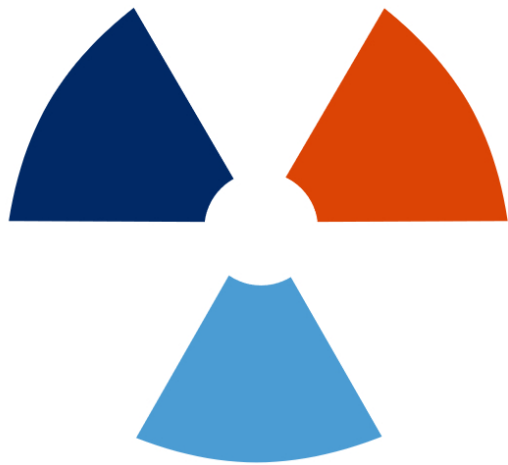




RENAISSANCE
CODE DEVELOPMENT

RCD Radiation Protection Associates

Dose Coefficients for Discrete Radioactive Particles (DRP)

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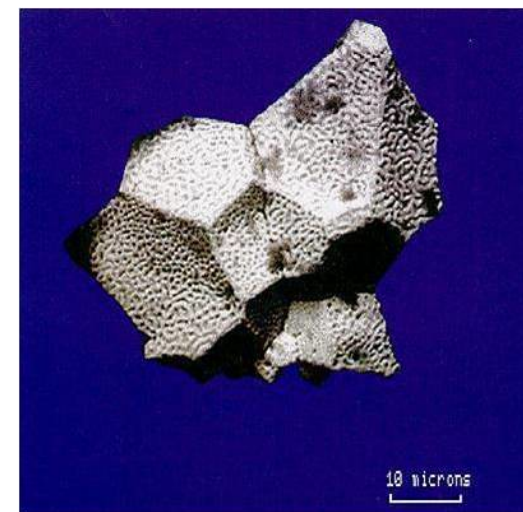
C.D. Mangini, C.T. Rose, and R.R. Benke

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

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 local tissues

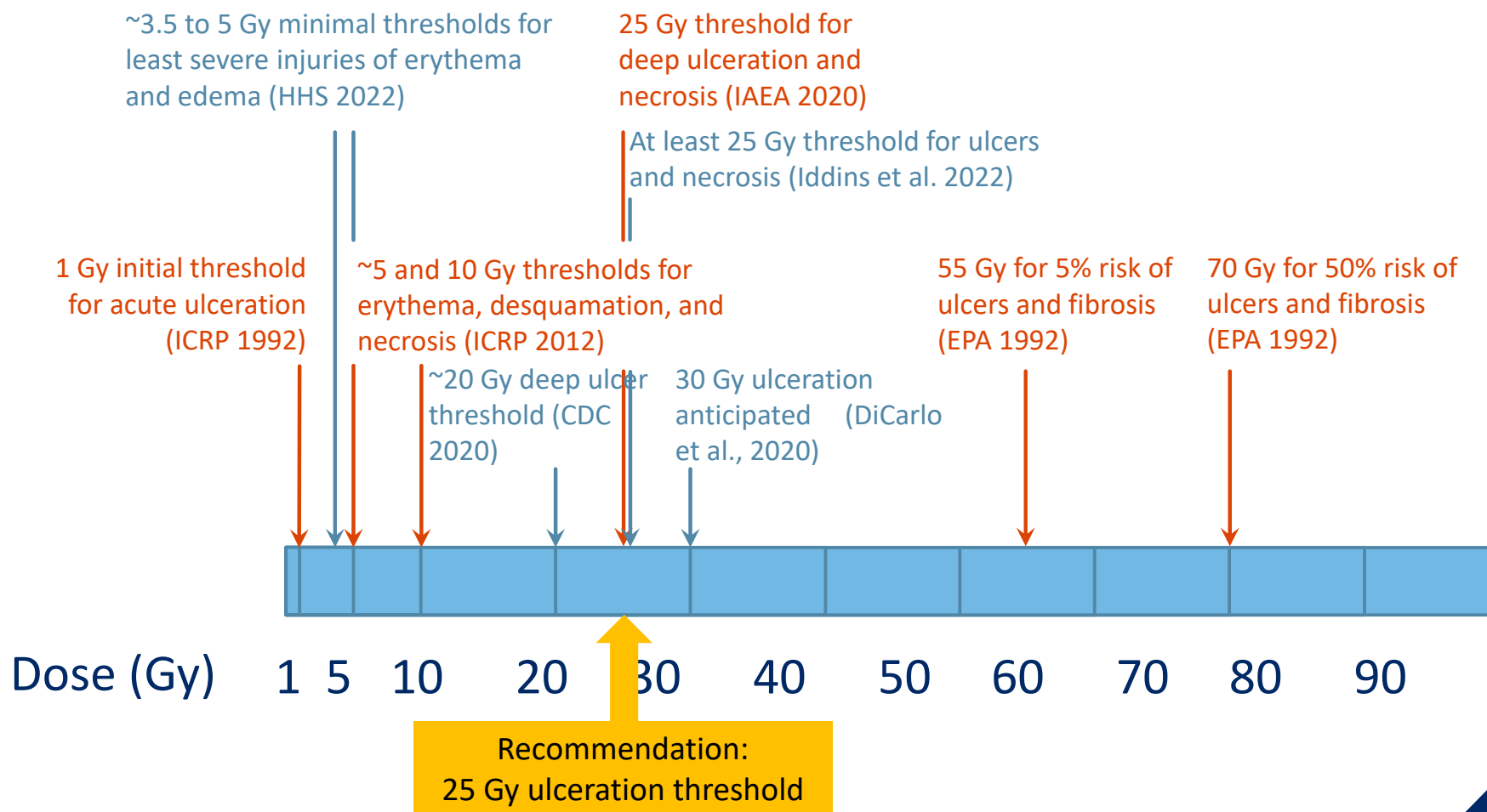


Uranium oxide from Chernobyl



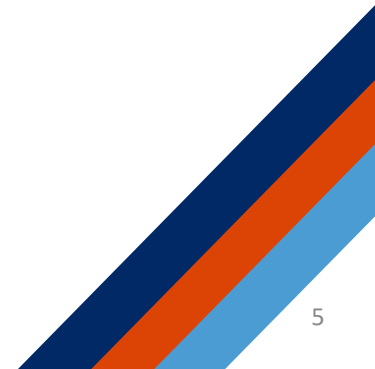
Table Salt (~ 300 microns)

Representative Ulceration Thresholds



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



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

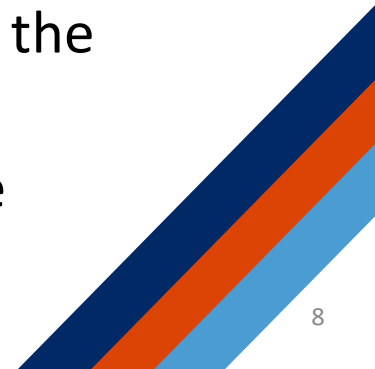
Nuclide	Half-Life (years)	Effective Atomic Number	Density (g/cm ³)
Stellite 6		33	8.4
Co-60	5.27		
Inconel 718		29	8.2
Ni-59	76,000		
Ni-63	101		
Regulatory Concrete		10	2.3
Fe-55	2.75		
Co-60	5.27		
Ba-133	10.5		
Eu-152	13.5		
Eu-154	8.6		
Fuel Fragment		88	11
Sr-90	28.8		
Cs-137	30.1		
Eu-154	8.6		
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



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



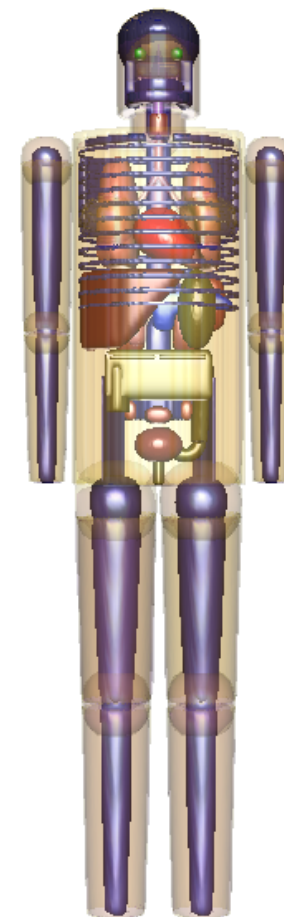
DRP on the Skin Surface

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)

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)



Sample Result for Shallow Dose Equivalent

SDE Dose Coefficients (Sv/Bq h)							
Diameter (μm)	10	20	50	100	200	500	1000
Stellite 6	(Z = 33; ρ = 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; ρ = 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; ρ = 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; ρ = 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; ρ = 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

DRP Inhaled or Ingested

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

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

CEDE Dose Coefficient for Internal DRP

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

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



CEDE: Ingestion

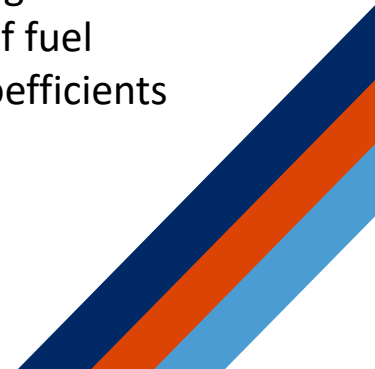
- CEDE coefficients for ingestion were developed using IMBA v5.0.1
- IMBA uses the ICRP 30 gastrointestinal (GI) tract model
 - ICRP 26/30 tissue weighting factors
- The biokinetic model in ICRP 30 was not intended for DRP ingestion events
 - i.e., first order kinetics with rate constants [probability 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

Dose Coefficient (Sv/Bq)		
	$f_1 = 0$	FGR 11
Stellite (Z = 33; $\rho = 8.4 \text{ g/cm}^3$)		
Co60	1.8E-09	-
Inconel (Z = 29; $\rho = 8.2 \text{ g/cm}^3$)		
Ni59	2.9E-11	-
Ni63	7.1E-11	-
NRC Concrete (Z = 10; $\rho = 2.3 \text{ g/cm}^3$)		
Fe55	2.4E-11	-
Co60	1.8E-09	-
Ba133	5.2E-10	-
Eu152	1.2E-09	-
Eu154	1.9E-09	-
Fuel Fragment (Z = 88; $\rho = 11 \text{ g/cm}^3$)		
Sr90	2.0E-09	3.9E-08
Cs137	1.3E-09	1.4E-08
Eu154	1.9E-09	2.6E-09
Eu155	3.0E-10	4.1E-10
Pu238	4.6E-09	8.7E-07
Pu239	4.3E-09	9.6E-07
Pu240	4.3E-09	9.6E-07
Pu241	2.2E-11	1.9E-08
Am241	4.8E-09	9.8E-07
Cm244	4.8E-09	5.5E-07
Thoriated Welding Rod (Z = 74; $\rho = 19 \text{ g/cm}^3$)		
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 and subsequent disintegration of fuel fragments, FGR 11 CEDE dose coefficients are provided



Stellite (Co-60) Example*

Source Location	Dose Quantity	Dose Coefficient	Reasonable Maximum Exposure Time [d]	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]	1	44	11	560
	DDE	1.4×10^{-9} [Sv/Bq h]	1	1.7	300	-
(mid torso)	EDE	5.8×10^{-10} [Sv/Bq h]	1	0.70	720	-
Upper Resp Tract	Local DE	4.8×10^{-7} [Sv/Bq h]	2	1,200	0.86	43
	EDE	8.8×10^{-8} [Sv/Bq h]	2	210	4.7	-
Small Intestine	Local DE	1.7×10^{-7} [Sv/Bq h]	0.5	100	2.5	120
Large Intestine	Local DE	5.9×10^{-8} [Sv/Bq h]	5	350	7.0	350
GI Tract	EDE	2.7×10^{-9} [Sv/Bq h]	5	16	150	-
Ingestion	CEDE	1.8×10^{-9} [Sv/Bq]	-	0.090	-	-

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

Fuel Fragment (Eu-154) Example*

Source Location	Dose Quantity	Dose Coefficient	Reasonable Maximum Exposure Time [d]	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]	1	16	32	1,600
	DDE	7.2×10^{-10} [Sv/Bq h]	1	0.14	3,600	-
(mid torso)	EDE	3.1×10^{-10} [Sv/Bq h]	1	0.060	8,400	-
Upper Resp Tract	Local DE	9.6×10^{-7} [Sv/Bq h]	2	370	2.8	140
	EDE	4.3×10^{-8} [Sv/Bq h]	2	17	60	-
Small Intestine	Local DE	5.6×10^{-7} [Sv/Bq h]	0.5	45	4.6	230
Large Intestine	Local DE	3.5×10^{-7} [Sv/Bq h]	5	340	7.4	370
GI Tract	EDE	1.5×10^{-9} [Sv/Bq h]	5	1.4	1,700	-
Ingestion	CEDE	1.9×10^{-9} [Sv/Bq]	-	0.015	-	-

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

