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CODE DEVELOPMENT
RCD Radiation Protection Associates

Determination of DRP Dose Coefficients

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The Focus of this Discussion

- Recommended ulceration dose threshold for internal DRPs
- Dose coefficients for stationary DRPs
  - skin surface
  - upper respiratory tract
  - small & large intestine

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Introduction

- Discrete Radioactive Particle (DRP)
  - < 1 mm in any dimension
  - insoluble in water
  - of high specific activity
- DRPs are potentially harmful
  - if on the skin [for a significant length of time]
  - if inhaled or ingested and become stuck in the upper respiratory or gastrointestinal tract [for a significant length of time]
- The harm is deterministic and generally related to ulceration or necrosis of <u>local</u> tissues

Uranium oxide from Chernobyl


Table Salt (~ 300 microns)

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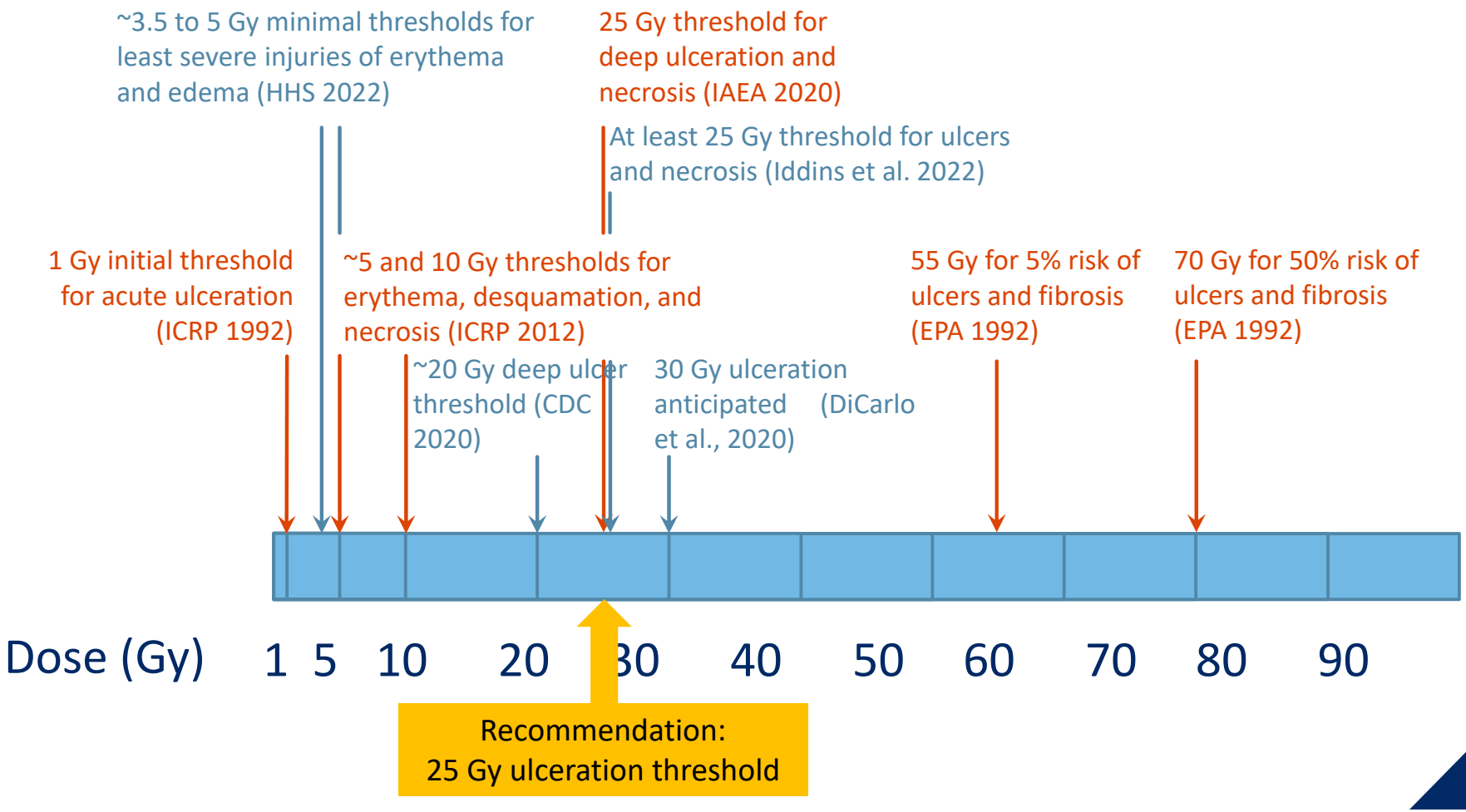
Representative Ulceration Thresholds



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Recommended Ulceration Dose Threshold

- Critical Tissue Depths
  - Upper Respiratory Tract – 45 µm
  - Small Intestine – 140 µm
  - Large Intestine – 290 µm
- Dose Averaging Area
  - 1 cm^2
- Recommended Ulceration Dose Threshold
  - 25 Gy delivered over the averaging area at the critical depth

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Dose Coefficients for DRP Exposures

- Skin Surface
  - Shallow Dose Equivalent (DE) rate
  - Deep DE rate (DDE*)
  - Effective DE rate
- Upper Respiratory Tract
  - ulceration (local) DE rate
  - EDE rate (stationary particle)
- Small & Large Intestine
  - ulceration (local) DE rate
  - EDE rate (stationary particle)
  - ingestion CEDE

Current Scope

Nuclide	Half-Life (years)	Effective Atomic Number	Density (g/cm^3)
Stellite 6		**33**	**8.4**
Co-60	5.27		
Inconel 718		**29**	**8.2**
Ni-59	76,000		
Ni-63	101		
Regulatory Concrete		**10**	**2.3**
Fe-55	2.75		
Co-60	5.27		
Ba-133	10.5		
Eu-152	13.5		
Eu-154	8.6		
Fuel Fragment		**88**	**11**
Sr-90	28.8		
Cs-137	30.1		
Eu-154	8.6		
Eu-155	4.75		
Pu-238	87.7		
Pu-239	24,000		
Pu-240	6,600		
Pu-241	14.3		
Am-241	433		
Cm-244	18.1		
Welding Rod		**74**	**19**
Th-232	14 billion		

- Five DRP materials
  - Stellite
  - Inconel
  - Concrete
  - Fuel Fragment
  - Welding Rod

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VARSKIN+ SkinDose Module

- SkinDose (classic Varskin) – originally (1987) intended for dosimetry following skin contamination by beta emitters (“hot particles”)
- Over the years, it has been redesigned to calculate alpha, beta, and gamma dose from skin and clothing contamination
- Users can specify source and exposure characteristics
  - > 1,200 nuclides; dosimetry for thin layers of tissue
- SkinDose was used to calculate dose coefficients for a DRP on the skin, in the upper respiratory tract, and in the GI tract
- The exposure conditions are essentially the same in each case except for tissue depth and averaging assumptions

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DRP on the Skin Surface

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Dose Coefficients for Skin DRP

- Particle resting on the skin surface
- Spherical source w/ diameters from 10 µm to 1,000 µm
- Bulk density and effective Z considered for self-shielding
- Shallow Dose Equivalent (SDE)
  - tissue depth of 70 µm; 10 cm^2 averaging
- Deep Dose Equivalent (DDE*)
  - tissue depth of 1 cm; 10 cm^2 averaging
- Effective Dose Equivalent (EDE)
  - weighted sum of organ dose equivalents; ICRP 26/30 w_T (10 CFR 20.1003)

Sample Result for Shallow Dose Equivalent

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SDE Dose Coefficients (Sv/Bq h)							
Diameter (μm)	10	20	50	100	200	500	1000
Stellite 6	($Z = 33$; $\rho = 8.4$ g/cm^3)						
Co-60	9.8E-08	8.8E-08	6.0E-08	3.7E-08	2.2E-08	1.2E-08	8.9E-09
Inconel 718	($Z = 29$; $\rho = 8.2$ g/cm^3)						
Ni-59	1.5E-09	1.5E-09	1.6E-09	1.6E-09	1.7E-09	1.7E-09	1.6E-09
Ni-63	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Regulatory Concrete	($Z = 10$; $\rho = 2.3$ g/cm^3)						
Fe-55	1.3E-09	1.3E-09	1.4E-09	1.4E-09	1.5E-09	1.5E-09	1.5E-09
Co-60	9.9E-08	9.7E-08	8.9E-08	7.6E-08	5.6E-08	3.0E-08	1.8E-08
Ba-133	1.1E-08	9.9E-09	9.5E-09	9.4E-09	9.3E-09	7.3E-09	5.0E-09
Eu-152	7.6E-08	7.5E-08	6.8E-08	5.9E-08	5.0E-08	3.8E-08	2.8E-08
Eu-154	1.8E-07	1.7E-07	1.5E-07	1.3E-07	1.1E-07	8.1E-08	5.7E-08
Fuel Fragment	($Z = 88$; $\rho = 11$ g/cm^3)						
Sr-90*	3.0E-07	2.9E-07	2.8E-07	2.5E-07	2.2E-07	1.3E-07	6.9E-08
Cs-137*	1.5E-07	1.5E-07	1.2E-07	9.3E-08	5.8E-08	2.6E-08	1.4E-08
Eu-154	1.6E-07	1.4E-07	1.1E-07	8.1E-08	5.4E-08	2.7E-08	1.5E-08
Eu-155	2.3E-08	1.5E-08	7.2E-09	4.0E-09	2.3E-09	1.3E-09	9.0E-10
Pu-238	2.4E-10	2.4E-10	2.5E-10	2.6E-10	2.6E-10	2.5E-10	2.3E-10
Pu-239	1.1E-10	1.1E-10	1.2E-10	1.3E-10	1.3E-10	1.2E-10	1.1E-10
Pu-240	2.2E-10	2.3E-10	2.4E-10	2.5E-10	2.5E-10	2.3E-10	2.1E-10
Pu-241	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Am-241	1.0E-09	1.0E-09	1.0E-09	1.1E-09	1.1E-09	9.8E-10	9.1E-10
Cm-244	1.8E-10	1.8E-10	1.9E-10	2.0E-10	2.0E-10	1.9E-10	1.7E-10
Welding Rod	($Z = 74$; $\rho = 19$ g/cm^3)						
Th-232	1.7E-10	1.8E-10	1.8E-10	1.9E-10	1.9E-10	1.8E-10	1.6E-10

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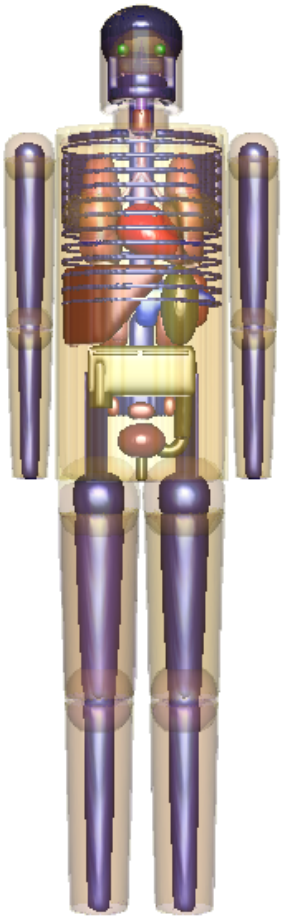
EDE Coefficients for Skin DRP

- Using the PiMAL phantom coupled with MCNP
- DRP on the skin surface
  - particles situated at the middle and lower torso
- Tissue weighting factors for gonads, breast, red bone marrow, lung, thyroid, bone surface, and remainder (10 CFR 20.1003)



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DRP Inhaled or Ingested

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Local DE Coefficients for Internal DRP

- Also, using the VARSKIN+ SkinDose module
- Particle stuck on the inner surface of the upper respiratory or GI tract
- Inner surface assumed to have no curvature (i.e., modeled as flat)
- Local Dose Equivalent at critical depths
  - upper respiratory tract (45 µm)
  - small intestine (140 µm)
  - large intestine (290 µm)
- Dose coefficients can be used to determine exposure time (or activity) required to exceed the dose threshold

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EDE Dose Coefficients for Internal DRP

- Using coupled PiMAL/MCNP
- DRP locations
  - upper respiratory tract (nasopharynx, larynx)
  - small and large intestine (various locations)
- DRP assumed to remain whole and stationary

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CEDE Dose Coefficient for Internal DRP

- From inhaled or ingested DRP
- Using the IMBA internal dosimetry package
  - Integrated Modules for Bioassay Analysis
- DRP remains whole (i.e., no activity to the bloodstream) and is moving through the body
  - fuel fragment exception

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CEDE: Inhalation

- In ICRP 30, large particles are captured in the nasopharynx (NP) region
- DRPs with physical dimensions greater than 10 microns are assumed to only reach the NP region
  - removal through physical excretion (i.e., sneezing) is the most likely outcome
- Therefore, a committed dose is not appropriate in this case
  - i.e., the DRP would not travel through the respiratory system
- EDE rate coefficients with DRP placed in the upper respiratory tract is the most applicable dosimetry method

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CEDE: Ingestion

- CEDE coefficients for ingestion were developed using IMBA v5.0.1
- IMBA uses the ICRP 30 gastrointestinal (GI) tract model
  - ICRP 26/30 tissue weighting factors
- The biokinetic model in ICRP 30 was not intended for DRP ingestion events
  - i.e., first order kinetics with rate constants [probability per unit time] governing movement through the GI, bloodstream, etc.
- If, however, the DRP is assumed to move with the GI contents (and does not become “stuck”), ICRP biokinetics are assumed valid for dose estimation

DRP CEDE Ingestion Coefficients

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	Dose Coefficient (Sv/Bq)	
	$f_1 = 0$	$f_1 /= 0$
Stellite (Z = 33; ρ = 8.4 g/cm³)		
Co60	1.8E-09	-
Inconel (Z = 29; ρ = 8.2 g/cm³)		
Ni59	2.9E-11	-
Ni63	7.1E-11	
NRC Concrete (Z = 10; ρ = 2.3 g/cm³)		
Fe55	2.4E-11	-
Co60	1.8E-09	-
Ba133	5.2E-10	-
Eu152	1.2E-09	-
Eu154	1.9E-09	-
Fuel Fragment (Z = 88; ρ = 11 g/cm³)		
Sr90	2.0E-09	3.1E-09
Cs137	1.3E-09	1.4E-08
Eu154	1.9E-09	2.5E-09
Eu155	3.0E-10	3.7E-10
Pu238	4.6E-09	1.2E-08
Pu239	4.3E-09	1.3E-08
Pu240	4.3E-09	1.3E-08
Pu241	2.2E-11	1.8E-10
Am241	4.8E-09	3.8E-07
Cm244	4.8E-09	2.2E-07
Thoriated Welding Rod (Z = 74; ρ = 19 g/cm³)		
Th232	3.3E-09	-

- Assumes that the DRP does not 'stick'
- f_1 is the fraction of the stable element that reaches the bloodstream following ingestion
- f_1 is assumed to be zero for all DRPs
  - except fuel fragments
- There is some evidence that irradiated fuel fragments are partially soluble in the fluids of the stomach and small intestine
- As a bounding method for the ingestion of fuel fragments, "f_1/=0" results use the ICRP 30 f_1 value for the corresponding element

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Stellite (Co-60) Example*

Source Location	Dose Quantity	Dose Coefficient	Reasonable Maximum Exposure Time [h]	Estimated Maximum Dose [mSv]	Time Required for 0.5 Sv [d]	Time Required for 25 Gy [d]
Skin Surface	SDE	3.7×10^{-8} [Sv/Bq h]	24	44	11	560
	DDE	1.4×10^{-9} [Sv/Bq h]	24	1.7	300	15,000
(mid torso)	EDE					
Upper Resp Tract	Local DE	4.8×10^{-7} [Sv/Bq h]	48	1,200	0.86	43
	EDE					
Small Intestine	Local DE	1.7×10^{-7} [Sv/Bq h]	10	85	2.4	120
	EDE					
Large Intestine	Local DE	5.9×10^{-8} [Sv/Bq h]	120	350	7.0	350
	EDE					
Ingestion	CEDE	1.8×10^{-9} [Sv/Bq]	-	0.090	-	-

*for this example, the DRP is assumed to have a diameter of 100 microns and Co-60 activity of 50 kBq

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Fuel Fragment (Eu-154) Example*

Source Location	Dose Quantity	Dose Coefficient	Reasonable Maximum Exposure Time [h]	Estimated Maximum Dose [mSv]	Time Required for 0.5 Sv [d]	Time Required for 25 Gy [d]
Skin Surface	SDE	8.1×10^{-8} [Sv/Bq h]	24	16	32	1,600
	DDE	7.2×10^{-10} [Sv/Bq h]	24	0.14	3,600	180,000
(mid torso)	EDE					
Upper Resp Tract	Local DE	9.6×10^{-7} [Sv/Bq h]	48	370	2.8	140
	EDE					
Small Intestine	Local DE	5.6×10^{-7} [Sv/Bq h]	10	45	4.6	230
	EDE					
Large Intestine	Local DE	3.5×10^{-7} [Sv/Bq h]	120	340	7.4	370
	EDE					
Ingestion	CEDE	1.9×10^{-9} [Sv/Bq]	-	0.015	-	-

*for this example, the DRP is assumed to have a diameter of 100 microns and Eu-154 activity of 8 kBq

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