCi	11
7	Pd-103	15 Ci	9
8	Tc-99	87.5 Ci	9
9	Se-75	150 Ci	8
10	Am-241	18,000 mCi	7
11	Ba-133	30 mCi	7
12	C-14	300 mCi	7
13	Cd-109	1 Ci	7
14	Fe-55	3 Ci	7
15	Mo-99	87.5 Ci	7
16	Na-22	10 mCi	7
17	P-32	1 Ci	7

AVAILABILITY SCORE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE)	OCCURRENCE
18	Ru-106	2 mCi	7
19	Y-90	> 500 Ci	7
20	Zn-65	10 mCi	7
21	Cr-51	> 100 mCi	6
22	Gd-153	3 Ci	6
23	Ni-63	2 Ci	6
24	S-35	1 Ci	6
25	Sr-85	10 mCi	6
26	Cf-252	6.5 Ci	5
27	Eu-152	20 mCi	5
28	Kr-85	30 Ci	5
29	Mn-54	2 mCi	5
30	P-33	> 1 Ci	5
31	Sr-89	500 mCi	5
32	Sr-90	50 mCi	5

SECTION 1: Global Source Survey

The Outcome…

Sample of "Top Government *and* Commercial Sources by Availability"

AVAILABILITY SCORE	RADIOISOTOPE	QUANTITIES UP TO (per SOURCE)	OCCURRENCE
1	**Co-60**	14,250 Ci	61
2	**Ir-192**	> 1000 Ci	54
3	**I-131**	30 Ci	51
4	**I-125**	250 Ci	50
5	**Mo-99**	87.5 Ci	34
6	**Tc-99**	87.5 Ci	34
7	**P-32**	1 Ci	26
8	**Sm-153**	< 8.6 Ci	23
9	**Cs-137**	2.2 kCi	22
10	**HEU***	N/A	20
11	**Pu-239**	~ 61.3 mCi	20

SECTION 2: Updated Downselection

What is the Downselection…

After determining the isotopes most readily available globally based on the Global Source Survey, these sources were subjected to the Radioactive Material Downselection…

"[A method to] identify, prioritize, and determine threshold quantities of radioactive materials that could be … of national security significance."

SECTION 2: Updated Downselection

Basics of the Downselection…

1. Start with the complete, current Chart of Nuclides,
2. Remove all non-radioactive nuclides,
3. Eliminate additional radionuclides based on certain physical and chemical characteristics such as half-life, etc.,
4. Utilize the availability of sources as ascertained in the Updated Source Production Survey to eliminate radionuclides remaining that have not been deemed readily available,
5. Eliminate any radioisotopes remaining on the list that were not documented to be available with activities of at least 0.1 Ci for alpha emitters or 1 Ci for beta and gamma emitters.

SECTION 2: Updated Downselection

Downselection Results…

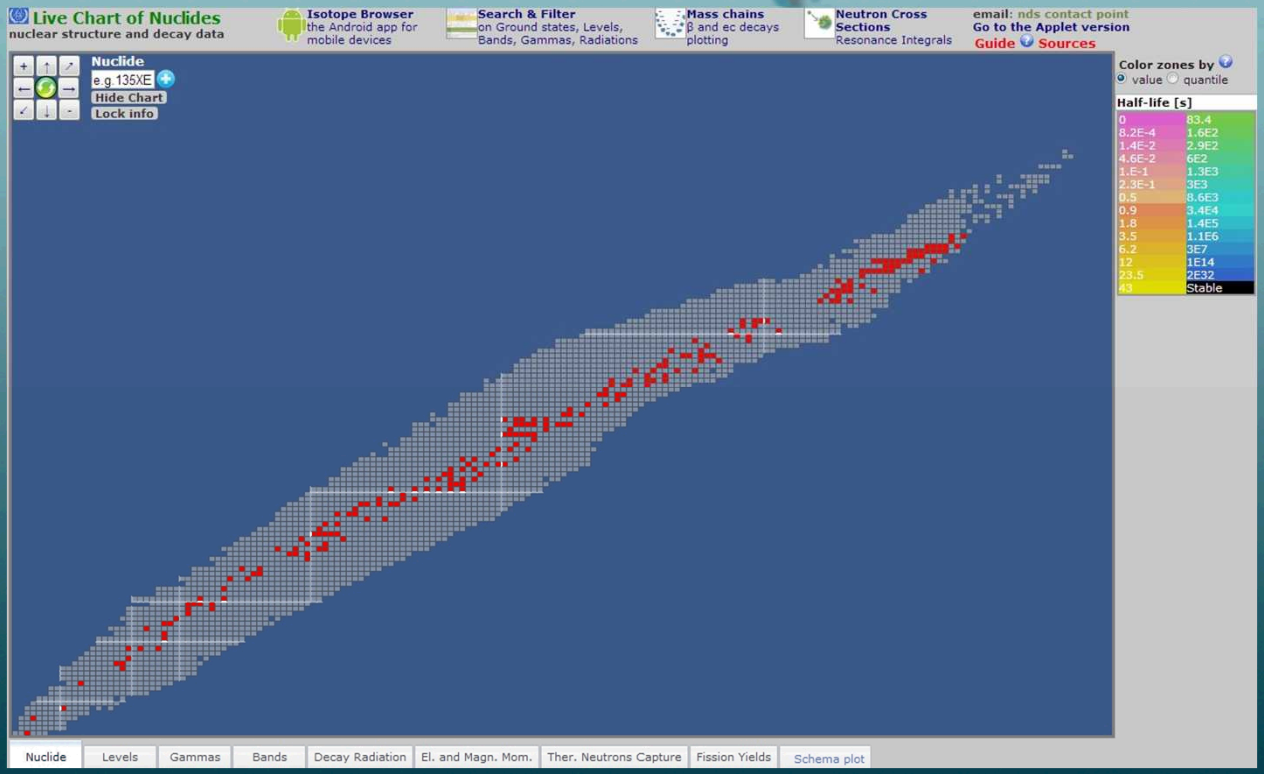
To begin, a live Table of Nuclides presented by the IAEA was used known as “Live Chart”

Here the Table was filtered to take account of the half-life and specific activity parameters specified in the downselection leaving only radioactive isotopes within the guidelines for consideration as potential radioisotopes of concern…

SECTION 2: Updated Downselection

Downselection Results…

"Live Chart" Filtering…



SECTION 2: Updated Downselection

Downselection Results…

The filtered Live Chart application listed 227 potential radioisotopes of concern for comparison to the compiled radioisotope availability data.

Those listed by Live Chart that were not found to be readily available (or included in the finalized “Top Government and Commercial Source by Availability Table) in the global source survey were eliminated leaving only those fitting the filtering parameters and with high availability for consideration as a potential radioisotope of concern.

These were compiled in the “Possible Radioisotopes of Concern Table”…

SECTION 2: Updated Downselection

Downselection Results…

Sample of "Possible Radioisotopes of Concern"

RADIOISOTOPE	QUANTITIES UP TO (per SOURCE)	OCCURRENCE
Co-60	14,250 Ci	61
Ir-192	> 1000 Ci	54
I-131	30 Ci	51
I-125	250 Ci	50
P-32	1 Ci	26
Cs-137	2.2 kCi	22
Pu-239	~ 61.3 mCi	20
Cr-51	> 100 mCi	18
Lu-177	80 Ci	15
Ho-166	10,000 Ci	13
P-33	> 4300 Ci	13
Se-75	150 Ci	13
Co-57	100 mCi	11
S-35	1 Ci	11

SECTION 2: Updated Downselection

Downselection Results…

These results were then further refined by emission types for each of the listed possible radioisotopes of concern to determine if the activities listed fit the parameters to indicate them as a finalized radioisotope of concern (0.1 Ci for alphas and 1 Ci for betas and gammas).

The finalized list can be seen in the “Finalized Radioisotopes of Concern” Table.

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SECTION 2: Updated Downselection

Downselection Results…

"Finalized Radioisotopes of Concern"

RADIOISOTOPE	QUANTITIES UP TO (per SOURCE)	MODE OF DECAY
Am-241	18,000 mCi	α
Cd-109	1 Ci	γ
Cf-252	6.5 Ci	α
Co-60	14,250 Ci	β
Cs-137	2.2 kCi	β
Fe-55	3 Ci	γ
Gd-153	3 Ci	γ
Ho-166	10,000 Ci	β
I-125	250 Ci	γ
I-131	30 Ci	β
Ir-192	> 1000 Ci	β
Kr-85	30 Ci	β
Lu-177	80 Ci	β
Ni-63	2 Ci	β
P-32	1 Ci	β
P-33	> 4300 Ci	β
Pd-103	15 Ci	γ
S-35	1 Ci	β
Se-75	150 Ci	γ
W-188	5 Ci	β

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Turbo FRMAC Basics

- Dose Projection modeling software suite developed by Sandia National Laboratory – Turbo FRMAC
  - More advanced and accurate modeling scheme
- Urban RDD characterization – uses weathering and roughness factors to model “real world” urban scenarios
  - Takes into account numerous exposure pathways

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Turbo FRMAC Pathway Analysis Methods

- 2 Pathway Method = Ground Contamination (Groundshine and Resuspension – no plume exposure)
- 4 Pathway Method = Ground + Airborne Contamination (Includes those above as well as plume exposures from plume inhalation and submersion)

Turbo FRMAC Configuration Settings for 2 Pathway versus 4 Pathway Calculations

SETTING	2 PATHWAY CONFIGURATION	4 PATHWAY CONFIGURATION
Category	Public Protection	"
Calculation	Projected Public Dose	"
Date/Time Mode	Time After Release	"
Time Phase Chart	Easrly Phase = 96 hrs, First Year = 365 days, Second Year = from day 365 to day 730, Fifty Years = from day 0 to 1.825×10^4 days	"
Radionuclide Mixture	Each Radioisotope of concern individually	"
Dose Pathway	Two-Pathway	Four-Pathway
Units	Activity per Units	"
Auto-Fill Daughter Values	Yes (Bateman Equations)	"
ICRP Guidance	ICRP 60	"
Commitment Period	Chronic	"
Breathing Rate	Default Settings (Table)	"
Ground Roughness Factor	Default (0.82)	"
Minimum Particle Size	Dependent on Radioisotope of Interest based on ERAD Model: Υ – 2 µm, β – 2 µm, α – 2 µm	"
Maximum Particle Size	Dependent on Radioisotope of Interest based on ERAD Model: Υ – 200 µm, β – 250 µm, α – 100 µm	"
Respirable Fraction	Dependent on Radioisotope of Interest based on ERAD Model: Υ – 0.5, β – 0.1, α – 0.35	"
Non-Respirable Fraction	Dependent on Radioisotope of Interest based on ERAD Model: Υ – 0.5, β – 0.9, α – 0.65	"
Geometric Std. Deviation	Dependent on Radioisotope of Interest based on ERAD Model: Υ – 3, β – 3, α – 3	"
KI Administration	No	"
Resuspension Factor	Default, Maxwell-Anspaugh Method	"
Weathering Factor	Default, Maxwell Method	"
Inhalation Coefficient Basis	Default, Lognormal	"
Lung Clearance Class	Default, Maximum	"

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

DRL – Derived Response Limit

An activity per square area for each radionuclide, that, if measured following a radiation exposure, would indicate that the limit for the particular radioisotope had been reached resulting in the enactment of specified emergency response actions.

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Modeling and Dose Limits…

EPA TEDE PAGs

In previous studies, the dose guidance used to characterize scenarios using radionuclides of concern were based on the EPA/DHS Protective Action Guide, which recommends the relocation of a population exposed at certain levels for certain time phases after exposure (starting at deposition of material – no plume exposure included; 2-Pathway Method).

Early Phase – 1 rem (0-96 hrs)

1st Year – 2 rem

2nd Year – 0.5 rem

50 Year – 5 rem *All Whole Body TEDE

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Modeling and Dose Limits…

10 CFR 20's CEDE Limit

This was contrasted by using the TEDE and CDE organ dose limits as identified in 10 CFR 20, or an intake that would result in a TEDE of 5 rem (whole body), or 50 rem CDE to any individual organ or tissue over a 50 year period following the intake from an exposure, as well as their lifetime correlation of 5 times any of these limits in 50 years to define DRL's.

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Modeling and Dose Limits…

These settings were then used to determine the DRL for each time phase using each radioisotope of interest, followed by the determination of the official, most limiting, DRL chosen from these calculated DRL's for each isotope of interest using the EPA TEDE PAG levels for each time phase (1 rem in the early phase, 2 rem in the first year, 0.5 rem in the second year, and 5 rem in fifty years (United States Environmental Protection Agency, 1992)), followed by the using 10 CFR 20 CEDE Worker Limits.

Activity per Unit Area DRLs for All Radioisotopes of Concern Using Std. EPA TEDE PAG Levels, 2 Pathway Model

2-Pathway Calculations	Early Phase, 1 rem Whole Body TEDE	1st Year, 2 rem Whole Body TEDE	2nd Year, 0.5 rem Whole Body TEDE	50 Year, 5 rem Whole Body TEDE
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}			
Am-241	8.31E+03	4.00E+03	1.07E+05	9.09E+03
Cd-109	2.51E+07	1.64E+06	8.93E+05	2.07E+06
Cf-252	2.14E+04	8.93E+03	2.17E+04	1.64E+04
Co-60	4.13E+05	8.73E+05	3.50E+03	4.73E+03
Cs-137	1.68E+06	4.20E+04	1.24E+04	6.58E+03
Fe-55	4.55E+08	2.22E+08	1.32E+10	5.52E+08
Gd-153	9.82E+06	3.92E+05	3.26E+05	6.79E+05
I-125	2.02E+07	2.67E+06	5.73E+07	6.61E+06
I-131	2.94E+06	1.75E+06	5.87E+17	4.38E+06
Ir-192	1.25E+06	1.00E+05	8.93E+05	2.43E+05
Kr-85	9.09E+07	2.24E+06	6.93E+05	6.04E+05
Lu-177	3.50E+07	2.40E+07	1.74E+23	6.01E+07
Ni-63	1.08E+09	5.21E+08	2.17E+10	1.29E+09
P-32	1.18E+07	4.31E+06	6.33E+13	1.08E+07
P-33	7.65E+08	4.65E+08	3.58E+13	1.16E+09
Pd-103	1.12E+08	3.58E+07	3.31E+13	8.96E+07
S-35	7.68E+08	3.83E+08	2.58E+10	9.54E+08
Se-75	2.69E+06	1.49E+05	3.61E+05	3.35E+05
W-188	6.04E+06	5.35E+05	6.07E+06	1.31E+06

Official DRL Values for 2-Pathway Calculations Using EPA TEDE PAG Guidelines

2-Pathway Calculations Following EPA TEDE PAG Levels	
Radioisotope	DRL, nCi m^{-2} ±0.01 nCi m^{-2}
Am-241	4.00E+03
Cd-109	8.93E+05
Cf-252	8.93E+03
Co-60	3.50E+03
Cs-137	6.58E+03
Fe-55	2.22E+08
Gd-153	3.26E+05
I-125	2.67E+06
I-131	1.75E+06
Ir-192	1.00E+05
Kr-85	6.04E+05
Lu-177	2.40E+07
Ni-63	5.21E+08
P-32	4.31E+06
P-33	4.65E+08
Pd-103	3.58E+07
S-35	3.83E+08
Se-75	1.49E+05
W-188	5.35E+05

Activity per Unit Area DRLs for All Radioisotopes of Concern Using 10 CFR 20 Worker Limits, 2 Pathway Model

2-Pathway Calculations	1st Yr. Whole Body TEDE, 5 rem	50 Yr. Whole Body TEDE, 25 rem	1st Yr. Adrenal CDE, 50 rem	50 Yr. Adrenal CDE, 250 rem	1st Yr. Bladder CDE, 50 rem	50 Yr. Bladder CDE, 250 rem	1st Yr. Bone Surface CDE, 50 rem	50 Yr. Bone Surface CDE, 250 rem	1st Yr. Brain CDE, 50 rem	50 Yr. Brain CDE, 250 rem	1st Yr. Breast CDE, 50 rem	50 Yr. Breast CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	1.00E+04	4.55E+04	1.30E+06	6.41E+06	1.30E+06	6.41E+06	2.21E+03	1.09E+04	1.30E+06	6.41E+06	1.30E+06	6.41E+06
Cf-252	2.23E+04	8.22E+04	3.52E+07	1.75E+08	1.79E+08	8.87E+08	6.87E+03	3.42E+04	9.88E+07	4.92E+08	1.39E+08	6.91E+08
Co-60	2.64E+04	2.37E+04	9.62E+08	4.77E+09	1.15E+09	5.71E+09	1.18E+09	5.84E+09	1.61E+09	8.01E+09	1.49E+09	7.35E+09
Cs-137	1.05E+05	3.29E+04	9.23E+08	4.56E+09	8.96E+08	4.43E+09	9.40E+08	4.65E+09	1.10E+09	5.41E+09	1.15E+09	5.71E+09
I-131	4.38E+06	2.19E+07	5.48E+11	2.74E+12	3.87E+10	1.93E+11	1.88E+11	9.40E+11	1.68E+11	8.39E+11	4.45E+11	2.22E+12
Ir-192	2.50E+05	1.21E+06	3.37E+09	1.69E+10	5.68E+09	2.84E+10	5.19E+09	2.59E+10	7.76E+09	3.89E+10	7.51E+09	3.75E+10
Kr-85	5.61E+06	3.02E+06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	6.01E+07	3.00E+08	1.53E+12	7.67E+12	3.71E+11	1.86E+12	2.56E+09	1.28E+10	2.07E+12	1.03E+13	3.35E+12	1.67E+13
Ni-63	1.30E+09	6.44E+09	1.35E+10	6.68E+10	1.29E+10	6.38E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10
P-32	1.08E+07	5.39E+07	3.82E+09	1.91E+10	3.03E+09	1.52E+10	8.62E+08	4.31E+09	3.69E+09	1.85E+10	2.92E+10	1.46E+11
P-33	1.16E+09	5.81E+09	1.68E+11	8.39E+11	7.00E+10	3.50E+11	1.16E+10	5.79E+10	1.68E+11	8.39E+11	1.68E+11	8.39E+11
S-35	9.58E+08	4.77E+09	1.66E+11	8.33E+11	5.52E+10	2.76E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11
W-188	1.34E+06	6.54E+06	1.07E+11	5.36E+11	1.32E+10	6.61E+10	6.67E+09	3.33E+10	1.25E+11	6.25E+11	1.13E+11	5.66E+11
Cd-109	4.11E+06	1.03E+07	1.82E+09	9.12E+09	3.41E+09	1.70E+10	2.34E+09	1.17E+10	3.23E+09	1.61E+10	3.36E+09	1.68E+10
Fe-55	5.56E+08	2.76E+09	2.02E+10	1.01E+11	2.02E+10	1.00E+11	2.90E+09	1.44E+10	2.02E+10	1.01E+11	2.02E+10	1.01E+11
Gd-153	9.80E+05	3.40E+06	3.43E+09	1.71E+10	2.83E+10	1.41E+11	9.36E+07	4.68E+08	1.53E+10	7.67E+10	2.12E+10	1.06E+11
I-125	6.68E+06	3.31E+07	2.27E+11	1.14E+12	8.56E+10	4.28E+11	7.27E+10	3.64E+11	3.56E+11	1.78E+12	1.87E+11	9.33E+11
Pd-103	8.96E+07	4.48E+08	7.18E+11	3.59E+12	3.21E+11	1.60E+12	2.71E+11	1.35E+12	3.04E+12	1.52E+13	3.36E+12	1.68E+13
Se-75	3.74E+05	1.68E+06	2.59E+09	1.29E+10	6.79E+09	3.40E+10	4.30E+06	2.15E+07	9.73E+09	4.86E+10	9.16E+09	4.58E+10

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2-Pathway Calculations	1st Yr. Stomach CDE, 50 rem	50 Yr. Stomach CDE, 250 rem	1st Yr. Small Intestine CDE, 50 rem	50 Yr. Small Intestine CDE, 250 rem	1st Yr. UL Intestine CDE, 50 rem	50 Yr. UL Intestine CDE, 250 rem	1st Yr. LL Intestine CDE, 50 rem	50 Yr. LL Intestine CDE, 250 rem	1st Yr. Kidneys CDE, 50 rem	50 Yr. Kidneys CDE, 250 rem	1st Yr. Liver CDE, 50 rem	50 Yr. Liver CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	1.30E+06	6.41E+06	1.30E+06	6.41E+06	1.30E+06	6.41E+06	1.30E+06	6.41E+06	4.31E+05	2.13E+06	3.60E+04	1.78E+05
Cf-252	1.07E+08	5.30E+08	7.65E+07	3.80E+08	6.68E+07	3.32E+08	6.65E+07	3.31E+08	5.39E+07	2.68E+08	7.12E+04	3.53E+05
Co-60	1.20E+09	5.92E+09	1.02E+09	5.02E+09	9.43E+08	4.68E+09	8.01E+08	3.97E+09	1.07E+09	5.30E+09	5.26E+08	2.61E+09
Cs-137	9.80E+08	4.84E+09	9.23E+08	4.58E+09	8.99E+08	4.45E+09	7.79E+08	3.85E+09	9.62E+08	4.75E+09	9.54E+08	4.72E+09
I-131	8.87E+10	4.43E+11	3.47E+10	1.73E+11	8.45E+09	4.22E+10	3.32E+09	1.66E+10	4.77E+11	2.39E+12	4.93E+11	2.47E+12
Ir-192	4.56E+09	2.28E+10	4.11E+09	2.05E+10	2.51E+09	1.25E+10	1.17E+09	5.87E+09	7.62E+08	3.81E+09	7.51E+08	3.75E+09
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	1.88E+11	9.40E+11	7.58E+10	3.79E+11	1.40E+10	6.98E+10	5.31E+09	2.65E+10	2.76E+11	1.38E+12	2.50E+11	1.25E+12
Ni-63	1.34E+10	6.61E+10	1.32E+10	6.51E+10	1.18E+10	5.84E+10	9.47E+09	4.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10
P-32	1.58E+10	7.91E+10	2.17E+10	1.09E+11	6.76E+09	3.38E+10	2.77E+09	1.38E+10	2.92E+10	1.46E+11	2.92E+10	1.46E+11
P-33	1.03E+11	5.14E+11	1.36E+11	6.79E+11	4.60E+10	2.30E+11	1.91E+10	9.54E+10	1.68E+11	8.39E+11	1.68E+11	8.39E+11
S-35	1.28E+11	6.38E+11	1.07E+11	5.36E+11	1.79E+10	8.93E+10	6.16E+09	3.08E+10	1.66E+11	8.28E+11	1.66E+11	8.28E+11
W-188	2.84E+09	1.42E+10	1.55E+10	7.76E+10	1.60E+09	8.01E+09	4.73E+08	2.36E+09	2.51E+09	1.26E+10	1.29E+10	6.48E+10
Cd-109	3.10E+09	1.54E+10	3.00E+09	1.50E+10	2.65E+09	1.32E+10	2.12E+09	1.06E+10	2.23E+07	1.12E+08	1.23E+08	6.10E+08
Fe-55	2.02E+10	1.00E+11	2.00E+10	9.92E+10	1.87E+10	9.26E+10	1.62E+10	8.06E+10	2.02E+10	1.01E+11	2.36E+09	1.17E+10
Gd-153	1.17E+10	5.84E+10	8.71E+09	4.34E+10	5.79E+09	2.89E+10	4.30E+09	2.15E+10	4.21E+09	2.10E+10	3.40E+08	1.70E+09
I-125	1.89E+11	9.47E+11	8.96E+10	4.48E+11	2.50E+10	1.25E+11	9.80E+09	4.90E+10	4.89E+11	2.45E+12	1.74E+11	8.68E+11
Pd-103	3.18E+11	1.59E+12	1.24E+11	6.19E+11	2.29E+10	1.15E+11	8.42E+09	4.21E+10	7.25E+09	3.62E+10	1.32E+10	6.61E+10
Se-75	4.51E+09	2.26E+10	4.58E+09	2.29E+10	4.19E+09	2.10E+10	5.18E+09	2.59E+10	7.46E+08	3.73E+09	1.02E+09	5.10E+09

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2-Pathway Calculations	1st Yr. Lung CDE, 50 rem	50 Yr. Lung CDE, 250 rem	1st Yr. Muscle CDE, 50 rem	50 Yr. Muscle CDE, 250 rem	1st Yr. Ovaries CDE, 50 rem	50 Yr. Ovaries CDE, 250 rem	1st Yr. Pancreas CDE, 50 rem	50 Yr. Pancreas CDE, 250 rem	1st Yr. Bone Marrow CDE, 50 rem	50 Yr. Bone Marrow CDE, 250 rem	1st Yr. Skin CDE, 50 rem	50 Yr. Skin CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	1.45E+05	7.18E+05	1.30E+06	6.41E+06	1.14E+05	5.61E+05	1.30E+06	6.41E+06	6.51E+04	3.21E+05	1.30E+06	6.41E+06
Cf-252	1.26E+05	6.22E+05	9.80E+07	4.88E+08	8.68E+05	4.31E+06	5.22E+07	2.59E+08	8.56E+04	4.25E+05	1.54E+08	7.67E+08
Co-60	1.82E+08	9.06E+08	1.32E+09	6.54E+09	1.01E+09	5.02E+09	9.58E+08	4.75E+09	1.26E+09	6.22E+09	1.88E+09	9.33E+09
Cs-137	1.14E+08	5.66E+08	1.03E+09	5.08E+09	9.06E+08	4.48E+09	8.99E+08	4.45E+09	9.84E+08	4.88E+09	1.21E+09	5.98E+09
I-131	4.36E+09	2.18E+10	1.95E+11	9.77E+11	7.91E+10	3.96E+11	4.28E+11	2.14E+12	2.50E+11	1.25E+12	3.72E+11	1.86E+12
Ir-192	5.66E+08	2.83E+09	6.07E+09	3.03E+10	4.78E+09	2.39E+10	3.37E+09	1.69E+10	5.49E+09	2.75E+10	8.22E+09	4.11E+10
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	5.80E+09	2.90E+10	1.94E+12	9.69E+12	8.71E+11	4.36E+12	1.88E+12	9.40E+12	3.10E+10	1.55E+11	3.03E+12	1.52E+13
Ni-63	3.51E+09	1.74E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10
P-32	1.55E+09	7.76E+09	2.92E+10	1.46E+11	2.92E+10	1.46E+11	2.92E+10	1.46E+11	2.36E+09	1.18E+10	2.92E+10	1.46E+11
P-33	2.05E+09	1.02E+10	1.68E+11	8.39E+11	1.68E+11	8.39E+11	1.68E+11	8.39E+11	3.09E+10	1.55E+11	1.68E+11	8.39E+11
S-35	1.70E+09	8.56E+09	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11
W-188	2.54E+08	1.27E+09	1.20E+11	6.01E+11	9.92E+10	5.56E+11	1.10E+11	5.51E+11	1.81E+10	9.06E+10	1.30E+11	6.51E+11
Cd-109	1.66E+08	8.28E+08	2.92E+09	1.46E+10	3.19E+09	1.59E+10	2.57E+09	1.28E+10	3.45E+09	1.72E+10	3.45E+09	1.72E+10
Fe-55	7.89E+09	3.92E+10	2.02E+10	1.01E+11	2.02E+10	1.01E+11	2.02E+10	1.01E+11	1.52E+09	7.58E+09	2.02E+10	1.01E+11
Gd-153	4.98E+08	2.49E+09	1.26E+10	6.28E+10	1.05E+10	5.23E+10	4.69E+09	2.34E+10	9.58E+08	4.79E+09	2.60E+10	1.30E+11
I-125	4.92E+09	2.46E+10	8.90E+10	4.45E+11	1.17E+11	5.87E+11	4.36E+11	2.18E+12	3.70E+11	1.85E+12	3.45E+11	1.72E+12
Pd-103	4.41E+09	2.20E+10	1.50E+12	7.49E+12	5.58E+11	2.79E+12	1.68E+12	8.39E+12	7.79E+11	3.89E+12	3.08E+12	1.54E+13
Se-75	1.18E+09	5.90E+09	6.58E+09	3.29E+10	5.07E+13	2.53E+10	2.14E+09	1.07E+10	5.72E+09	2.86E+10	1.07E+10	5.36E+10

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2-Pathway Calculations	1st Yr. Spleen CDE, 50 rem	50 Yr. Spleen CDE, 250 rem	1st Yr. Testes CDE, 50 rem	50 Yr. Testes CDE, 250 rem	1st Yr. Thymus - Esophagus CDE, 50 rem	50 Yr. Thymus - Esophagus CDE, 250 rem	1st Yr. Thyroid CDE, 50 rem	50 Yr. Thyroid CDE, 250 rem	1st Yr. Uterus CDE, 50 rem	50 Yr. Uterus CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}									
Am-241	1.30E+06	6.41E+06	1.15E+05	5.66E+05	1.30E+06	6.41E+06	1.30E+06	6.41E+06	1.30E+06	6.41E+06
Cf-252	1.19E+08	5.92E+08	8.74E+05	4.36E+06	1.22E+08	6.07E+08	1.38E+08	6.87E+08	1.18E+08	5.87E+08
Co-60	1.20E+09	5.92E+09	1.40E+09	6.91E+09	1.26E+09	6.22E+09	1.30E+09	6.41E+09	1.05E+09	5.19E+09
Cs-137	9.62E+08	4.75E+09	1.03E+09	5.10E+09	9.84E+08	4.86E+09	9.88E+08	4.88E+09	8.96E+08	4.43E+09
I-131	5.10E+11	2.55E+12	7.27E+11	3.63E+12	1.59E+11	7.96E+11	6.78E+07	3.39E+08	1.71E+11	8.56E+11
Ir-192	8.80E+08	4.40E+09	7.27E+09	3.63E+10	6.30E+09	3.15E+10	6.68E+09	3.34E+10	5.25E+09	2.63E+10
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	2.40E+12	1.20E+13	3.14E+12	1.57E+13	2.34E+12	1.17E+13	2.31E+12	1.16E+13	1.38E+12	6.91E+12
Ni-63	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10	1.35E+10	6.68E+10
P-32	2.92E+10	1.46E+11	2.92E+10	1.46E+11	2.92E+10	1.46E+11	2.92E+10	1.46E+11	2.92E+10	1.46E+11
P-33	1.68E+11	8.39E+11	1.68E+11	8.39E+11	1.68E+11	8.39E+11	1.68E+11	8.39E+11	1.68E+11	8.39E+11
S-35	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11	1.66E+11	8.28E+11
W-188	2.91E+09	1.46E+10	1.30E+11	6.51E+11	1.04E+11	5.21E+11	1.89E+09	9.47E+09	1.15E+11	5.73E+11
Cd-109	2.14E+09	1.06E+10	3.32E+09	1.66E+10	3.23E+09	1.61E+10	3.23E+09	1.61E+10	3.19E+09	1.59E+10
Fe-55	6.83E+08	3.40E+09	2.02E+10	1.01E+11	2.02E+10	1.01E+11	2.02E+10	1.01E+11	2.02E+10	1.01E+11
Gd-153	1.74E+10	8.68E+10	6.81E+10	3.40E+11	1.85E+10	9.19E+10	2.40E+10	1.20E+11	1.75E+10	8.74E+10
I-125	2.66E+11	1.33E+12	5.36E+11	2.69E+12	2.43E+11	1.21E+12	4.10E+07	2.05E+08	4.18E+11	2.09E+12
Pd-103	1.30E+12	6.48E+12	3.36E+12	1.68E+13	3.21E+12	1.61E+13	3.26E+12	1.63E+13	2.76E+12	1.38E+13
Se-75	2.38E+09	1.19E+10	6.13E+09	3.06E+10	7.00E+09	3.50E+10	7.69E+09	3.85E+10	5.68E+09	2.84E+10

Official DRL Values for 2-Pathway Calculations Using 10 CFR 20 Worker Does Limits

2-Pathway Calculations Following 10 CFR 20 Worker Dose Limits	
Radioisotope	DRL, nCi m^{-2} ±0.01 nCi m^{-2}
Am-241	2.21E+03
Cd-109	4.11E+06
Cf-252	6.87E+03
Co-60	2.37E+04
Cs-137	3.29E+04
Fe-55	5.56E+08
Gd-153	9.80E+05
I-125	6.68E+06
I-131	4.38E+06
Ir-192	2.50E+05
Kr-85	3.02E+06
Lu-177	6.01E+07
Ni-63	1.30E+09
P-32	1.08E+07
P-33	1.16E+09
Pd-103	8.96E+07
S-35	9.58E+08
Se-75	3.74E+05
W-188	1.34E+06

Activity per Unit Area DRLs for All Radioisotopes of Concern Using Std. EPA TEDE PAG Levels, 4 Pathway Model

4-Pathway Calculations	Early Phase 1 rem Whole Body TEDE	1st Year 2 rem Whole Body TEDE	2nd Year 0.5 rem Whole Body TEDE	50 Year 5 rem Whole Body TEDE
Radioisotope	Activity per Unit Area, nCi m^{-2} ± 0.01 nCi m^{-2}			
Am-241	4.59E+01	9.01E+01	1.07E+05	2.25E+02
Cd-109	2.44E+05	3.79E+05	8.93E+05	7.72E+05
Cf-252	1.20E+02	2.34E+02	2.17E+04	5.80E+02
Co-60	1.85E+05	1.04E+04	3.50E+03	4.73E+03
Cs-137	2.55E+05	3.92E+04	1.24E+04	6.54E+03
Fe-55	2.53E+06	4.95E+06	1.32E+10	1.24E+07
Gd-153	8.68E+05	3.25E+05	3.26E+05	5.95E+05
I-125	1.01E+06	1.19E+06	5.73E+07	2.96E+06
I-131	6.94E+05	8.93E+05	5.87E+17	2.23E+06
Ir-192	5.71E+05	9.52E+04	8.93E+05	2.31E+05
Kr-85	9.09E+07	2.19E+06	6.93E+05	6.04E+05
Lu-177	3.94E+06	6.45E+06	1.74E+23	1.61E+07
Ni-63	5.98E+06	1.18E+07	2.17E+10	2.94E+07
P-32	1.29E+06	1.73E+06	6.33E+13	4.32E+06
P-33	4.13E+06	8.20E+06	3.58E+13	2.05E+07
Pd-103	6.78E+06	1.03E+07	3.31E+13	2.57E+07
S-35	4.24E+06	8.33E+06	2.58E+10	2.08E+07
Se-75	1.01E+06	1.43E+05	3.61E+05	3.22E+05
W-188	4.95E+05	3.58E+05	6.07E+06	8.80E+05

Official DRL Values for 4-Pathway Calculations Using EPA TEDE PAG Guidelines

4-Pathway Calculations Following EPA TEDE PAG Levels	
Radioisotope	DRL, nCi m^{-2} ±0.01 nCi m^{-2}
Am-241	4.59E+01
Cd-109	2.44E+05
Cf-252	1.20E+02
Co-60	3.50E+03
Cs-137	6.54E+03
Fe-55	2.53E+06
Gd-153	3.25E+05
I-125	1.01E+06
I-131	6.94E+05
Ir-192	9.52E+04
Kr-85	6.04E+05
Lu-177	3.94E+06
Ni-63	5.98E+06
P-32	1.29E+06
P-33	4.13E+06
Pd-103	6.78E+06
S-35	4.24E+06
Se-75	1.43E+05
W-188	3.58E+05

Activity per Unit Area DRLs for All Radioisotopes of Concern Using 10 CFR 20 Worker Limits, 4 Pathway Model

4-Pathway Calculations	1st Yr. Whole Body TEDE, 5 rem	50 Yr. Whole Body TEDE, 25 rem	1st Yr. Adrenal CDE, 50 rem	50 Yr. Adrenal CDE, 250 rem	1st Yr. Bladder CDE, 50 rem	50 Yr. Bladder CDE, 250 rem	1st Yr. Bone Surface CDE, 50 rem	50 Yr. Bone Surface CDE, 250 rem	1st Yr. Brain CDE, 50 rem	50 Yr. Brain CDE, 250 rem	1st Yr. Breast CDE, 50 rem	50 Yr. Breast CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	2.25E+02	1.13E+03	2.93E+04	1.46E+05	2.93E+04	1.47E+05	5.00E+01	2.50E+02	2.93E+04	1.47E+05	2.93E+04	1.47E+05
Cf-252	5.85E+02	2.90E+03	7.84E+05	3.92E+06	3.97E+06	1.99E+07	1.53E+02	7.67E+02	2.21E+06	1.11E+07	3.10E+06	1.55E+07
Co-60	2.60E+04	2.36E+04	2.16E+07	1.08E+08	2.59E+07	1.29E+08	2.64E+07	1.32E+08	3.63E+07	1.81E+08	3.33E+07	1.66E+08
Cs-137	9.80E+04	3.27E+04	2.08E+07	1.04E+08	2.02E+07	1.01E+08	2.12E+07	1.06E+08	2.48E+07	1.24E+08	2.60E+07	1.30E+08
I-131	2.23E+06	1.12E+07	1.80E+10	8.99E+10	1.28E+09	6.38E+09	6.19E+09	3.09E+10	5.54E+09	2.77E+10	1.46E+10	7.31E+10
Ir-192	2.38E+05	1.16E+06	6.68E+07	3.34E+08	1.13E+08	5.63E+08	1.02E+08	5.12E+08	1.54E+08	7.72E+08	1.49E+08	7.44E+08
Kr-85	5.61E+06	3.02E+06	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	1.61E+07	8.06E+07	1.40E+10	6.98E+10	3.39E+09	1.69E+10	2.34E+07	1.17E+08	1.89E+10	9.47E+10	3.05E+10	1.53E+11
Ni-63	2.94E+07	1.47E+08	3.05E+08	1.52E+09	2.91E+08	1.46E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09
P-32	4.32E+06	2.16E+07	3.88E+08	1.94E+09	1.52E+08	7.62E+08	3.14E+07	1.57E+08	3.88E+08	1.94E+09	3.88E+08	1.94E+09
P-33	2.05E+07	1.02E+08	2.71E+09	1.35E+10	1.13E+09	5.66E+09	1.88E+08	9.40E+08	2.71E+09	1.35E+10	2.71E+09	1.35E+10
S-35	2.08E+07	1.04E+08	3.34E+09	1.67E+10	1.11E+09	5.56E+09	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10
W-188	8.96E+05	4.40E+06	2.10E+09	1.05E+10	2.59E+08	1.30E+09	1.31E+08	6.54E+08	2.45E+09	1.23E+10	2.21E+09	1.11E+10
Cd-109	9.47E+05	3.86E+06	4.03E+07	2.01E+08	7.51E+07	3.75E+08	5.15E+07	2.58E+08	7.12E+07	3.56E+08	7.42E+07	3.71E+08
Fe-55	1.24E+07	6.19E+07	4.51E+08	2.26E+09	4.50E+08	2.25E+09	6.46E+07	3.23E+08	4.51E+08	2.26E+09	4.51E+08	2.26E+09
Gd-153	8.12E+05	2.98E+06	7.42E+07	3.71E+08	6.11E+08	3.06E+09	2.03E+06	1.02E+07	3.31E+08	1.66E+09	4.57E+08	2.29E+09
I-125	2.97E+06	1.48E+07	1.40E+10	6.98E+10	5.26E+09	2.63E+10	4.47E+09	2.24E+10	2.19E+10	1.10E+11	1.14E+10	5.71E+10
Pd-103	2.57E+07	1.29E+08	1.02E+10	5.10E+10	4.55E+09	2.28E+10	3.84E+09	1.92E+10	4.31E+10	2.16E+11	4.76E+10	2.38E+11
Se-75	3.58E+05	1.61E+06	5.36E+07	2.68E+08	1.41E+08	7.06E+08	8.90E+07	4.45E+08	2.02E+08	1.01E+09	1.89E+08	9.47E+08

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4-Pathway Calculations	1st Yr. Stomach CDE, 50 rem	50 Yr. Stomach CDE, 250 rem	1st Yr. Small Intestine CDE, 50 rem	50 Yr. Small Intestine CDE, 250 rem	1st Yr. UL Intestine CDE, 50 rem	50 Yr. UL Intestine CDE, 250 rem	1st Yr. LL Intestine CDE, 50 rem	50 Yr. LL Intestine CDE, 250 rem	1st Yr. Kidneys CDE, 50 rem	50 Yr. Kidneys CDE, 250 rem	1st Yr. Liver CDE, 50 rem	50 Yr. Liver CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	2.93E+04	1.47E+05	2.93E+04	1.47E+05	2.93E+04	1.47E+05	2.93E+04	1.46E+05	9.73E+03	4.86E+04	8.12E+02	4.06E+03
Cf-252	2.38E+06	1.19E+07	1.71E+06	8.56E+06	1.52E+06	7.44E+06	1.48E+06	7.40E+06	1.20E+06	6.01E+06	1.59E+03	7.96E+03
Co-60	2.69E+07	1.34E+08	2.27E+07	1.14E+08	2.12E+07	1.06E+08	1.80E+07	8.99E+07	2.40E+07	1.20E+08	1.18E+07	5.90E+07
Cs-137	2.21E+07	1.11E+08	2.08E+07	1.04E+08	2.03E+07	1.02E+08	1.76E+07	8.80E+07	2.16E+07	1.08E+08	2.16E+07	1.08E+08
I-131	2.91E+09	1.46E+10	1.14E+09	5.71E+09	2.78E+08	1.39E+09	1.10E+08	5.48E+08	1.57E+10	7.86E+10	1.62E+09	8.12E+09
Ir-192	9.03E+07	4.51E+08	8.12E+07	4.06E+08	4.96E+07	2.48E+08	2.34E+07	1.17E+08	1.51E+07	7.53E+07	1.49E+07	7.44E+07
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	1.71E+09	8.56E+09	6.91E+08	3.45E+09	1.28E+08	6.38E+08	4.84E+07	2.42E+08	2.52E+09	1.26E+10	2.27E+09	1.14E+10
Ni-63	3.02E+08	1.51E+09	2.98E+08	1.49E+09	2.66E+08	1.33E+09	2.14E+08	1.07E+09	3.04E+08	1.52E+09	3.05E+08	1.52E+09
P-32	2.10E+08	1.05E+09	2.89E+08	1.45E+09	8.99E+07	4.50E+08	3.68E+07	1.84E+08	3.88E+08	1.94E+09	3.88E+08	1.94E+09
P-33	1.67E+09	8.33E+09	2.19E+09	1.10E+10	7.44E+08	3.72E+09	3.08E+08	1.54E+09	2.71E+09	1.35E+10	2.71E+09	1.35E+10
S-35	2.57E+09	1.28E+10	2.17E+09	1.09E+10	3.61E+08	1.81E+09	1.24E+08	6.19E+08	3.34E+09	1.67E+10	3.34E+09	1.67E+10
W-188	5.57E+07	2.78E+08	3.05E+08	1.53E+09	3.16E+07	1.58E+08	9.29E+06	4.65E+07	4.93E+07	2.47E+08	2.54E+08	1.27E+09
Cd-109	6.83E+07	3.42E+08	6.63E+07	3.32E+08	5.83E+07	2.91E+08	4.68E+07	2.34E+08	4.92E+05	2.46E+06	2.70E+06	1.35E+07
Fe-55	4.48E+08	2.24E+09	4.45E+08	2.22E+09	4.16E+08	2.08E+09	3.61E+08	1.81E+09	4.51E+08	2.26E+09	5.26E+07	2.63E+08
Gd-153	2.53E+08	1.27E+09	1.88E+08	9.40E+08	1.25E+08	6.25E+08	9.29E+07	4.65E+08	9.09E+07	4.55E+08	7.96E+06	3.98E+07
I-125	1.16E+10	5.81E+10	5.52E+09	2.76E+10	1.53E+09	7.67E+09	6.02E+08	3.01E+09	3.01E+10	1.50E+11	1.06E+10	5.32E+10
Pd-103	4.50E+09	2.25E+10	1.76E+09	8.80E+09	3.26E+08	1.63E+09	1.20E+08	5.98E+08	1.03E+08	5.14E+08	1.88E+08	9.40E+08
Se-75	9.36E+07	4.68E+08	9.51E+07	4.75E+08	2.87E+07	1.44E+08	1.07E+08	5.36E+08	1.55E+07	7.76E+07	2.12E+07	1.06E+08

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4-Pathway Calculations	1st Yr. Lung CDE, 50 rem	50 Yr. Lung CDE, 250 rem	1st Yr. Muscle CDE, 50 rem	50 Yr. Muscle CDE, 250 rem	1st Yr. Ovaries CDE, 50 rem	50 Yr. Ovaries CDE, 250 rem	1st Yr. Pancreas CDE, 50 rem	50 Yr. Pancreas CDE, 250 rem	1st Yr. Bone Marrow CDE, 50 rem	50 Yr. Bone Marrow CDE, 250 rem	1st Yr. Skin CDE, 50 rem	50 Yr. Skin CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}											
Am-241	3.27E+03	1.64E+04	2.93E+04	1.47E+05	2.56E+03	1.28E+04	2.93E+04	1.47E+05	1.47E+03	7.35E+03	2.93E+04	1.47E+05
Cf-252	2.80E+03	1.40E+04	2.19E+06	1.10E+07	1.94E+04	9.69E+04	1.16E+06	5.81E+06	1.92E+03	9.62E+03	3.44E+02	1.72E+03
Co-60	4.09E+06	2.05E+07	2.97E+07	1.48E+08	2.27E+07	1.14E+08	2.16E+07	1.08E+08	2.82E+07	1.41E+08	4.22E+07	2.11E+08
Cs-137	2.58E+06	1.29E+07	2.31E+07	1.16E+08	2.05E+07	1.02E+08	2.03E+07	1.02E+08	2.23E+07	1.11E+08	2.72E+07	1.36E+08
I-131	1.44E+08	7.18E+08	6.41E+09	3.21E+10	2.61E+09	1.30E+10	1.41E+10	7.06E+10	8.20E+09	4.10E+10	1.23E+10	6.13E+10
Ir-192	1.12E+07	5.61E+07	1.20E+08	6.01E+08	9.47E+07	4.73E+08	6.68E+07	3.34E+08	1.09E+08	5.43E+08	1.62E+08	8.12E+08
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	5.29E+07	2.64E+08	1.77E+10	8.87E+10	7.94E+09	3.97E+10	1.71E+10	8.56E+10	2.83E+08	1.42E+09	2.77E+10	1.38E+11
Ni-63	7.91E+07	3.96E+08	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09
P-32	2.07E+07	1.03E+08	3.88E+08	1.94E+09	3.88E+08	1.94E+09	3.88E+08	1.94E+09	3.14E+07	1.57E+08	3.88E+08	1.94E+09
P-33	3.30E+07	1.65E+08	2.71E+09	1.35E+10	2.71E+09	1.35E+10	2.71E+09	1.35E+10	4.99E+08	2.50E+09	2.71E+09	1.35E+10
S-35	3.44E+07	1.72E+08	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10
W-188	4.99E+06	2.50E+07	2.36E+09	1.18E+10	1.95E+09	9.77E+09	2.17E+09	1.09E+10	3.56E+08	1.78E+09	2.56E+09	1.28E+10
Cd-109	3.66E+06	1.83E+07	6.44E+07	3.22E+08	7.04E+07	3.52E+08	5.67E+07	2.83E+08	7.60E+07	3.80E+08	7.60E+07	3.80E+08
Fe-55	1.76E+08	8.80E+08	4.51E+08	2.26E+09	4.51E+08	2.26E+09	4.51E+08	2.26E+09	3.41E+07	1.71E+08	4.51E+08	2.26E+09
Gd-153	1.08E+07	5.39E+07	2.71E+08	1.36E+09	2.25E+08	1.13E+09	1.01E+08	5.06E+08	2.07E+07	1.03E+08	5.63E+08	2.82E+09
I-125	3.03E+08	1.51E+09	5.47E+09	2.74E+10	7.23E+09	3.61E+10	2.68E+10	1.34E+11	2.27E+10	1.14E+11	2.12E+10	1.06E+11
Pd-103	6.25E+07	3.13E+08	2.12E+10	1.06E+11	7.91E+09	3.96E+10	2.38E+10	1.19E+11	1.11E+10	5.53E+10	4.36E+10	2.18E+11
Se-75	2.45E+07	1.23E+08	1.37E+08	6.83E+08	1.05E+08	5.25E+08	4.42E+07	2.21E+08	1.18E+08	5.92E+08	2.23E+08	1.12E+09

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4-Pathway Calculations	1st Yr. Spleen CDE, 50 rem	50 Yr. Spleen CDE, 250 rem	1st Yr. Testes CDE, 50 rem	50 Yr. Testes CDE, 250 rem	1st Yr. Thymus - Esophagus CDE, 50 rem	50 Yr. Thymus - Esophagus CDE, 250 rem	1st Yr. Thyroid CDE, 50 rem	50 Yr. Thyroid CDE, 250 rem	1st Yr. Uterus CDE, 50 rem	50 Yr. Uterus CDE, 250 rem
Radioisotope	Activity per Unit Area, nCi m^{-2} ±0.01 nCi m^{-2}									
Am-241	2.93E+04	1.47E+05	2.59E+03	1.28E+04	2.93E+04	1.47E+05	2.93E+04	1.47E+05	2.93E+04	1.47E+05
Cf-252	2.66E+06	1.33E+07	1.95E+04	9.77E+04	2.73E+06	1.36E+07	3.08E+06	1.54E+07	2.64E+06	1.32E+07
Co-60	2.68E+07	1.34E+08	3.13E+07	1.57E+08	2.82E+07	1.41E+08	2.91E+07	1.45E+08	2.36E+07	1.18E+08
Cs-137	2.16E+07	1.08E+08	2.31E+07	1.16E+08	2.21E+07	1.11E+08	2.23E+07	1.12E+08	2.02E+07	1.01E+08
I-131	1.68E+10	8.39E+10	2.40E+10	1.20E+11	5.24E+09	2.62E+10	2.23E+06	1.12E+07	5.63E+09	2.82E+10
Ir-192	1.75E+07	8.74E+07	1.44E+08	7.18E+08	1.25E+08	6.25E+08	1.32E+08	6.61E+08	1.04E+08	5.21E+08
Kr-85	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Lu-177	2.19E+10	1.10E+11	2.86E+10	1.43E+11	2.12E+10	1.06E+11	2.12E+10	1.06E+11	1.26E+10	6.28E+10
Ni-63	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09	3.05E+08	1.52E+09
P-32	3.88E+08	1.94E+09	3.88E+08	1.94E+09	3.88E+08	1.94E+09	3.88E+08	1.94E+09	3.88E+08	1.94E+09
P-33	2.71E+09	1.35E+10	2.71E+09	1.35E+10	2.71E+09	1.35E+10	2.71E+09	1.35E+10	2.71E+09	1.35E+10
S-35	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10	3.34E+09	1.67E+10
W-188	5.72E+07	2.86E+08	2.55E+09	1.28E+10	2.05E+09	1.02E+10	3.73E+07	1.86E+08	2.25E+09	1.13E+10
Cd-109	4.69E+07	2.35E+08	7.33E+07	3.67E+08	7.12E+07	3.56E+08	7.12E+07	3.56E+08	7.04E+07	3.52E+08
Fe-55	1.52E+07	7.62E+07	4.51E+08	2.26E+09	4.51E+08	2.26E+09	4.51E+08	2.26E+09	4.51E+08	2.26E+09
Gd-153	3.75E+08	1.88E+09	1.47E+09	7.35E+09	3.99E+08	1.99E+09	5.19E+08	2.59E+09	3.77E+08	1.89E+09
I-125	1.63E+10	8.17E+10	3.30E+10	1.65E+11	1.49E+10	7.44E+10	2.52E+06	1.26E+07	2.56E+10	1.28E+11
Pd-103	1.84E+10	9.19E+10	4.78E+10	2.39E+11	4.56E+10	2.28E+11	4.62E+10	2.31E+11	3.92E+10	1.96E+11
Se-75	4.96E+07	2.48E+08	1.28E+08	6.38E+08	1.45E+08	7.27E+08	1.59E+08	7.96E+08	1.18E+08	5.90E+08

Official DRL Values for 4-Pathway Calculations Using 10 CFR 20 Worker Does Limits

4-Pathway Calculations Following 10 CFR 20 Worker Dose Limits	
Radioisotope	DRL, nCi m^{-2} ±0.01 nCi m^{-2}
Am-241	5.00E+01
Cd-109	4.92E+05
Cf-252	1.53E+02
Co-60	2.36E+04
Cs-137	3.27E+04
Fe-55	1.24E+07
Gd-153	8.12E+05
I-125	2.52E+06
I-131	2.23E+06
Ir-192	2.38E+05
Kr-85	3.02E+06
Lu-177	1.61E+07
Ni-63	2.94E+07
P-32	4.32E+06
P-33	2.05E+07
Pd-103	2.57E+07
S-35	2.08E+07
Se-75	3.58E+05
W-188	8.96E+05

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Power to Contaminate…

Once all official DRL's have been determined for each radionuclide of concern using the EPA TEDE PAG levels or 10 CFR 20 Worker Dose limits, the Power to Contaminate, or the maximum area affected by a release of this radioactive material can be calculated.

This concept is used by the Government Accountability Office (GAO), known as the audit, evaluation and investigative arm of the United States Congress, and assumes 100 percent efficient dispersion over the calculated area of land. While this calculation is an over simplification of the dynamics of such a scenario, it offers a consistent mechanism for comparing dose limits and protective actions.

SECTION 3: Characterization of the determined radioisotopes of concern using Dose Projection Modeling software

Power to Contaminate…

$$\textit{Power to Contaminate} = \frac{\textit{Maximum Radioisotope Activity}}{\textit{TEDE PAG DRL (Activity per Area)}}$$

Where the maximum activity of the radionuclide of interest was determined from the global source survey or from IAEA maximum activity's for specific radioisotope usage – whichever is larger and is divided by the TEDE PAG DRL (Activity per Area) OR the 10 CFR 20 Worker Dose Limit DRL (also Activity per Area).

Maximum Activities for Radioisotopes of Concern for Use in Power to Contaminate Calculations

RADIOISOTOPE	SOURCE APPLICATION (International Atomic Energy Agency, 2006)	MAXIMUM ACTIVITY FOR SOURCE APPLICATION, Ci (International Atomic Energy Agency, 2006)	MAXIMUM ACTIVITY PER SOURCE, Ci (Table 11)	DETERMINED *MAXIMUM* ACTIVITY, Ci
Am-241	Calibration	2.00E+01	18	2.00E+01
Cd-109	Bone Densitometry	2.00E-02	1	1.00E+00
Cf-252	Conveyer Gauge	3.70E-02	6.5	6.50E+00
Co-60	Sterilization Irradiator	1.50E+07	14250	1.50E+07
Cs-137	Sterilization Irradiator	5.00E+06	2200	5.00E+06
Fe-55	XRF Analyzer	1.40E-01	3	3.00E+00
Gd-153	Bone Densitometry	1.50E+00	3	3.00E+00
I-125	LDR Brachytherapy	4.00E-02	250	2.50E+02
I-131	Unsealed Medical	2.00E-01	30	3.00E+01
Ir-192	Industrial Radiography	2.00E+02	1000	1.00E+03
Kr-85	Thickness Gauge	1.00E+00	30	3.00E+01
Lu-177	N/A	N/A	80	8.00E+01
Ni-63	Electron Capture Detector	2.00E-02	2	2.00E+00
P-32	Unsealed Medical	6.00E-01	1	1.00E+00
P-33	N/A	N/A	4300	4.30E+03
Pd-103	LDR Brachytherapy	3.00E-02	15	1.50E+01
S-35	N/A	N/A	1	1.00E+00
Se-75	Industrial Radiography	8.00E+01	150	1.50E+02
W-188	N/A	N/A	5	5.00E+00

Power to Contaminate Determined by 2-Pathway EPA TEDE PAG DRLs and Determined Max Activities

Radioisotope	Max. Activity Source Application / Manufacturer	Maximum Activity, nCi	DRL, nCi m^{-2} ±0.01 nCi m^{-2}	Power to Contaminate, m^2 ±0.01 m^2
Am-241	Calibration Source (International Atomic Energy Agency, 2006)	2.00E+10	4.00E+03	**5.00E+06**
Cd-109	REVISS, UK (Table 11)	1.00E+09	8.93E+05	**1.12E+03**
Cf-252	REVISS, UK (Table 11)	6.50E+09	8.93E+03	**7.28E+05**
Co-60	Sterilization Irradiator (International Atomic Energy Agency, 2006)	1.50E+16	3.50E+03	**4.29E+12**
Cs-137	Sterilization Irradiator (International Atomic Energy Agency, 2006)	5.00E+15	6.58E+03	**7.60E+11**
Fe-55	REVISS, UK (Table 11)	3.00E+09	2.22E+08	**1.35E+01**
Gd-153	REVISS, UK (Table 11)	3.00E+09	3.26E+05	**9.22E+03**
I-125	IZOTOP, Hungary (Table 11)	2.50E+11	2.67E+06	**9.35E+04**
I-131	MDS Nordion, Canada (Table 11)	3.00E+10	1.75E+06	**1.71E+04**
Ir-192	NIDC ORNL, USA (Table 11)	1.00E+12	1.00E+05	**1.00E+07**
Kr-85	REVISS, UK (Table 11)	3.00E+10	6.04E+05	**4.97E+04**
Lu-177	NIDC ORNL, USA (Table 11)	8.00E+10	2.40E+07	**3.33E+03**
Ni-63	REVISS, UK (Table 11)	2.00E+09	5.21E+08	**3.84E+00**
P-32	NTP, S. Africa (Table 11)	1.00E+09	4.31E+06	**2.32E+02**
P-33	U. of Missouri, USA (Table 11)	4.30E+12	4.65E+08	**9.24E+03**
Pd-103	MDS Nordion, Canada (Table 11)	1.50E+10	3.58E+07	**4.19E+02**
S-35	NTP, S. Africa (Table 11)	1.00E+09	3.83E+08	**2.61E+00**
Se-75	QSA Global, USA (Table 11)	1.50E+11	1.49E+05	**1.00E+06**
W-188	NIDC ORNL, USA (Table 11)	5.00E+09	5.35E+05	**9.35E+03**

Power to Contaminate Determined by 2-Pathway 10 CFR 20 Worker Dose Limit DRLs and Determined Max Activities

Radioisotope	Max. Activity Source Application / Manufacturer	Maximum Activity, nCi	DRL, nCi m^{-2} ±0.01 nCi m^{-2}	Power to Contaminate, m^2 ±0.01 m^2
Am-241	Calibration Source (International Atomic Energy Agency, 2006)	2.00E+10	2.21E+03	**9.04E+06**
Cd-109	REVISS, UK (Table 11)	1.00E+09	4.11E+06	**2.43E+02**
Cf-252	REVISS, UK (Table 11)	6.50E+09	6.87E+03	**9.46E+05**
Co-60	Sterilization Irradiator (International Atomic Energy Agency, 2006)	1.50E+16	2.37E+04	**6.34E+11**
Cs-137	Sterilization Irradiator (International Atomic Energy Agency, 2006)	5.00E+15	3.29E+04	**1.52E+11**
Fe-55	REVISS, UK (Table 11)	3.00E+09	5.56E+08	**5.40E+00**
Gd-153	REVISS, UK (Table 11)	3.00E+09	9.80E+05	**3.06E+03**
I-125	IZOTOP, Hungary (Table 11)	2.50E+11	6.68E+06	**3.74E+04**
I-131	MDS Nordion, Canada (Table 11)	3.00E+10	4.38E+06	**6.85E+03**
Ir-192	NIDC ORNL, USA (Table 11)	1.00E+12	2.50E+05	**4.00E+06**
Kr-85	REVISS, UK (Table 11)	3.00E+10	3.02E+06	**9.94E+03**
Lu-177	NIDC ORNL, USA (Table 11)	8.00E+10	6.01E+07	**1.33E+03**
Ni-63	REVISS, UK (Table 11)	2.00E+09	1.30E+09	**1.54E+00**
P-32	NTP, S. Africa (Table 11)	1.00E+09	1.08E+07	**9.28E+01**
P-33	U. of Missouri, USA (Table 11)	4.30E+12	1.16E+09	**3.70E+03**
Pd-103	MDS Nordion, Canada (Table 11)	1.50E+10	8.96E+07	**1.67E+02**
S-35	NTP, S. Africa (Table 11)	1.00E+09	9.58E+08	**1.04E+00**
Se-75	QSA Global, USA (Table 11)	1.50E+11	3.74E+05	**4.01E+05**
W-188	NIDC ORNL, USA (Table 11)	5.00E+09	1.34E+06	**3.74E+03**

Power to Contaminate Determined by 4-Pathway EPA TEDE PAG DRLs and Determined Max Activities

Radioisotope	Max. Activity Source Application / Manufacturer	Maximum Activity, nCi	DRL, nCi m^{-2} ±0.01 nCi m^{-2}	Power to Contaminate, m^2 ±0.01 m^2
Am-241	Calibration Source (International Atomic Energy Agency, 2006)	2.00E+10	4.59E+01	**4.36E+08**
Cd-109	REVISS, UK (Table 11)	1.00E+09	2.44E+05	**4.10E+03**
Cf-252	REVISS, UK (Table 11)	6.50E+09	1.20E+02	**5.43E+07**
Co-60	Sterilization Irradiator (International Atomic Energy Agency, 2006)	1.50E+16	3.50E+03	**4.29E+12**
Cs-137	Sterilization Irradiator (International Atomic Energy Agency, 2006)	5.00E+15	6.54E+03	**7.64E+11**
Fe-55	REVISS, UK (Table 11)	3.00E+09	2.53E+06	**1.19E+03**
Gd-153	REVISS, UK (Table 11)	3.00E+09	3.25E+05	**9.24E+03**
I-125	IZOTOP, Hungary (Table 11)	2.50E+11	1.01E+06	**2.47E+05**
I-131	MDS Nordion, Canada (Table 11)	3.00E+10	6.94E+05	**4.32E+04**
Ir-192	NIDC ORNL, USA (Table 11)	1.00E+12	9.52E+04	**1.05E+07**
Kr-85	REVISS, UK (Table 11)	3.00E+10	6.04E+05	**4.97E+04**
Lu-177	NIDC ORNL, USA (Table 11)	8.00E+10	3.94E+06	**2.03E+04**
Ni-63	REVISS, UK (Table 11)	2.00E+09	5.98E+06	**3.34E+02**
P-32	NTP, S. Africa (Table 11)	1.00E+09	1.29E+06	**7.78E+02**
P-33	U. of Missouri, USA (Table 11)	4.30E+12	4.13E+06	**1.04E+06**
Pd-103	MDS Nordion, Canada (Table 11)	1.50E+10	6.78E+06	**2.21E+03**
S-35	NTP, S. Africa (Table 11)	1.00E+09	4.24E+06	**2.36E+02**
Se-75	QSA Global, USA (Table 11)	1.50E+11	1.43E+05	**1.05E+06**
W-188	NIDC ORNL, USA (Table 11)	5.00E+09	3.58E+05	**1.40E+04**

Power to Contaminate Determined by 4-Pathway 10 CFR 20 Worker Dose Limit DRLs and Determined Max Activities

Radioisotope	Max. Activity Source Application / Manufacturer	Maximum Activity, nCi	DRL, nCi m^{-2} ±0.01 nCi m^{-2}	Power to Contaminate, m^2 ±0.01 m^2
Am-241	Calibration Source (International Atomic Energy Agency, 2006)	2.00E+10	5.00E+01	**4.00E+08**
Cd-109	REVISS, UK (Table 11)	1.00E+09	4.92E+05	**2.03E+03**
Cf-252	REVISS, UK (Table 11)	6.50E+09	1.53E+02	**4.24E+07**
Co-60	Sterilization Irradiator (International Atomic Energy Agency, 2006)	1.50E+16	2.36E+04	**6.35E+11**
Cs-137	Sterilization Irradiator (International Atomic Energy Agency, 2006)	5.00E+15	3.27E+04	**1.53E+11**
Fe-55	REVISS, UK (Table 11)	3.00E+09	1.24E+07	**2.42E+02**
Gd-153	REVISS, UK (Table 11)	3.00E+09	8.12E+05	**3.70E+03**
I-125	IZOTOP, Hungary (Table 11)	2.50E+11	2.52E+06	**9.93E+04**
I-131	MDS Nordion, Canada (Table 11)	3.00E+10	2.23E+06	**1.34E+04**
Ir-192	NIDC ORNL, USA (Table 11)	1.00E+12	2.38E+05	**4.20E+06**
Kr-85	REVISS, UK (Table 11)	3.00E+10	3.02E+06	**9.94E+03**
Lu-177	NIDC ORNL, USA (Table 11)	8.00E+10	1.61E+07	**4.96E+03**
Ni-63	REVISS, UK (Table 11)	2.00E+09	2.94E+07	**6.81E+01**
P-32	NTP, S. Africa (Table 11)	1.00E+09	4.32E+06	**2.32E+02**
P-33	U. of Missouri, USA (Table 11)	4.30E+12	2.05E+07	**2.10E+05**
Pd-103	MDS Nordion, Canada (Table 11)	1.50E+10	2.57E+07	**5.83E+02**
S-35	NTP, S. Africa (Table 11)	1.00E+09	2.08E+07	**4.80E+01**
Se-75	QSA Global, USA (Table 11)	1.50E+11	3.58E+05	**4.19E+05**
W-188	NIDC ORNL, USA (Table 11)	5.00E+09	8.96E+05	**5.58E+03**

Final Comparisons

After the production of models and D-Value calculations, whole body dose approximations and CEDE's were calculated using the determined radionuclides of concern and their corresponding available activities to analyze the feasibility and effectiveness of using 10 CFR 20 CEDE limits for emergency response criterion following an exposure scenario.

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