Minor Changes Leading to Major Impacts

Practical Implications of ICRP137 on NORM Industries

NORM IX

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September 2019

Content

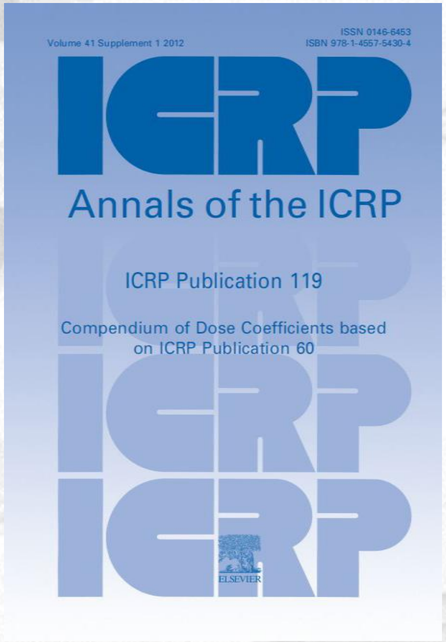
- Aim of presentation
- ICRP changes
- Inhalation dose assessment “101”
- Process for determining Implications
- Comparisons
- Practical considerations
- Summary

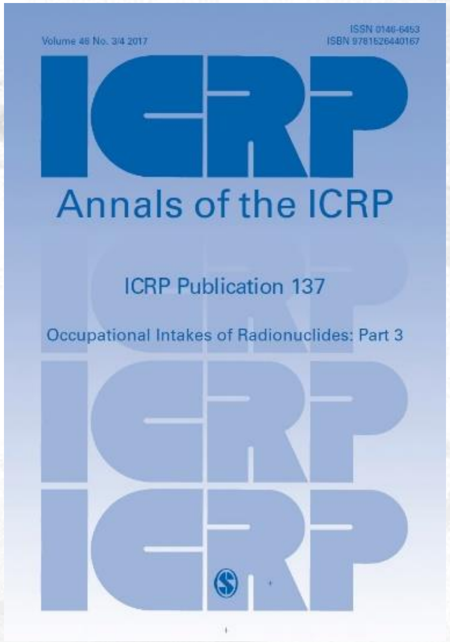
Aims

- Consider the new ICRP dose factors (ICRP 137)
- Compare factors to ICRP119 figures
- Identify changes
- Highlight new information requirements
- Think about practical considerations

Inhalation Dose Factors

- ICRP Publication 119 Compendium of Dose Coefficients based on ICRP Publication 60
- Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137





Radon

ICRP INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

ICRP ref 4836-9756-8598
January 26, 2018

Summary of ICRP Recommendations on Radon

- Previous dose factor was 1.4 mSv per mJh/m^3 for workers in mines
- New dose factor is 3 mSv per mJh/m^3
- Increase by factor of **2.2**

Statement on new radon dose coefficients: implications for worker dose assessments

February 2018

Radiation Health Committee - Statement on new radon dose coefficients: implications for worker dose assessments

Radon is a naturally occurring radioactive gas. Radon levels outdoors are typically very low but can be higher in buildings, including homes and workplaces, and especially underground such as in tourist caves and mines. While tobacco smoking remains the main cause of lung cancer, long-term exposure to radon can also lead to lung cancer (WHO 2017). The International Commission on Radiological Protection (ICRP) makes recommendations for protection of people against exposure to radon at home and at work.

ICRP 119

ICRP_2011_2 - Compatibility Mode - Excel

A1258 | Ra-224

Table A.1. Effective dose coefficient for ingested and inhaled (AMAD = 1 and 5 µm) particulates by workers.

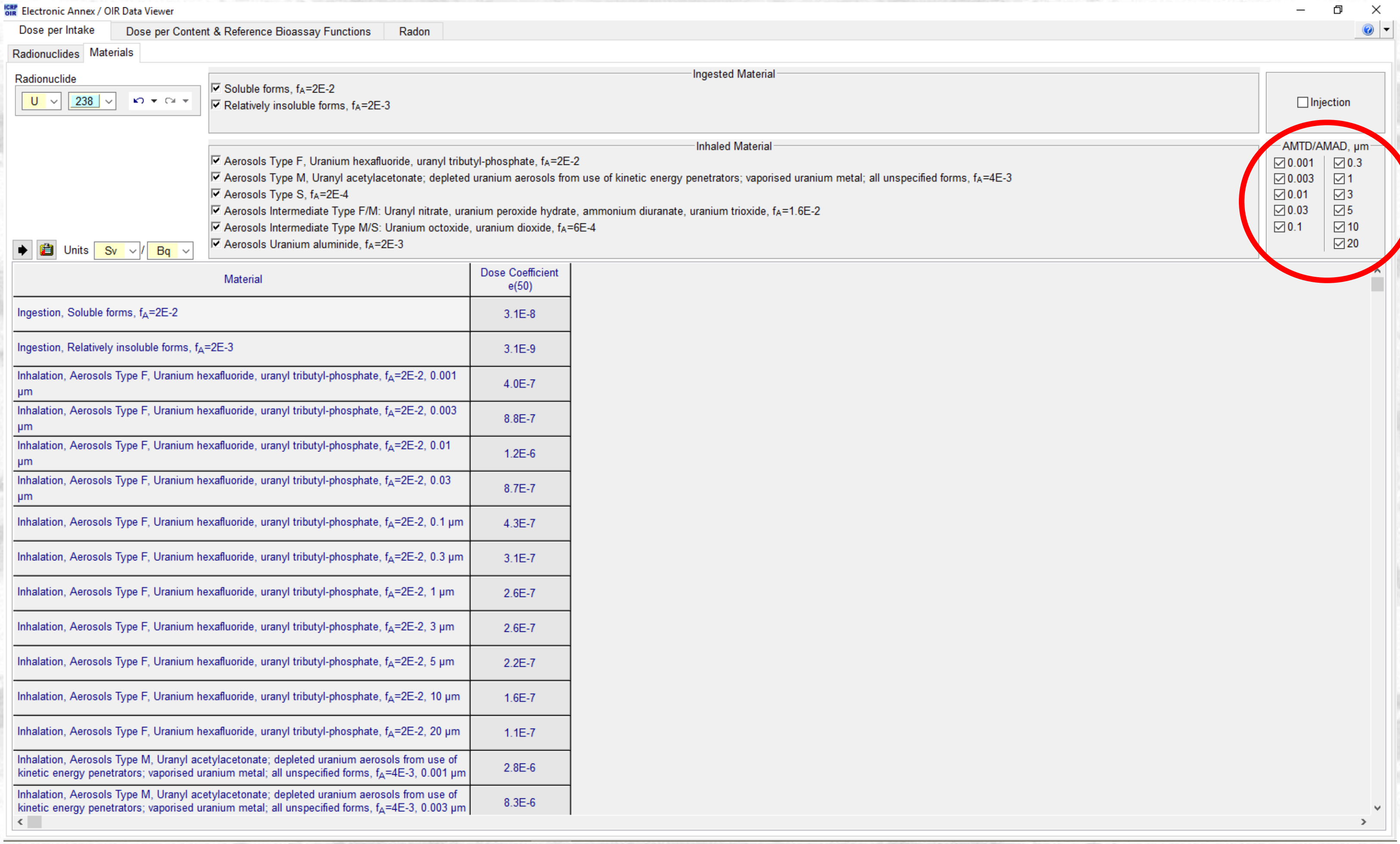
			Effective Dose Coefficient (Sv Bq^{-1})					
			Inhalation				Ingestion	
	Nuclide	$T_{1/2}$	Type	f_1	e (1 µm)	e (5 µm)	f_1	e
1225	Bi-206	6.243 d	F	0.05	7.9E-10	1.3E-09	0.05	1.9E-09
1226			M	0.05	1.7E-09	2.1E-09		
1227	Bi-207	38 y	F	0.05	5.2E-10	8.4E-10	0.05	1.3E-09
1228			M	0.05	5.2E-09	3.2E-09		
1229	Bi-210	5.012 d	F	0.05	1.1E-09	1.4E-09	0.05	1.3E-09
1230			M	0.05	8.4E-08	6.0E-08		
1231	Bi-210m	3.0E6 y	F	0.05	4.5E-08	5.3E-08	0.05	1.5E-08
1232			M	0.05	3.1E-06	2.1E-06		
1233	Bi-212	60.55 m	F	0.05	9.3E-09	1.5E-08	0.05	2.6E-10
1234			M	0.05	3.0E-08	3.9E-08		
1235	Bi-213	45.65 m	F	0.05	1.1E-08	1.8E-08	0.05	2.0E-10
1236			M	0.05	2.9E-08	4.1E-08		
1237	Bi-214	19.9 m	F	0.05	7.2E-09	1.2E-08	0.05	1.1E-10
1238			M	0.05	1.4E-08	2.1E-08		
1239	**Polonium**							
1240	Po-203	36.7 m	F	0.1	2.5E-11	4.5E-11	0.1	5.2E-11
1241			M	0.1	3.6E-11	6.1E-11		
1242	Po-205	1.80 h	F	0.1	3.5E-11	6.0E-11	0.1	5.9E-11

ICRP 119

Table A.1. Effective dose coefficient for ingested and inhaled (AMAD = 1 and 5 µm) particulates by workers.

		Effective Dose Coefficient ($Sv\ Bq^{-1}$)					
		Inhalation				Ingestion	
Nuclide	$T_{1/2}$	**Type**	f_1	*e* (1 µm)	*e* (5 µm)	f_1	*e*
Bi-206	6.243 d	F	0.05	7.9E-10	1.3E-09	0.05	1.9E-09
		M	0.05	1.7E-09	2.1E-09		
Bi-207	38 y	F	0.05	5.2E-10	8.4E-10	0.05	1.3E-09
		M	0.05	5.2E-09	3.2E-09		
Bi-210	5.012 d	F	0.05	1.1E-09	1.4E-09	0.05	1.3E-09
		M	0.05	8.4E-08	6.0E-08		
Bi-210m	3.0E6 y	F	0.05	4.5E-08	5.3E-08	0.05	1.5E-08
		M	0.05	3.1E-06	2.1E-06		
Bi-212	60.55 m	F	0.05	9.3E-09	1.5E-08	0.05	2.6E-10
		M	0.05	3.0E-08	3.9E-08		
Bi-213	45.65 m	F	0.05	1.1E-08	1.8E-08	0.05	2.0E-10
		M	0.05	2.9E-08	4.1E-08		
Bi-214	19.9 m	F	0.05	7.2E-09	1.2E-08	0.05	1.1E-10
		M	0.05	1.4E-08	2.1E-08		
Polonium							
Po-203	36.7 m	F	0.1	2.5E-11	4.5E-11	0.1	5.2E-11
		M	0.1	3.6E-11	6.1E-11		
Po-205	1.80 h	F	0.1	3.5E-11	6.0E-11	0.1	5.9E-11

ICRP 137



Material	Dose Coefficient e(50)
Ingestion, Soluble forms, f_A=2E-2	3.1E-8
Ingestion, Relatively insoluble forms, f_A=2E-3	3.1E-9
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.001 μm	4.0E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.003 μm	8.8E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.01 μm	1.2E-6
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.03 μm	8.7E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.1 μm	4.3E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.3 μm	3.1E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 1 μm	2.6E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 3 μm	2.6E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 5 μm	2.2E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 10 μm	1.6E-7
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 20 μm	1.1E-7
Inhalation, Aerosols Type M, Uranyl acetylacetonate; depleted uranium aerosols from use of kinetic energy penetrators; vaporised uranium metal; all unspecified forms, f_A=4E-3, 0.001 μm	2.8E-6
Inhalation, Aerosols Type M, Uranyl acetylacetonate; depleted uranium aerosols from use of kinetic energy penetrators; vaporised uranium metal; all unspecified forms, f_A=4E-3, 0.003 μm	8.3E-6

ICRP 137

Electronic Annex / OIR Data Viewer

Dose per Intake | Dose per Content & Reference Bioassay Functions | Radon

Radionuclides | Materials

Radionuclide: U 238

Ingested Material

- ☑ Soluble forms, f_A=2E-2
- ☑ Relatively insoluble forms, f_A=2E-3

☐ Injection

Inhaled Material

- ☑ Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2
- ☑ Aerosols Type M, Uranyl acetylacetonate; depleted uranium aerosols from use of kinetic energy penetrators; vaporised uranium metal; all unspecified forms, f_A=4E-3
- ☑ Aerosols Type S, f_A=2E-4
- ☑ Aerosols Intermediate Type F/M: Uranyl nitrate, uranium peroxide hydrate, ammonium diuranate, uranium trioxide, f_A=1.6E-2
- ☑ Aerosols Intermediate Type M/S: Uranium octoxide, uranium dioxide, f_A=6E-4
- ☑ Aerosols Uranium aluminide, f_A=2E-3

AMTD/AMAD, µm

☑ 0.001 ☑ 0.003 ☑ 0.01 ☑ 0.03 ☑ 0.1 ☑ 0.3 ☑ 1 ☑ 3 ☑ 5 ☑ 10 ☑ 20

Units: Sv / Bq

Material	Dose Coefficient e(50)	Dose Coefficients $h_T(50)$	Bone marrow	Colon	Lung	Stomach	Breast	Ovaries	Testes	Urinary bladder	Oesophagus	Liver	Th
Ingestion, Soluble forms, f_A=2E-2	3.1E-8	Male	3.8E-8	1.9E-8	1.5E-8	2.0E-8	2.4E-8	0.0E+0	2.4E-8	2.5E-8	2.0E-8	7.3E-8	2.
		Female	4.6E-8	2.4E-8	1.8E-8	2.4E-8	2.9E-8	2.4E-8	0.0E+0	2.9E-8	2.4E-8	9.5E-8	2.
Ingestion, Relatively insoluble forms, f_A=2E-3	3.1E-9	Male	3.8E-9	2.0E-9	1.5E-9	2.0E-9	2.4E-9	0.0E+0	2.4E-9	2.5E-9	2.0E-9	7.3E-9	2.
		Female	4.6E-9	2.5E-9	1.8E-9	2.4E-9	2.9E-9	2.4E-9	0.0E+0	2.9E-9	2.4E-9	9.5E-9	2.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.001 µm	4.0E-7	Male	4.1E-7	2.1E-7	6.9E-7	2.1E-7	2.6E-7	0.0E+0	2.6E-7	2.7E-7	2.1E-7	7.9E-7	2.
		Female	5.0E-7	2.6E-7	7.5E-7	2.6E-7	3.1E-7	2.6E-7	0.0E+0	3.2E-7	2.7E-7	1.0E-6	2.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.003 µm	8.8E-7	Male	8.9E-7	4.5E-7	1.7E-6	4.6E-7	5.7E-7	0.0E+0	5.6E-7	5.8E-7	4.6E-7	1.7E-6	5.
		Female	1.1E-6	5.6E-7	1.8E-6	5.7E-7	6.7E-7	5.6E-7	0.0E+0	6.9E-7	5.7E-7	2.2E-6	6.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.01 µm	1.2E-6	Male	1.3E-6	6.6E-7	1.5E-6	6.8E-7	8.4E-7	0.0E+0	8.3E-7	8.6E-7	6.9E-7	2.5E-6	7.
		Female	1.6E-6	8.2E-7	1.6E-6	8.4E-7	1.0E-6	8.2E-7	0.0E+0	1.0E-6	8.5E-7	3.3E-6	9.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.03 µm	8.7E-7	Male	1.0E-6	5.0E-7	8.9E-7	5.2E-7	6.4E-7	0.0E+0	6.3E-7	6.5E-7	5.2E-7	1.9E-6	5.
		Female	1.2E-6	6.3E-7	9.9E-7	6.4E-7	7.6E-7	6.3E-7	0.0E+0	7.7E-7	6.5E-7	2.5E-6	6.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.1 µm	4.3E-7	Male	5.0E-7	2.5E-7	4.3E-7	2.6E-7	3.2E-7	0.0E+0	3.2E-7	3.3E-7	2.6E-7	9.6E-7	2.
		Female	6.0E-7	3.1E-7	4.8E-7	3.2E-7	3.8E-7	3.1E-7	0.0E+0	3.9E-7	3.2E-7	1.3E-6	3.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 0.3 µm	3.1E-7	Male	3.7E-7	1.8E-7	3.0E-7	1.9E-7	2.3E-7	0.0E+0	2.3E-7	2.4E-7	1.9E-7	7.1E-7	2.
		Female	4.4E-7	2.3E-7	3.4E-7	2.3E-7	2.8E-7	2.3E-7	0.0E+0	2.8E-7	2.4E-7	9.2E-7	2.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 1 µm	2.6E-7	Male	3.1E-7	1.6E-7	2.2E-7	1.6E-7	2.0E-7	0.0E+0	2.0E-7	2.0E-7	1.6E-7	6.0E-7	1.
		Female	3.7E-7	1.9E-7	2.4E-7	2.0E-7	2.4E-7	1.9E-7	0.0E+0	2.4E-7	2.0E-7	7.8E-7	2.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 3 µm	2.6E-7	Male	3.1E-7	1.5E-7	2.1E-7	1.6E-7	2.0E-7	0.0E+0	1.9E-7	2.0E-7	1.6E-7	5.9E-7	1.
		Female	3.7E-7	1.9E-7	2.3E-7	1.9E-7	2.3E-7	1.9E-7	0.0E+0	2.4E-7	2.0E-7	7.7E-7	2.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 5 µm	2.2E-7	Male	2.7E-7	1.3E-7	1.8E-7	1.4E-7	1.7E-7	0.0E+0	1.7E-7	1.7E-7	1.4E-7	5.1E-7	1.
		Female	3.2E-7	1.7E-7	2.0E-7	1.7E-7	2.0E-7	1.7E-7	0.0E+0	2.1E-7	1.7E-7	6.7E-7	1.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 10 µm	1.6E-7	Male	2.0E-7	9.8E-8	1.2E-7	1.0E-7	1.2E-7	0.0E+0	1.2E-7	1.3E-7	1.0E-7	3.7E-7	1.
		Female	2.3E-7	1.2E-7	1.4E-7	1.2E-7	1.5E-7	1.2E-7	0.0E+0	1.5E-7	1.3E-7	4.9E-7	1.
Inhalation, Aerosols Type F, Uranium hexafluoride, uranyl tributyl-phosphate, f_A=2E-2, 20 µm	1.1E-7	Male	1.4E-7	6.9E-8	7.2E-8	7.1E-8	8.7E-8	0.0E+0	8.6E-8	8.9E-8	7.1E-8	2.6E-7	7.
		Female	1.6E-7	8.5E-8	8.3E-8	8.7E-8	1.0E-7	8.5E-8	0.0E+0	1.1E-7	8.8E-8	3.4E-7	9.
Inhalation, Aerosols Type M, Uranyl acetylacetonate; depleted uranium aerosols from use of kinetic energy penetrators; vaporised uranium metal; all unspecified forms, f_A=4E-3, 0.001 µm	2.8E-6	Male	6.8E-8	3.4E-8	2.0E-5	3.5E-8	4.3E-8	0.0E+0	4.2E-8	4.4E-8	3.5E-8	1.3E-7	3.
		Female	8.1E-8	4.2E-8	2.1E-5	4.3E-8	5.1E-8	4.2E-8	0.0E+0	5.2E-8	4.4E-8	1.7E-7	4.
Inhalation, Aerosols Type M, Uranyl acetylacetonate; depleted uranium aerosols from use of kinetic energy penetrators; vaporised uranium metal; all unspecified forms, f_A=4E-3, 0.003 µm	8.3E-6	Male	3.1E-7	1.5E-7	6.4E-5	1.6E-7	1.9E-7	0.0E+0	1.9E-7	2.0E-7	1.6E-7	5.9E-7	1.
		Female	3.7E-7	1.9E-7	6.7E-5	1.9E-7	2.3E-7	1.9E-7	0.0E+0	2.4E-7	2.0E-7	7.7E-7	2.

Dose Estimation 101

(a few ways of doing this)

- Used to convert an exposure into a dose
- Dose is a standardised measure of impact (Sv)
- Take sufficient dust samples to determine a representative activity in air concentration
- Activity concentration usually measured by alpha counting, giving $\alpha Bq/m^3$
- Multiply by exposure hours and an assumed breathing rate (m^3/h), giving an inhalation intake (as Bq)
- Convert intake to dose using ICRP dose factors (in units of Sv/Bq).
- However…

Other Factors to Know

- Dose factors are radionuclide dependant
  - So, need to know what radionuclides the alphas came from and their relative proportion
  - Can do this by;
    - Estimating (eg; secular equilibrium)
    - Radionuclide analysis of dust samples (difficult)
    - Radionuclide analysis of dust sources (eg; process materials)
- Dose factors are particle size dependant
  - Need to measure AMADs or use default figures
- Dose factors depend on the solubility of the minerals and compounds
  - Need to understand mineralogy

- Tendency is to use the most conservative dose factors…….

Solubility Types
(Important)

- Defines the clearance rate of the radionuclide from the lung and is dependant upon:
  - Chemical and mineralogy properties
  - Treatment it has undergone (mechanical, chemical, thermal)
  - Physical properties (which define size)
- Type F materials:
  - Deposited materials that are **readily** absorbed into blood from the respiratory tract (fast rate of absorption).
- Type M materials:
  - Deposited materials that have **intermediate rates** of absorption into blood from the respiratory tract (moderate rate of absorption).
- Type S materials:
  - Deposited materials that are relatively **insoluble** in the respiratory tract (slow rate of absorption)

Process for Determining Implications

- Use factors from both ICRP119, ICRP137
- Main radionuclides in the U-238 and Th-232 decay chains;
  - U-238, U-234, Th-230, Ra-226, Pb-210, Po-210
  - Th-232, Ra-228, Th-228, Ra-224
- 1 and 5 µm figures
- Available ICRP 119 types and then matched to ICRP 137
- Compare "like with like" and show percentage differences
- Compare some typical dusts

Dose Factors

U-238 Chain Long Lived Radionuclides

(using same "type" dose factors)

Radionuclide	Percentage DECREASE (compared to ICRP 119)		
	1 µm	5 µm	Type
U-238	88	164	F
U-238	37	33	M
U-238	174 ↑	111 ↑	S
U-234	83	156	F
U-234	41	50	M
U-234	171 ↑	91 ↑	S
Th-230	208	284	M
Th-230	92 ↑	108 ↑	S
Ra-226	52	57	M
Po-210	94	154	F
Po-210	88	100	M
Pb-210	78	57	F

U-238 Chain Long Lived Radionuclides

(using same "type" dose factors)

Radionuclide	Percentage DECREASE (compared to ICRP 119)		
	1 µm	5 µm	Type
U-238	88	164	F
U-238	37	33	M
U-238	174 ↑	111 ↑	S
U-234	83	156	F
U-234	41	50	M
U-234	171 ↑	91 ↑	S
Th-230	208	284	M
Th-230	92 ↑	108 ↑	S
Ra-226	52	57	M
Po-210	94	154	F
Po-210	88	100	M
Pb-210	78	57	F

Something odd with Pb-210. There is a new type "S" for "mineral dusts". If this factor is used, change is increase by almost 1000% (10 fold increase)

Th-232 Chain Long Lived Radionuclides

(using same "type" dose factors)

Radionuclide	Percentage **DECREASE** (compared to ICRP 119)		
	1 µm	**5 µm**	**Type**
Th-232	180	254	M
Th-232	335 ↑	350 ↑	S
Th-228	100	144	M
Th-228	6	9	S
Ra-228	37	42	M
Ra-224	123	164	M

U-238 and Th-232 Radionuclides

(using conservative dose factors)

Radionuclide	Percentage INCREASE (compared to ICRP 119)	
	1 µm	5 µm
U-238	174	111
U-234	171	91
Th-230	43 ↓	21
Ra-226	619	491
Po-210	7 ↓	22 ↓
Pb-210	1,585	736
Th-232	138	86
Th-228	9	6
Ra-228	1,323	1,194
Ra-224	81 ↓	118 ↓

Comparison of Dose Conversion Factors for Materials

- For dust size of 5µm
- Standard types
- (not including "errant" Pb-210 factor)

Material	µSv/Bq	
	ICRP 119 Dose Factor	ICRP 137 Dose Factor
Uranium Ore	25	43
Uranium Oxide	16	33
Thorium Ore	41	79

Practical Considerations

- Generally dust doses are low and controlled with good safety practices.
- However, there are many many different dusts with different radionuclide concentrations in NORM
- Need to characterise and manage appropriately
- “Controls commensurate with risk”

Summary

- Many types of dusts associated with NORM
- New dust inhalation dose factors in ICRP137
- Software makes getting factors straight forward
- Need to characterize the dust (size, radionuclides, solubility)
- Using conservative assumptions is likely to result in very high dose factors.