HUMAN EXPOSURE TO NORM WASTE HEAPS

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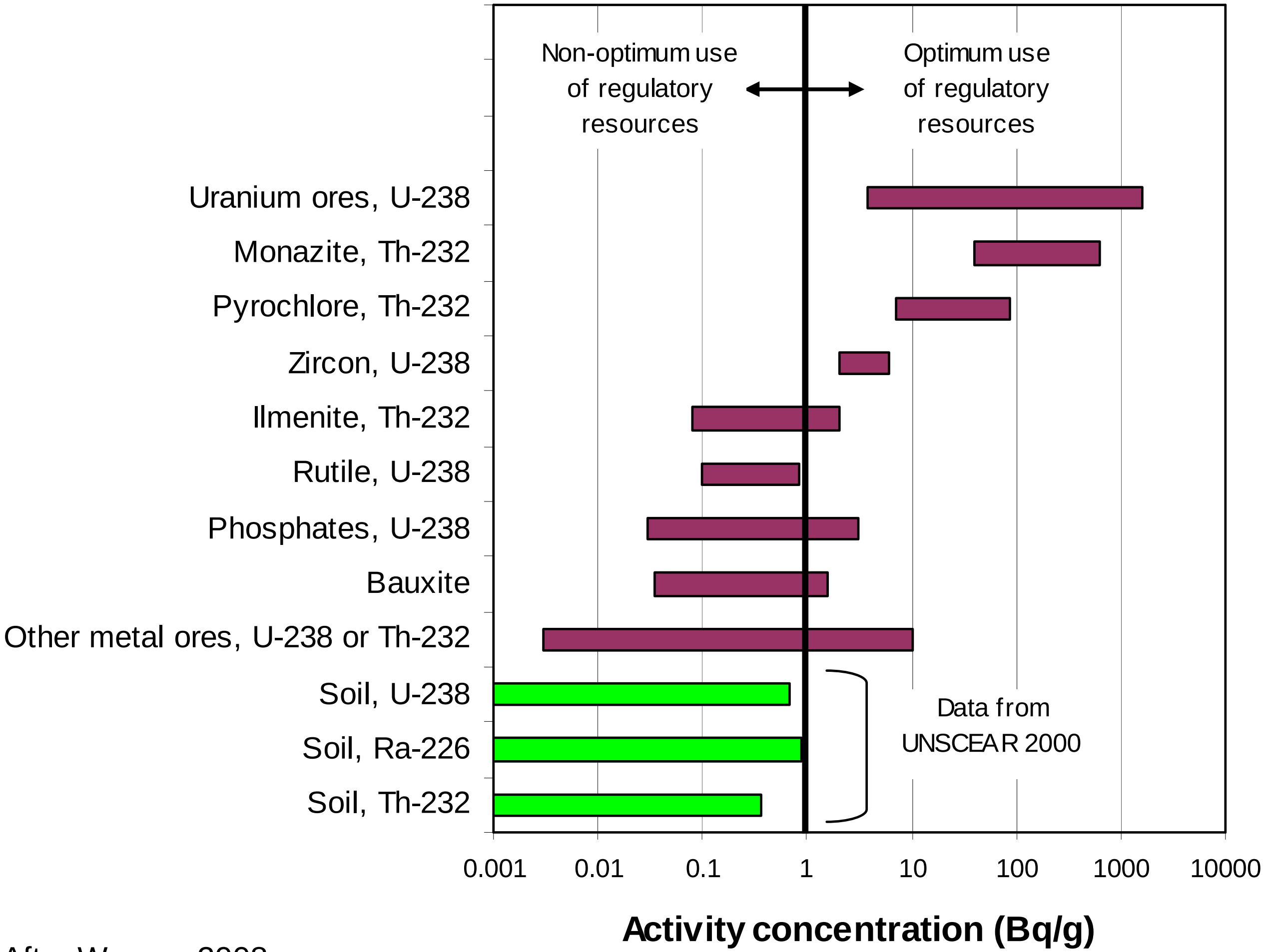
Introduction

- **NORM is an acronym for <u>n</u>aturally-<u>o</u>ccurring <u>r</u>adioactive <u>m</u>aterials**
- **NORM is ubiquitous and is present in all soils and rocks**
- **NORM can be enhanced through man's activities (sometimes referred to as TENORM)**

Introduction

Concentration ranges of uranium and thorium series radionuclides in minerals



Source: After Wymer, 2008

Introduction

In the majority of situations, the NORM concentrations do not pose potential problems to the environment or human health	*But*	Processing of ores can lead to further enhancement of the radioactivity in the products, by-products, residues or wastes

Introduction

- **IAEA RS-G-1.7 (2004) states :**

> **"It is usually unnecessary to regulate…" material containing radionuclides of natural origin at activity concentrations below 1 Bq/g for radionuclides in the uranium and thorium decay series and below 10 Bq/g for K-40.**

- **Doses to individuals as a consequence of these activity concentrations would be unlikely to exceed about 1 mSv in a year "<u>excluding</u> the contribution from the emanation of radon"**

Objectives and Scope of Study

- **IAEA decided to perform independent calculations to confirm or otherwise, that expected doses would be**

  "*unlikely to exceed about 1 mSv in a year <u>excluding</u> the contribution from the emanation of radon*"

- **The scope of the study was to provide calculations for human exposures potentially arising from a "generic" waste heap containing NORM**

Pathways Models

- Models range from simple to complex
- Data requirements depend on model
- Select model based on study objectives and level of analysis required
- Pathways modelling can be iterative

Study Assumptions

Assumptions:

- a nominal heap volume of 2 million m^3 covering 10 ha (100,000 m^2);
- either (or both) the radionuclides in the natural uranium (U-238) decay chain or the natural thorium (Th-232) decay chain are present in the heap materials at a concentration of 1 Bq/g;
- the mine waste heap could potentially be acid generating; and
- the models and assumptions of SRS 44 are to be used where possible.

The Approach (1)

- To consider reasonably available information from "real-world" examples of actual heaps that could be used to "benchmark" the hypothetical heap and seepage characteristics
- Define the characteristics of the hypothetical heap (in part from real world experience)

The Approach (2)

- Develop exposure pathways and dose assessment for the hypothetical waste heap building on SRS 44 models/assumptions
- Focus on Groundwater
- Discuss the likely doses arising to persons living in close proximity to such a heap.

Release From Heap Materials (1)

- The characteristics of waste heap sources are quite variable and are dependent on:
  - the geological setting,
  - the specific uranium/thorium content of the raw materials
  - the effects of processing
- Radionuclides are leached as the mineralization dissolves in rainwater passing through the pile.

Release From Heap Materials (2)

- **Radium may be dissolved and its solubility is controlled by sulphate levels.**
- **Uranium release from carbonate minerals is likely to be dominated by dissolution mechanism.**
- **Pb-210 and Po-210 levels tend to be below that of Ra-226.**
- **Releases can also be influenced by the pH and redox changes associated with oxidation**

Waste Rock
Physical Characteristics

- **Waste rocks are characterized as:**
  - **having low moisture content,**
  - **large particle size (50% of the material in the pile is greater than 10 cm)**
  - **containing rocks and stones.**

Leachate from Waste Rocks

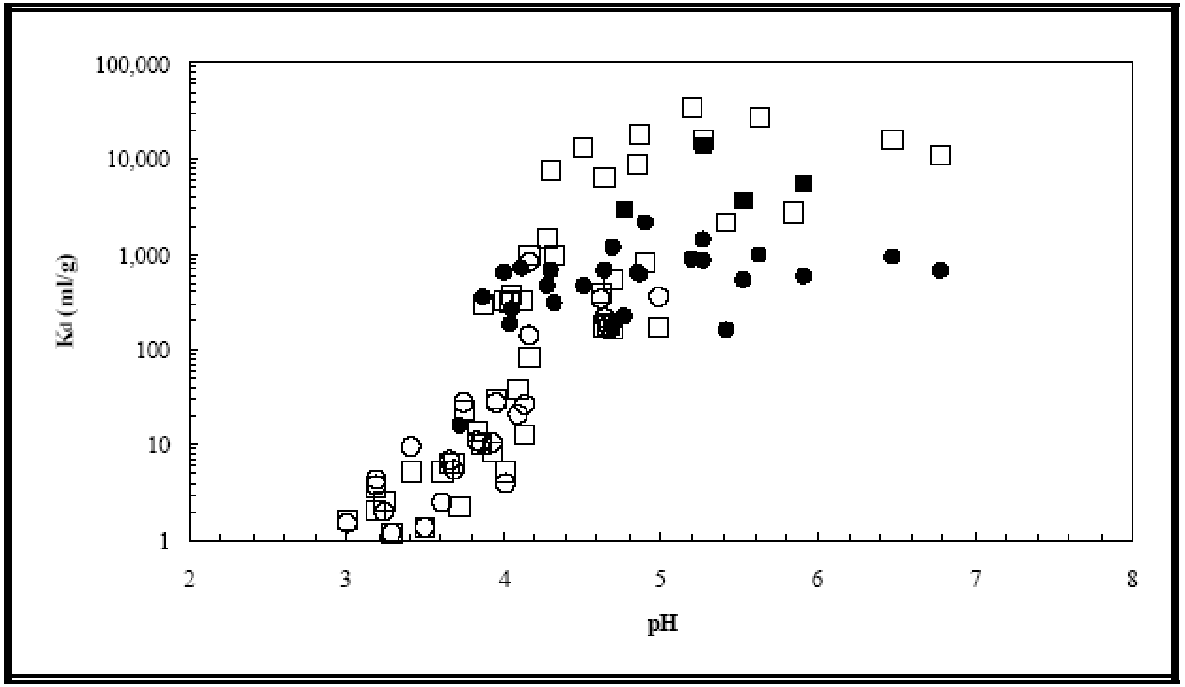
- The range of radionuclide concentrations in leachate from waste heap materials:

- Source:
  - Key Lake uranium mine
  - Rabbit Lake uranium mine
  - Various non-uranium studies

radionuclides	Range of concentrations
U (mg/L)	0.01-13.8
Ra-226 (Bq/L)	0.02-5.5
Th-232 (μg/L)	0.01-0.1
Pb-210 (Bq/L)	0.025-8
Po-210 (Bq/L)	0.05-0.1

Partition Coefficients

- **Field-derived K_d values for U-238 and U-235 plotted as a function of pore water ph for contaminated soil/pore water samples**



Source: DOE/EPA 1999

Estimated Range of K_d Values for Uranium

K_d, ml/g	pH							
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Minimum	<1	0.4	0.25	100	63	0.4	<1	<1
Maximum	32	5,000	160,000	1,000,000	630,000	250,000	7,900	5

Source: DOE/EPA 1999

Estimated Range of K_d Values for Thorium

- **Thorium K_d values (ml/g) based on pH**

K_d (ml/g)	pH: 3-5	pH: 5-8	pH: 8-10
Minimum	62	1,700	20
Maximum	6,200	170,000	2,000

Source: DOE/EPA 1999

Estimated Range of K_d Values for Lead

Soil Type	pH	K_d, ml/g
Sand	4.5	280
Sand	5	1,295
Sand	5.27	13,000-79,000
Medium sand	5.8	19
Sandy Loam	7.5	3,000
Sandy Loam	8	4,000
Fine sandy loam	8.7	59,000
Loam	7.3	21,000
Organic soil	5.5	30,000

Source: DOE/EPA 1999

Partition Coefficients

- **Geometric Mean K_d values (ml/g) Provided by the RESRAD Data Collection**

Radionuclide	Sand	Clay
Lead	270	550
Polonium	150	3,000
Radium	500	9,100
Thorium	3,200	5,800
Uranium	35	1,600

Source: Yu et al. 1993

Nominal Seepage From Waste Heaps

Waste Type	Typical NORM Waste Non-acidic	Typical NORM Waste Acidic
U and Th content		
-U_3O_8 %	0.01	0.01
-Th-232% [1]	0.01	0.01
Leachate Quality		
-U (mg/L)	1	10[1]
-Ra-226 (Bq/L)	1	1
-Th (mg/L)	<0.01	0.1
-Pb-210 (Bq/L)[2]	0.2	1
-Po-210 (Bq/L) [2]	0.05	0.1

Note 1- It is highly unlikely that a person would have an acidic water supply. Constituents such as pH, salinity, iron levels and metals would likely preclude the use of the water.

Note 2- Based upon seepage/groundwater monitoring data for a uranium mine

Transport in Groundwater

- The transport of radionuclides in ground water and soils can be described by a convection-dispersion model

Retardation

is defined using K_d values, soil water content and density

The greater the K_d, the greater the retardation factor

causes the mean radionuclides velocity to be slower than the groundwater velocity

- Therefore, sorption of radionuclides onto the soil particles will slow down its advection and dispersion in groundwater.

$$R_f = 1 + \frac{K_d \rho}{\theta}$$

Transport in Groundwater (1)

- **Case 1: White King uranium mine site in Oregon:**

- **Pore water samples in the stockpile were over 10^6 Bq/m^3**	***But***	- **Overburden, pore water immediately under the stockpile, activities were less than 670 Bq/m^3**

- **A reduction of more than 1000**
- **The uranium appears to be quite immobile**

Transport in Groundwater (2)

- Case 2: Groundwater migration from a tailings pile is the Nordic uranium tailings pile in Elliot Lake region of Ontario, Canada
- Uranium and radium migration from acid leachates is greatly retarded in the groundwater aquifer below the pile (Morin and Cherry (1981)

Dose Assessment (1)

- The pathway calculations based on the IAEA Safety Report Series No.44 (SRS 44)
- K_d values from RESRAD data for sands conservative (i.e., high) estimate of groundwater concentration
- K_d values in following table estimated based on the leachate and waste concentrations cited in this study, are believed to represent the mine waste piles more realistically.

Dose Assessment (2)

- **Suggested (literature this study) K_d values (ml/g)**

Radionuclide	K_d (ml/g)
Lead	5000
Polonium	2000
Radium	1800
Thorium	1000
Uranium	50

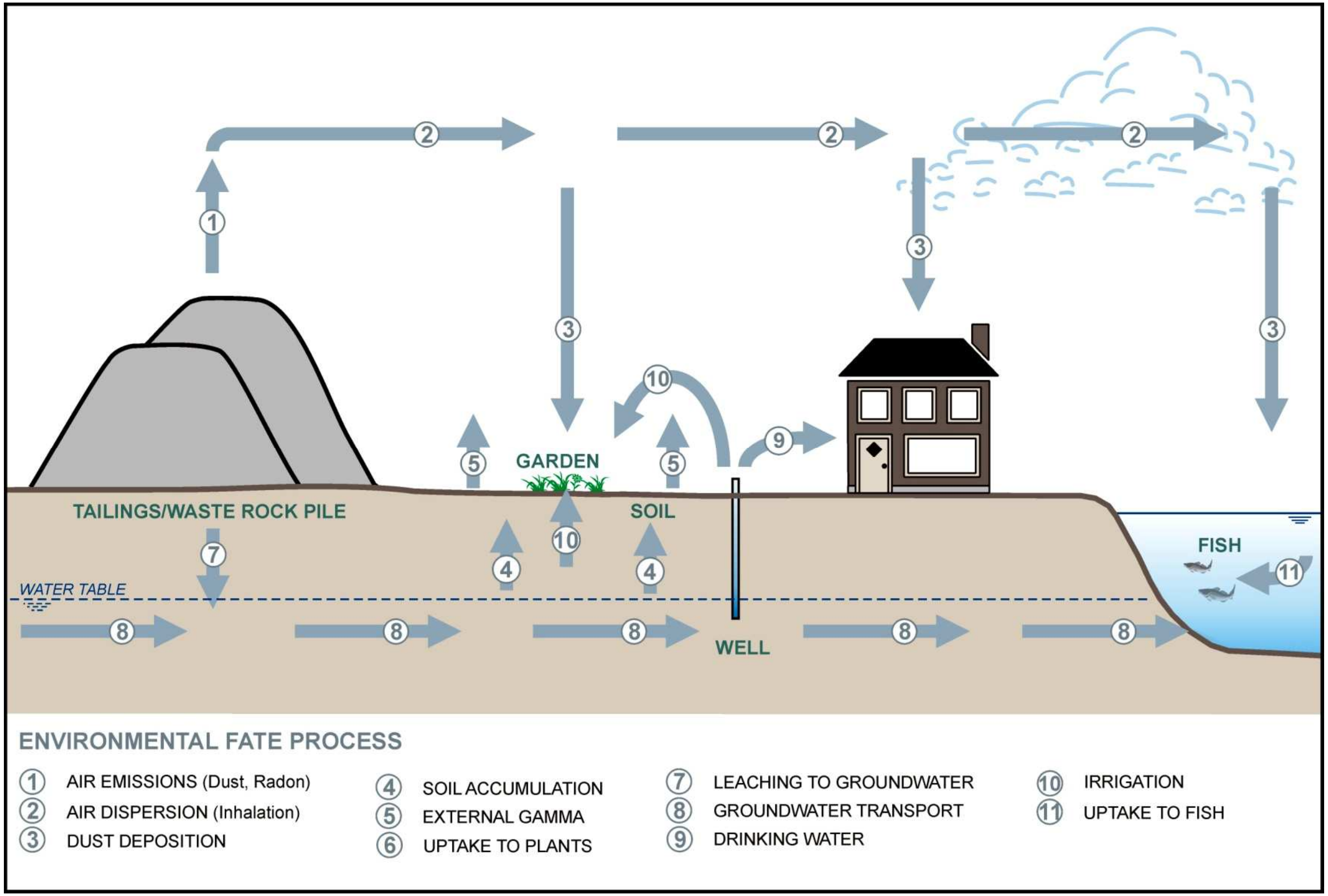
Dose Assessment (3)

- Two dose assessment scenarios were performed in this assessment:
  - using RESRAD K_d values for sand, very conservative estimate
  - using K_d values proposed in this study, considered more realistic

Pathways Considered

- The pathways considered in this assessment include:
  - inhalation of dust,
  - external exposure (from dust depositing on the ground at the residence),
  - ingestion of dust,
  - ingestion of garden and agricultural products
  - radon exposure,
  - groundwater pathway, and
  - surface water pathway.

Pathways Considered



Key Parameters (1)

- The K_d from the RESRAD data collection for sandy soil or from this study
- Inhalation and ingestion dose coefficients from ICRP 72
- Root transfer factors for irrigation of plants were taken from both IAEA TRS No.364 and CSA N288.1-08

Key Parameters (2)

- **Freshwater-to-fish transfer factors from CSA N288.1-08 and other published sources**
- **The approach to estimating radon dose was based on UNSCEAR 2000**

Results of Pathways Calculations

(U and Th both at 1Bq/g)

Pathway	Committed Effective Dose (mSv/a)			
	Proposed Distribution Coefficients		Sand Distribution Coefficients	
	Child	Adult	Child	Adult
Inhalation of Dust	3.4E-04	6.5E-04	3.4E-04	6.5E-04
Ingestion of Dust	0.011	1.8E-03	0.011	1.8E-03
External Exposure	5.6E-03	4.3E-03	5.0E-03	3.9E-03
Ingestion of Garden and Agricultural Products	5.2E-05	2.7E-05	2.8E-04	1.0E-04
Groundwater Pathway	0.24	0.19	1.3	0.74
Surface Water Pathway (Consumption of Fish)	7.6E-05	3.9E-05	5.9E-04	2.5E-04
Total	**0.26**	**0.20**	**1.3**	**0.75**

U Series Dose by Pathway

Pathway	Committed Effective Dose (mSv/a)			
	Proposed Distribution Coefficients		Sand Distribution Coefficients	
	Child	Adult	Child	Adult
Inhalation of Dust	1.3E-04	2.5E-04	1.3E-04	2.5E-04
Ingestion of Dust	7.0E-03	1.2E-03	7.0E-03	1.2E-03
External Exposure	2.5E-03	1.9E-03	1.9E-03	1.5E-03
Ingestion of Garden and Agricultural Products	3.4E-05	2.1E-05	2.4E-04	9.4E-05
Groundwater Pathway	0.16	0.15	1.1	0.67
Surface Water Pathway (Consumption of Fish)	4.7E-05	2.7E-05	5.5E-04	2.4E-04
Total	**0.17**	**0.15**	**1.1**	**0.67**

Groundwater Dose by Radionuclide
(U-238 and TH-232 Series)

Radionuclide	Dose, mSv/a			
	Proposed Distribution Coefficients		Sand Distribution Coefficients	
	Child	Adult	Child	Adult
U	7.05E-02	9.27E-02	1.01E-01	1.32E-01
Th-230	5.65E-03	1.01E-02	1.77E-03	3.17E-03
Ra-226	1.06E-02	1.08E-02	2.65E-02	2.70E-02
Pb-210	9.93E-03	6.66E-03	1.84E-01	1.23E-01
Po-210	6.07E-02	2.90E-02	8.09E-01	3.86E-01
Th-228	1.42E-02	6.61E-03	4.44E-03	2.07E-03
Th-232	6.21E-03	1.11E02	1.94E-03	3.47E-03
Ra-228	6.29E-02	2.66E-02	1.57E-01	6.66E-02
Total	**0.24**	**0.19**	**1.3**	**0.74**
Total (Only U-238)	**0.16**	**0.15**	**1.1**	**0.67**
Total (Only Ra-226, Pb-210, Po-210)	**0.081**	**0.046**	**1.0**	**0.54**

Discussion (1)

- Waste heaps have widely varying characteristics
- Diluted leachate may be used indvertently as a drinking water source
- Unlikely to drink acid seepage because of taste, colour and general poor water quality
- Other exposure pathways are also possible

Discussion (2)

- Results of dose assessment vary depending on pathways considered, model used and assumptions (i.e., involves judgement)
- For "realistic" scenarios, doses are likely to be below 1 mSv/y

Questions?