

Radiological Toolbox 3.0.0 Training

Health Physics Society
50th Midyear Meeting

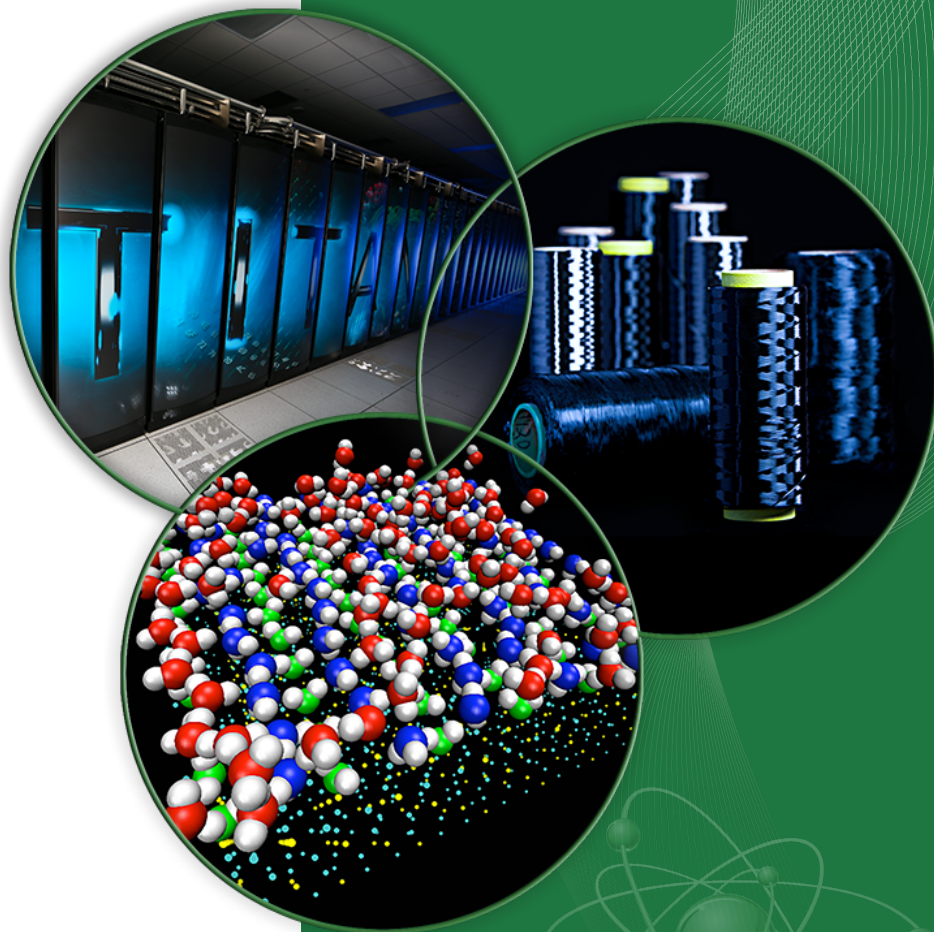
Shaheen Dewji, Ph.D.
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22-25 January, 2017

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for the US Department of Energy



Radiological Toolbox 3.0.0 - Outline

1. Meet the Developers
2. Introduction to Radiological Toolbox 3.0.0
3. Radiological Toolbox Functionality
4. Demo (7)

Slide Acknowledgements:

Casper Sun (NRC)

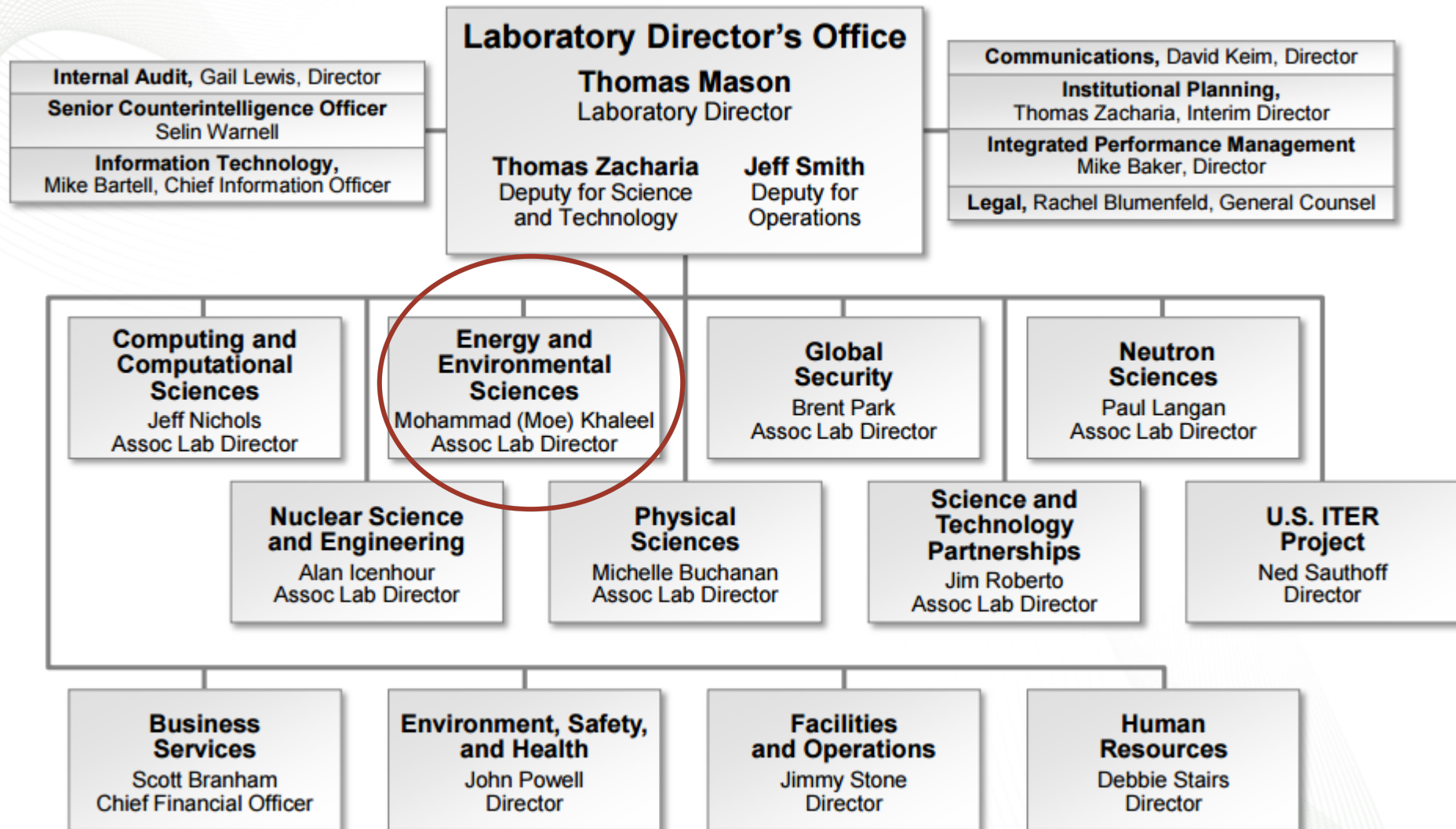
Sami Sherbini (NRC)

Nolan Hertel (Georgia Tech/ORNL-CRPK)

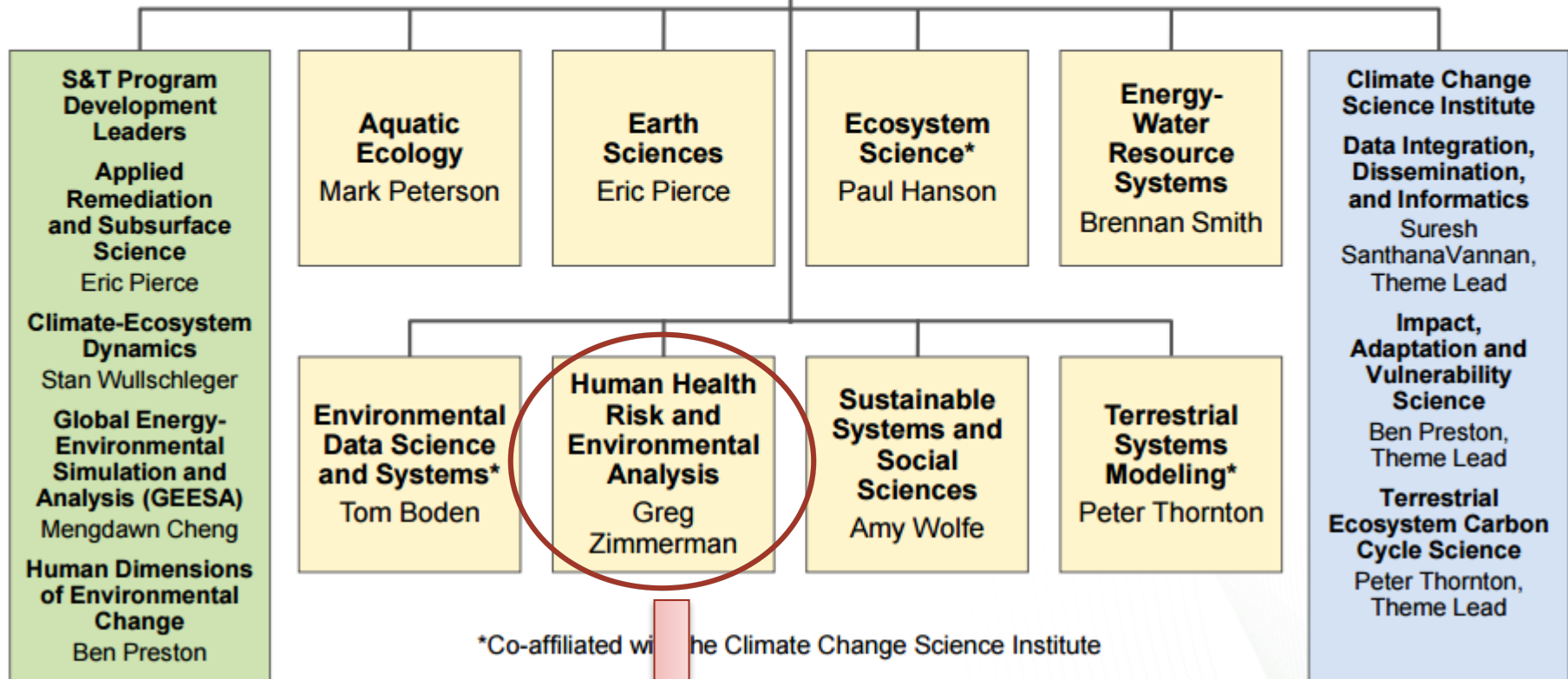
Meet the Developers



Oak Ridge National Laboratory



**Environmental
Sciences Division**
Stan Wullschleger, Acting Director



**Center for Radiation
Protection Knowledge
(CRPK)**

Center for Radiation Protection Knowledge

<http://crpk.ornl.gov/>

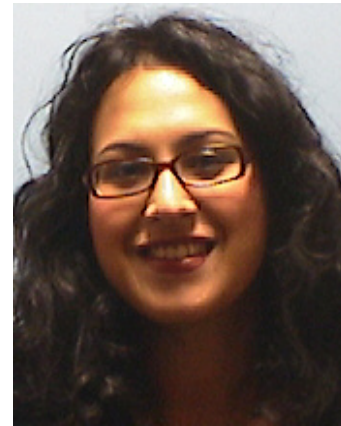
Top:

Nolan Hertel (JFA, Georgia Institute of Technology)
Keith Eckerman (Emeritus)
Rich Leggett (Senior R&D Scientist)



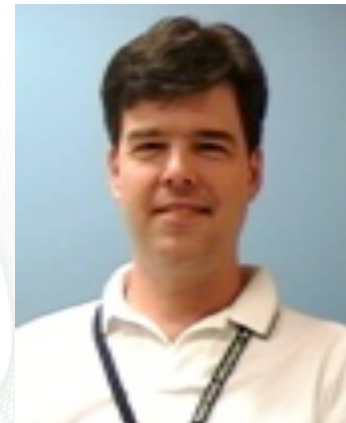
Middle:

Michael Bellamy (ORNL, R&D Engineer)
Shaheen Dewji (ORNL, R&D Engineer)
Derek Jokisch (JFA, Francis Marion U)



Bottom:

Clay Easterly (Consultant)
Ken Veinot (Consultant)
Pat Scofield (ORNL)
Scott Schwahn (ORNL)



ORNL Dosimetry Research Program: The Legacy

- Provided the national and international scientific communities with models and data
 - To estimate doses from exposure to radionuclides
 - To establish exposure guidelines for radionuclides.
- These models generally have become international standards.
- A center for archival and computer implementation of biokinetic and dosimetric models.

Center for Radiation Protection Knowledge (<http://crpk.ornl.gov/>)

- Established at ORNL per MOU 2010
 - DOE, DoD, EPA, NRC, and OSHA
- MOU Renewal in 2015



- Objectives
 - Maintaining/Preserving U.S. expertise and leadership
 - Development/Application of Radiation Dosimetry and Risk Assessment Methodologies/Models
 - Ensure the best scientifically available knowledge in regulatory processes and decision making

Introduction to Radiological Toolbox 3.0.0



Radiological Toolbox Software



- Developed for the NRC
- K.F. Eckerman, A.L. Sjoreen, “Radiological Toolbox User’s Guide”, ORNL/TM-2013/16, 2013
- Provide electronic access to a vast and varied array of data for radiation protection and shielding
 - Physical, chemical, anatomical, physiological, and mathematical parameters that normally requires access to multiple sources
- Latest release/update is version 3.0.0
 - Available at <https://www.usnrc-ramp.com/Radiological-Tools>

Radiological Toolbox User's Guide (NUREG/CR-7166, ORNL/TM-2013/16)



- Provides electronic access to the vast and varied data that underlies the field of radiation protection.
 - The initial motivation was to serve the needs of the health physicist away from his office, e.g., NRC inspectors
 - Earlier releases were widely used and accepted around the world by not only practicing health physicists but also those within educational programs
- Version 3.0.0
 - Updated to run on Windows 7 and 8 and on 32- and 64-bit machines
 - Nuclear decay data updated and now includes thermal neutron capture cross sections and cancer risk coefficients

RadToolbox

- **Available** (registration required) on **U.S. Nuclear Regulatory Commission Radiation Protection and Computer Code Maintenance Program (RAMP)**

NRC RAMP Website | RAMP Website

- <https://www.usnrc-ramp.com>

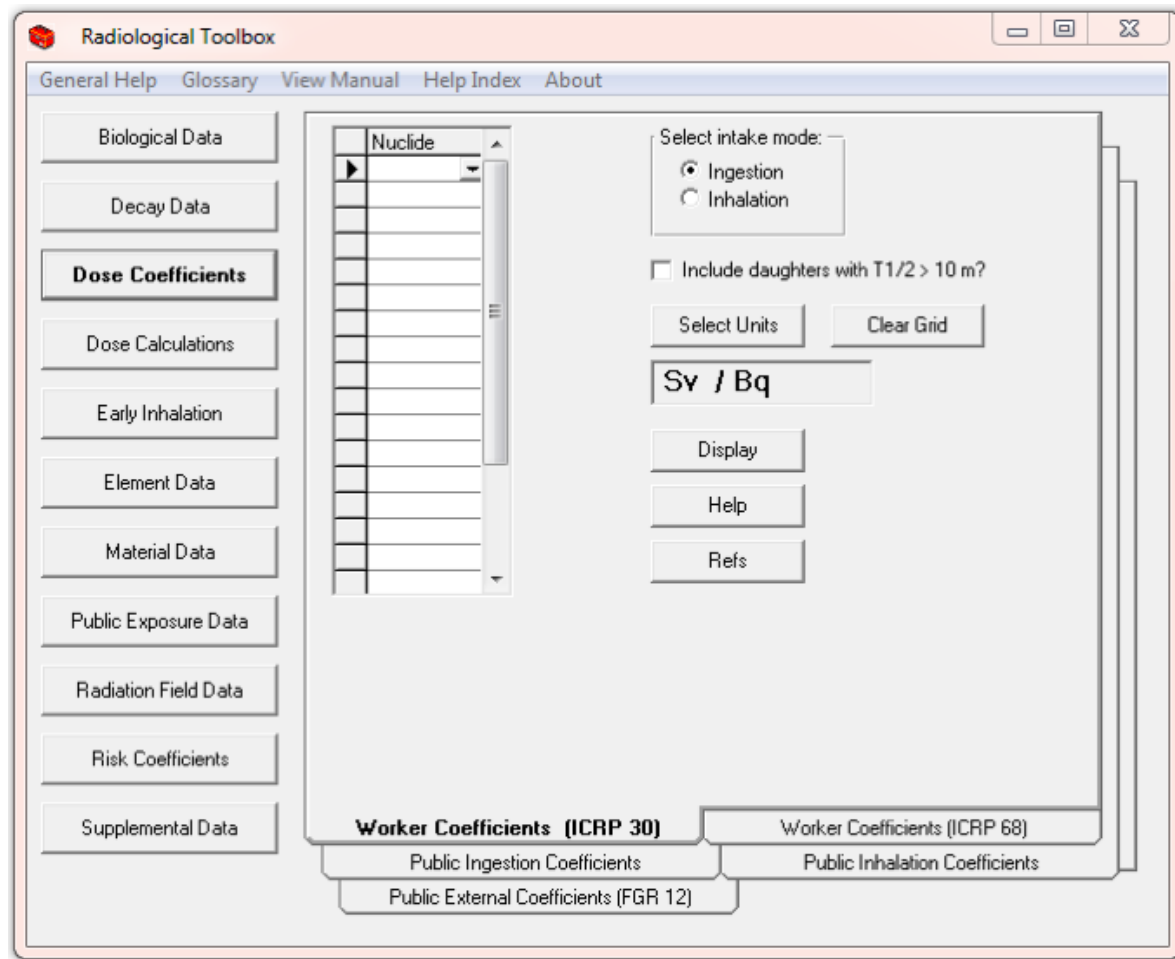
- ORNL inquiry:
crpk@ornl.gov



Radiological Toolbox Functionality



RadToolbox Interface



Biological Data

- Biokinetic Models from ICRP 68 and 72
- Bioassay Data - urinary and fecal excretion data and retention data
- Composition of Tissues from Coursey
- Organ Masses from ICRP Publications 23, 72, and 89
- ICRP 89 - extensive set of anatomical and physiological reference values
- Radiation Health Effects
 - deterministic and stochastic
 - summarized from various source

Decay Data

- Detailed radionuclide energy-intensity emission data
- ICRP Publication 107 data
 - NNDC ENSDF - input data into the analysis
 - Updated if necessary to those of NUBAS2003 and AME2003
- Radionuclide activity including the building of radioactive progeny can be calculated
- Option to export Tables of energy-intensity data to EXCEL
- ICRU-defined air kerma-rate constant air-kerma coefficient for the radionuclides
- The decay chain table includes the specific activity, half-life, decay mode, and identification of radioactive progeny with their branching fractions

Dose Coefficients

- External Environmental Dose Coefficients - 826 radionuclides from FGR12
- Committed Dose Coefficients for inhalation and ingestion – 738 radionuclides
 - Workers from ICRP 30 and 68
 - Age-dependent members of the public (six ages at intake) from ICRP 72.
- Display up to 20 nuclides at a time for a chosen route of exposure or intake.
 - Exportable to EXCEL spreadsheet
 - Organ equivalent dose and the effective dose for the selected radionuclide

Dose Calculations

- Simple numerical calculations of dose for a mixture of radionuclides
 - Select appropriate dose coefficients, nuclides and activities
 - ≤ 20 radionuclides
 - External exposure, total dose for the mixture
 - Intake of radionuclides
 - Dose for intake of each chemical form is reported and not the total.
 - User can export the table to EXCEL, delete columns of irrelevant chemical forms, and derive the total dose

Early Inhalation

- Inhalation dose coefficients for deterministic health effects
- Separate low- and high-LET values of absorbed dose are provided and the RBE can then be applied to the absorbed dose components
- These absorbed dose coefficients may be exported to EXCEL

Risk Coefficients

- Federal Guidance Report 13
- Average member of the US public
 - Mortality risk coefficient per unit activity inhaled or ingested for internal exposures or per unit time-integrated activity concentration in air or soil for external exposure
 - Morbidity risk coefficient is a comparable estimate of the average total risk of experiencing a radiogenic cancer, whether or not the cancer is fatal
 - Data presented for 14 cancer sites

Element Data

- Interaction coefficients for alpha, electron, photon, and neutron radiations in elemental absorbers.
 - Not available for every element or for each radiation type
 - Can be plotted
- Geometric progression form of the photon buildup factors from ANSI Standard 6.4
 - 0.015 and 15 MeV at distances ranging from 0.5 to 60 MFP
 - The photon and neutron kerma coefficients were taken from KERMAL, RSICC package DLC-143
- Atomic mass and isotopic abundance data
 - 16th edition of the Chart of the Nuclides
- Can be exported to EXCEL

Public Exposure Data

- Natural Background Radiation
- Background Radiation in the Body
- Radionuclides in Materials
- Radionuclides in Devices
- Primordial Radionuclides
- Typical Exposures during Medical Procedures

Other Data

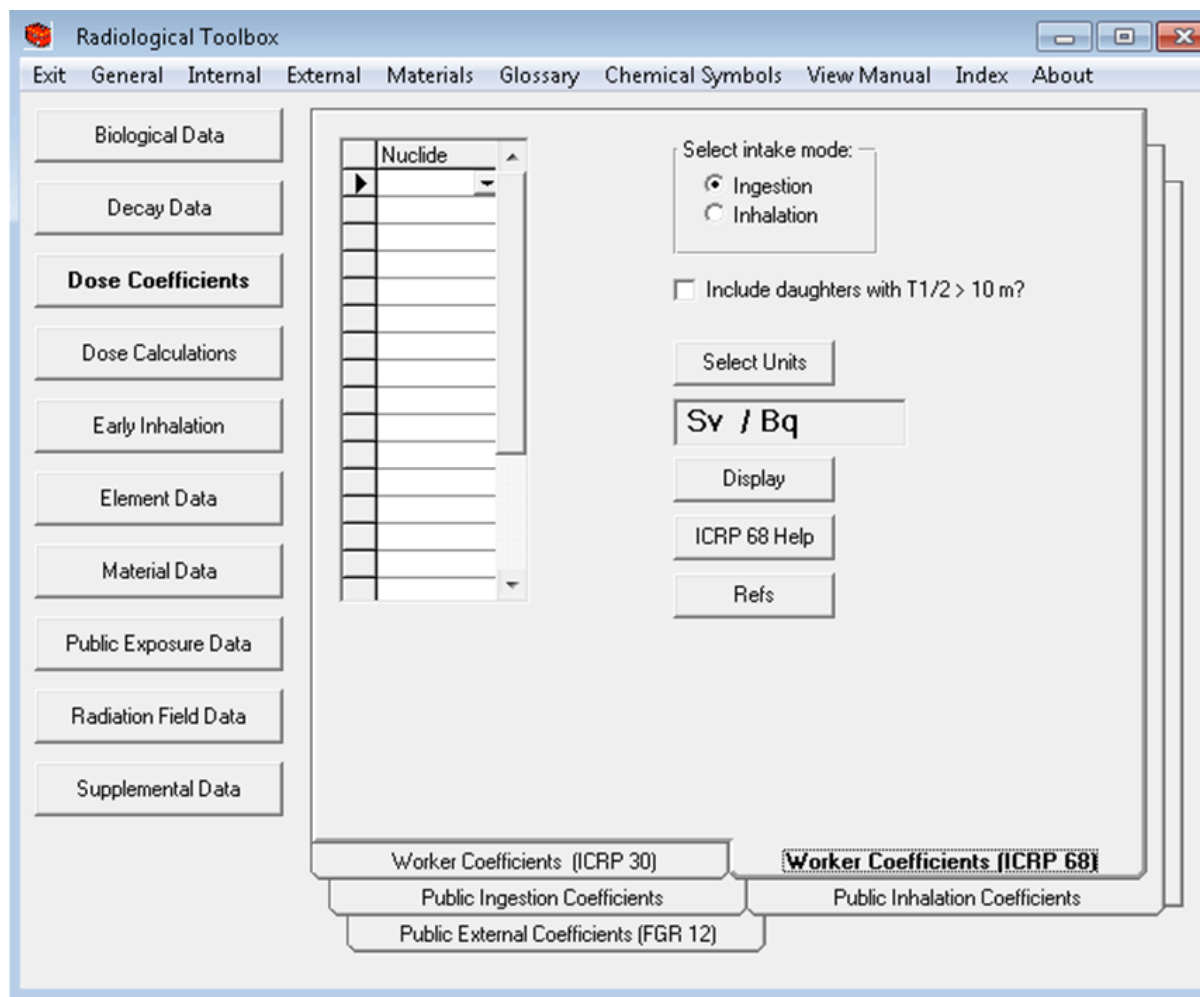
- **Radiation Field Data**

- ICRP Publication 74/ICRU Report 57 Dose Coefficients

- **Supplemental Data**

- SI Units
- Physical Constants
- Conversion Factors
- International Nuclear and Radiological Event Scale (INES)
- Formulas
- Web Pages
- DOE Dose Ranges
- Transport Package Regulations (A1/A2 Table)

RadToolbox – Future Outlook



Time for a smart phone version?

Radiological Toolbox Demo

a.k.a. “Homework”

The following questions and solutions were designed by Dr. Sami Sherbini, US-NRC.

Question 1

- Calculate committed effective dose from repair work in areas where the airborne concentration of ^{60}Co (Type W) is $4 \times 10^3 \text{ Bq m}^{-3}$. The workers will be remaining in this for 2.5 hours. What are the results from using ICRP-26 and ICRP-60 dose coefficients (Sv/Bq)?

Question 1

Radiological Toolbox

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Dose Coefficients

Dose Calculations

Early Inhalation

Element Data

Material Data

Public Exposure Data

Radiation Field Data

Risk Coefficients

Supplemental Data

Nuclide
Co-60

Select intake mode:
☐ Ingestion
☒ Inhalation

☐ Include daughters with T1/2 > 10 m?

Select Units Clear Grid

Sv / Bq

Display

Help

Refs

Worker Coefficients (ICRP 30)

Public Ingestion Coefficients

Public External Coefficients (FGR 12)

Worker Coefficients (ICRP 68)

Public Inhalation Coefficients

Inhalation dose coefficients (Sv / Bq) from ICRP 30

Nuclide	Co-60	Co-60
Class	W	Y
f1	5.00E-02	5.00E-02
Adrenals	6.95E-09	3.00E-08
Bladder Wall	3.43E-09	2.95E-09
Bone Surface	3.54E-09	1.35E-08
Brain	0.00E+00	0.00E+00
Breast	4.16E-09	1.84E-08
Esophagus	8.00E-09	5.75E-08
Stomach Wall	5.39E-09	2.73E-08
Small Intestine Wall	4.74E-09	7.05E-09
Upper Large Intestine Wall	5.89E-09	9.70E-09
Lower Large Intestine Wall	8.15E-09	7.93E-09
Kidneys	4.50E-09	1.56E-08
Liver	9.17E-09	3.35E-08
Lungs	3.57E-08	3.45E-07
Muscle	4.16E-09	1.84E-08
Ovaries	4.05E-09	4.76E-09
Pancreas	5.97E-09	3.17E-08
Red Marrow	4.25E-09	1.72E-08
Skin	2.63E-09	1.02E-08
Spleen	5.21E-09	2.70E-08
Testes	2.68E-09	1.70E-09
Thymus	8.00E-09	5.75E-08
Thyroid	3.72E-09	1.62E-08
Uterus	3.84E-09	4.62E-09
Effective (ICRP 26)	8.94E-09	5.91E-08
Effective (ICRP 60)	8.92E-09	5.62E-08

Solving Question 1

1. Click **Dose Coefficients** tab.
2. Click **Worker Coefficients (ICRP 30)** tab.
3. Click **Units** and choose **Sv/Bq** (this is the default).
4. Enter **Co** and **select Co-60** from the Nuclide drop down menu.
5. Select the **Inhalation** button for intake mode.
6. Click the **Display** tab.
7. Read off the dose coefficients for **Type W**:
 - **8.94E-9 Sv/Bq for ICRP 26**
 - **8.92E-9 Sv/Bq for ICRP 60**

The coefficients show that for ^{60}Co , there is little difference between ICRP26 and ICRP 60.

Radiological Toolbox

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Public Exposure Data

Radiation Field Data

Risk Coefficients

Supplemental Data

Nuclide
Co-60

Select intake mode:
☐ Ingestion
☒ Inhalation

☐ Include daughters with T1/2 > 10 m?

Select Units Clear Grid

Sv / Bq

Display

Help

Refs

Worker Coefficients (ICRP 30)

Worker Coefficients (ICRP 68)

Public Ingestion Coefficients

Public Inhalation Coefficients

Public External Coefficients (FGR 12)

Inhalation dose coefficients (Sv / Bq) from ICRP 30

Nuclide	Co-60	Co-60
Class	W	Y
Al	5.00E-02	5.00E-02
Adrenals	6.95E-09	3.00E-08
Bladder Wall	3.43E-09	2.95E-09
Bone Surface	3.54E-09	1.35E-08
Brain	0.00E+00	0.00E+00
Breast	4.16E-09	1.84E-08
Esophagus	8.00E-09	5.75E-08
Stomach Wall	5.39E-09	2.73E-08
Small Intestine Wall	4.74E-09	7.05E-09
Upper Large Intestine Wall	5.89E-09	9.70E-09
Lower Large Intestine Wall	8.15E-09	7.93E-09
Kidneys	4.50E-09	1.56E-08
Liver	9.17E-09	3.35E-08
Lungs	3.57E-08	3.45E-07
Muscle	4.16E-09	1.84E-08
Ovaries	4.05E-09	4.76E-09
Pancreas	5.97E-09	3.17E-08
Red Marrow	4.25E-09	1.72E-08
Skin	2.63E-09	1.02E-08
Spleen	5.21E-09	2.70E-08
Testes	2.68E-09	1.70E-09
Thymus	8.00E-09	5.75E-08
Thyroid	3.72E-09	1.62E-08
Uterus	3.84E-09	4.62E-09
Effective (ICRP 26)	8.94E-09	5.91E-08
Effective (ICRP 60)	8.92E-09	5.62E-08

Solving Question 1

Radiological Toolbox

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Dose Coefficients

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Early Inhalation

Element Data

Material Data

Public Exposure Data

Radiation Field Data

Risk Coefficients

Supplemental Data

Biokinetic Models
Display: GI model

Bioassay Data
Display: Am-241 Type: M

Composition of Tissues
Display: ADIPOSE TISSUE (ICRP)

Organ Masses - ICRP 23/89/72
Display: Select Units: g

ICRP89 Reference Values
ICRP 89 Data: respiratory function

Radiation Health Effects
Display: Summary of Health Effects

Biological Data

ICRP 89 Reference Data for respiratory function

Age	Age Unit	Gender	Value	Units	Reference
3	mo	both	0.19	m ³ h ⁻¹	Table 2.32, p. 25
1	y	both	0.35	m ³ h ⁻¹	Table 2.32, p. 25
5	y	both	0.57	m ³ h ⁻¹	Table 2.32, p. 25
10	y	both	1.1	m ³ h ⁻¹	Table 2.32, p. 25
15	y	male	1.4	m ³ h ⁻¹	Table 2.32, p. 25
15	y	female	1.3	m ³ h ⁻¹	Table 2.32, p. 25
20	y	male	1.5	m ³ h ⁻¹	Table 2.32, p. 25
20	y	female	1.3	m ³ h ⁻¹	Table 2.32, p. 25

Select Reference Characteristics

Ventilation (L Exercise 32%)

Apply

Print

Export

- Click **OK** to close the Dose Coefficient window.
- Click the **Biological Data** tab.
- Under the **ICRP-89 Reference Values** tab, select **Respiratory Functions** from the drop-down menu.
- Click **ICRP89** Data tab.
- Select **Ventilation (L Exercise)** from the dropdown menu.
- Read the rate of **1.3 m³/hr** for a female worker.

Solution 1

Committed effective dose

$$= 8.92 \times 10^{-9} \text{ (Sv/Bq)} \times 1.3 \text{ (m}^3\text{/hr)} \times 2.5 \text{ (hr)} \times 4 \times 10^5 \text{ (Bq/m}^3\text{)}$$

$$= \mathbf{11.6 \text{ mSv (1.16 rem)}}$$

Question 2

- The concentration of ^{131}I (Type F) in air in an unrestricted area is $3 \times 10^2 \text{ Bq/m}^3$. Assuming this concentration to remain constant over a period of one year, and using ICRP-60 data
 - a) What is the dose coefficient in this case for a 1 year-old child and for an adult?
 - b) What is the ratio of these coefficients?
 - c) What would be the effective dose to the child and to the adult as a result of the 1 year exposure?
 - d) What is the ratio?

Question 2 (a) and (b)

- The concentration of ^{131}I (Type F) in air in an unrestricted area is $3 \times 10^2 \text{ Bq/m}^3$. Assuming this concentration to remain constant over a period of one year, and using ICRP-60 data
 - a) What is the dose coefficient in this case for a 1 year-old child and for an adult?
 - b) What is the ratio of these coefficients?
 - c) What would be the effective dose to the child and to the adult as a result of the 1 year exposure?
 - d) What is the ratio?

Question 2 (a) and (b)

The screenshot displays the 'Radiological Toolbox' application. On the left is a vertical sidebar with buttons for 'General Help', 'Glossary', 'View Manual', 'Help Index', 'About', 'Biological Data', 'Decay Data', 'Dose Coefficients' (highlighted), 'Dose Calculations', 'Early Inhalation', 'Element Data', 'Material Data', 'Public Exposure Data', 'Radiation Field Data', 'Risk Coefficients', and 'Supplemental Data'. The main window is titled 'Dose Coefficients' and contains a 'Nuclide' dropdown menu set to 'I-131'. To the right of the menu is a 'Select age:' section with radio buttons for 'Newborn', '1 yr-old' (selected), '5 yr-old', '10 yr-old', '15 yr-old', and 'Adult'. Below this is a checkbox for 'Include daughters with T1/2 > 10 m?' which is unchecked. Further right are 'Select Units' and 'Clear Grid' buttons, followed by a 'Sv / Bq' unit label. At the bottom of the main window are buttons for 'Display', 'Help', and 'Refs'. Below the main window area are four buttons: 'Public Ingestion Coefficients', 'Public Inhalation Coefficients' (highlighted), 'Public External Coefficients (FGR 12)', and 'Worker Coefficients (ICRP 30)'. On the far right, there are 'Print', 'Export', and 'OK' buttons. The 'Public Inhalation Coefficients' window is open, showing a table titled 'Inhalation 1 yr-old dose coefficients (Sv / Bq) from ICRP 72'. The table has five columns: 'Nuclide', 'I-131', 'I-131', 'I-131', and 'I-131'. The rows list various organs and tissues with their corresponding dose coefficients. The 'Effective (ICRP 60)' row is highlighted in blue.

Nuclide	I-131	I-131	I-131	I-131
Half Life	8.04d	8.04d	8.04d	8.04d
Type	V	V	F	M
AMAD	1.00E+00	1.00E+00	1.00E+00	1.00E+00
f1	1 CH3I	1 I2	1.00E+00	1.00E-01
Adrenals	2.30E-10	3.00E-10	1.40E-10	3.60E-10
Urinary Bladder	1.10E-09	1.40E-09	6.00E-10	2.60E-10
Bone Surface	3.10E-10	4.10E-10	1.90E-10	2.20E-10
Brain	2.70E-10	3.50E-10	1.60E-10	5.30E-11
Breast	2.90E-10	3.90E-10	1.80E-10	3.10E-10
Esophagus	1.20E-09	1.60E-09	8.20E-10	4.70E-10
Stomach	2.10E-10	6.30E-10	3.60E-10	7.30E-10
Small Intestine	2.10E-10	2.80E-10	1.30E-10	1.50E-09
Upper Large Intestine	5.30E-10	7.40E-10	3.40E-10	6.70E-09
Lower Large Intestine	1.00E-09	1.50E-09	6.80E-10	1.70E-08
Colon	7.50E-10	1.10E-09	4.90E-10	1.10E-08
Kidneys	2.00E-10	2.60E-10	1.20E-10	1.90E-10
Liver	2.30E-10	3.00E-10	1.40E-10	3.10E-10
Muscle	4.60E-10	6.10E-10	3.00E-10	2.50E-10
Ovaries	2.20E-10	2.80E-10	1.30E-10	5.30E-10
Pancreas	2.30E-10	3.10E-10	1.40E-10	3.20E-10
Red Marrow	2.60E-10	3.40E-10	1.60E-10	1.70E-10
Extratrachial Airways	2.80E-10	8.60E-09	1.50E-08	1.80E-08
Lungs	3.80E-10	2.10E-09	2.90E-10	2.70E-08
Skin	2.40E-10	3.10E-10	1.50E-10	1.10E-10
Spleen	2.20E-10	2.90E-10	1.30E-10	3.00E-10
Testes	1.80E-10	2.30E-10	1.00E-10	9.40E-11
Thymus	1.20E-09	1.60E-09	8.20E-10	4.70E-10
Thyroid	2.50E-06	3.20E-06	1.40E-06	2.10E-07
Uterus	2.20E-10	2.80E-10	1.30E-10	2.90E-10
Remainder	4.20E-10	5.60E-10	2.70E-10	2.40E-10
Effective (ICRP 60)	1.30E-07	1.60E-07	7.20E-08	1.50E-08

Solving Question 2 (a) and (b)

1. Click **Dose Coefficients** tab.
2. Click **Public Inhalation Coefficients**.
3. Select **I-131** from the drop-down nuclide menu,
 - 1 year old button from the age menu.
 - Click **Display**.

Solution 2 (a) and (b)

- a) *Child (1-y) = 7.2E-8 Sv/Bq*
Adult (>17) = 7.4E-9 Sv/Bq
- b) Ratio of dose coefficients (Child/Adult) = $7.2\text{E-}8/7.4\text{E-}9 = 9.7$

Question 2 (c) and (d)

- The concentration of ^{131}I (Type F) in air in an unrestricted area is $3 \times 10^2 \text{ Bq/m}^3$. Assuming this concentration to remain constant over a period of one year, and using ICRP-60 data
 - a) What is the dose coefficient in this case for a 1 year-old child and for an adult?
 - b) What is the ratio of these coefficients?
 - c) What would be the effective dose to the child and to the adult as a result of the 1 year exposure?
 - d) What is the ratio?

Question 2 (c) and (d)

Radiological Toolbox

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Risk Coefficients

Supplemental Data

Biokinetic Models
Display GI model

Bioassay Data
Display Am-241 Type: M

Composition of Tissues
Display ADIPOSE TISSUE (ICRP)

Organ Masses - ICRP 23/89/72
Display Select Units g

ICRP89 Reference Values
ICRP 89 Data respiratory function

Radiation Health Effects
Display Summary of Health Effects

Biological Data

ICRP 89 Reference Data for respiratory function

Age	Age Unit	Gender	Value	Units	Reference
3	mo	both	0.19	m3h-1	Table 2.32, p. 25
1	y	both	0.35	m3h-1	Table 2.32, p. 25
5	y	both	0.57	m3h-1	Table 2.32, p. 25
10	y	both	1.1	m3h-1	Table 2.32, p. 25
15	y	male	1.4	m3h-1	Table 2.32, p. 25
15	y	female	1.3	m3h-1	Table 2.32, p. 25
20	y	male	1.5	m3h-1	Table 2.32, p. 25
20	y	female	1.3	m3h-1	Table 2.32, p. 25

Select Reference Characteristics
Ventilation (L Exercise 32%)

Apply

Print

Export

OK

Solving Question 2 (c) and (d)

1. Click Biological Data.
2. ICRP-89 Reference Values.
3. Respiratory Function, Ventilation, Light Exercise:

Child = $0.35 \text{ m}^3/\text{hr}$

Adult = $1.5 \text{ m}^3/\text{hr}$

Solution 2 (c) and (d)

c) The annual doses are:

- **Child:**

$$D = 7.2\text{E-}8 \text{ Sv/Bq} \times 300 \text{ Bq/m}^3 \times 0.35 \text{ m}^3/\text{hr} \times 8760 \text{ hr/yr} \times 1 \text{ yr} = \mathbf{0.066 \text{ Sv}}$$

- **Adult:**

$$D = 7.4\text{E-}9 \text{ Sv/Bq} \times 300 \text{ Bq/m}^3 \times 1.50 \text{ m}^3/\text{hr} \times 8760 \text{ hr/yr} \times 1 \text{ yr} = \mathbf{0.029 \text{ Sv}}$$

d) Ratio of annual dose (Child/Adult) = $0.066/0.029 = \mathbf{2.3}$

Although the ratio of dose coefficients is 9.7, the ratio of annual doses is 2.3. The reason for this difference in ratios is the difference in breathing rates.

Question 3

- A worker is suspected of having inhaled airborne ^{134}Cs (Type F) and was asked to collect a 24-hour urine sample. The sample was collected 5 days following the suspected intake incident, and showed an activity of 50 Bq/mL of urine. The volume of urine was 950 mL.
 - a) What is the estimated intake?
 - b) What is the resulting effective dose?
 - c) Which organ receive the highest dose from this exposure and does it exceed the 0.5 Sv imposed by US regulations on organ dose?

Question 3 (a)

- A worker is suspected of having inhaled airborne ^{134}Cs (Type F) and was asked to collect a 24-hour urine sample. The sample was collected 5 days following the suspected intake incident, and showed an activity of 50 Bq/mL of urine. The volume of urine was 950 mL.
 - a) What is the estimated intake?
 - b) What is the resulting effective dose?
 - c) Which organ receive the highest dose from this exposure and does it exceed the 0.5 Sv imposed by US regulations on organ dose?

Solving 3 (a)

1. Click the **Biological data** tab.
2. In the **Bioassay Data** tab, select **Cs-134** and select **Type F** and click **Display**.
3. In the **E_Urine(t)** column select the row corresponding to **5 days** and read the value **5.43E-3**.

This is the urine excretion fraction for that time post-intake.

Radiological Toolbox

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ICRP89 Reference Values

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Radiation Health Effects

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Bioassay data of occupational inhalation intakes of Cs-134 ICRP 68, Absorption Type F

Time (days)	E_Fecal(t)	Cumulative Fecal Excretion	E_Urine(t)	Cumulative Urin Excretion
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+00	9.64E-04	9.64E-04	7.86E-03	7.86E-03
1.50E+00	1.66E-03	1.93E-03	1.13E-02	1.36E-02
2.00E+00	2.10E-03	3.06E-03	1.11E-02	1.89E-02
2.50E+00	2.34E-03	4.27E-03	9.93E-03	2.36E-02
3.00E+00	2.41E-03	5.47E-03	8.76E-03	2.77E-02
3.50E+00	2.36E-03	6.63E-03	7.71E-03	3.13E-02
4.00E+00	2.23E-03	7.71E-03	6.82E-03	3.45E-02
4.50E+00	2.07E-03	8.69E-03	6.06E-03	3.74E-02
5.00E+00	1.89E-03	9.59E-03	5.43E-03	3.99E-02
5.50E+00	1.71E-03	1.04E-02	4.89E-03	4.22E-02
6.00E+00	1.55E-03	1.11E-02	4.44E-03	4.44E-02
7.00E+00	1.27E-03	1.24E-02	3.74E-03	4.81E-02
8.00E+00	1.05E-03	1.35E-02	3.24E-03	5.13E-02
9.00E+00	8.96E-04	1.44E-02	2.88E-03	5.42E-02
1.00E+01	7.82E-04	1.51E-02	2.62E-03	5.68E-02
1.50E+01	5.43E-04	1.82E-02	2.07E-03	6.79E-02
2.00E+01	4.86E-04	2.07E-02	1.91E-03	7.78E-02
2.50E+01	4.62E-04	2.31E-02	1.83E-03	8.71E-02
3.00E+01	4.45E-04	2.53E-02	1.76E-03	9.60E-02
3.50E+01	4.29E-04	2.75E-02	1.70E-03	1.05E-01
4.00E+01	4.14E-04	2.96E-02	1.64E-03	1.13E-01
4.50E+01	3.99E-04	3.16E-02	1.58E-03	1.21E-01
5.00E+01	3.85E-04	3.36E-02	1.53E-03	1.29E-01
5.50E+01	3.71E-04	3.54E-02	1.47E-03	1.36E-01
6.00E+01	3.58E-04	3.73E-02	1.42E-03	1.43E-01
7.00E+01	3.33E-04	4.07E-02	1.32E-03	1.57E-01
8.00E+01	3.10E-04	4.39E-02	1.23E-03	1.70E-01

Double-click any column to plot those data.

Help

Export

Print

OK

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Solution 3 (a)

Intake =

$$(50 \text{ (Bq/mL)} \times 900 \text{ (mL)}) / 5.43\text{E-}3 = 8.29\text{E}6 \text{ Bq}$$

Question 3 (b)

- A worker is suspected of having inhaled airborne ^{134}Cs (Type F) and was asked to collect a 24-hour urine sample. The sample was collected 5 days following the suspected intake incident, and showed an activity of 50 Bq/mL of urine. The volume of urine was 950 mL.
 - a) What is the estimated intake?
 - b) What is the resulting effective dose?
 - c) Which organ receive the highest dose from this exposure and does it exceed the 0.5 Sv imposed by US regulations on organ dose?

Solving 3 (b)

1. Click **Dose Coefficient** tab.
2. ICRP-68 worker data
3. Select Inhalation of Cs-134,
b) Effective dose coefficient is **9.6E-9 Sv/Bq**.

The screenshot shows the 'Radiological Toolbox' application window. The 'Dose Coefficients' tab is selected in the left sidebar. The main window displays the 'Inhalation dose coefficients (Sv / Bq) from ICRP 68' table. The 'Nuclide' dropdown is set to 'Cs-134', and the 'Intake mode' is set to 'Inhalation'. The 'Effective (ICRP 60)' coefficient is highlighted in the table.

Nuclide	Cs-134
Half Life	2.062y
Type	F
AMAD	5.00E+00
f1	1.00E+00
Adrenals	1.00E-08
Urinary Bladder	9.70E-09
Bone Surface	9.60E-09
Brain	7.40E-09
Breast	6.80E-09
Esophagus	9.00E-09
Stomach	9.00E-09
Small Intestine	1.00E-08
Upper Large Intestine	9.70E-09
Lower Large Intestine	1.10E-08
Colon	1.00E-08
Kidneys	9.40E-09
Liver	9.50E-09
Muscle	8.40E-09
Ovaries	1.00E-08
Pancreas	1.00E-08
Red Marrow	9.00E-09
Extrathoracic Airways	2.30E-08
Lungs	8.50E-09
Skin	6.30E-09
Spleen	9.40E-09
Testes	8.40E-09
Thymus	9.00E-09
Thyroid	9.00E-09
Uterus	1.00E-08
Remainder	1.50E-08
Effective (ICRP 60)	9.60E-09

Solution 3 (b)

Committed effective dose

$$= 9.6\text{E-}9 \text{ (Sv/Bq)} \times 8.29\text{E}6 \text{ (Bq)}$$

$$= \mathbf{0.08 \text{ Sv}}$$

Question 3 (c)

- A worker is suspected of having inhaled airborne ^{134}Cs (Type F) and was asked to collect a 24-hour urine sample. The sample was collected 5 days following the suspected intake incident, and showed an activity of 50 Bq/mL of urine. The volume of urine was 950 mL.
 - a) What is the estimated intake?
 - b) What is the resulting effective dose?
 - c) Which organ receive the highest dose from this exposure and does it exceed the 0.5 Sv imposed by US regulations on organ dose?

Solution 3 (c)

- Using the limit of 0.5 Sv for any organ, and an intake of **8.29E6 Bq**, any organ with a dose coefficient greater than $0.5/8.29E6 = 6.0E-8 \text{ Sv/Bq}$ will exceed the limit.
- A review of the dose coefficient table shows that none of the organs exceeds that dose.

Inhalation dose coefficients (Sv / Bq) from ICRP 68

Nuclide	Cs-134
Half Life	2.062y
Type	F
AMAD	5.00E+00
f1	1.00E+00
Adrenals	1.00E-08
Urinary Bladder	9.70E-09
Bone Surface	9.60E-09
Brain	7.40E-09
Breast	6.80E-09
Esophagus	9.00E-09
Stomach	9.00E-09
Small Intestine	1.00E-08
Upper Large Intestine	9.70E-09
Lower Large Intestine	1.10E-08
Colon	1.00E-08
Kidneys	9.40E-09
Liver	9.50E-09
Muscle	8.40E-09
Ovaries	1.00E-08
Pancreas	1.00E-08
Red Marrow	9.00E-09
Extrathoracic Airways	2.30E-08
Lungs	8.50E-09
Skin	6.30E-09
Spleen	9.40E-09
Testes	8.40E-09
Thymus	9.00E-09
Thyroid	9.00E-09
Uterus	1.00E-08
Remainder	1.50E-08
Effective (ICRP 60)	9.60E-09

Question 4

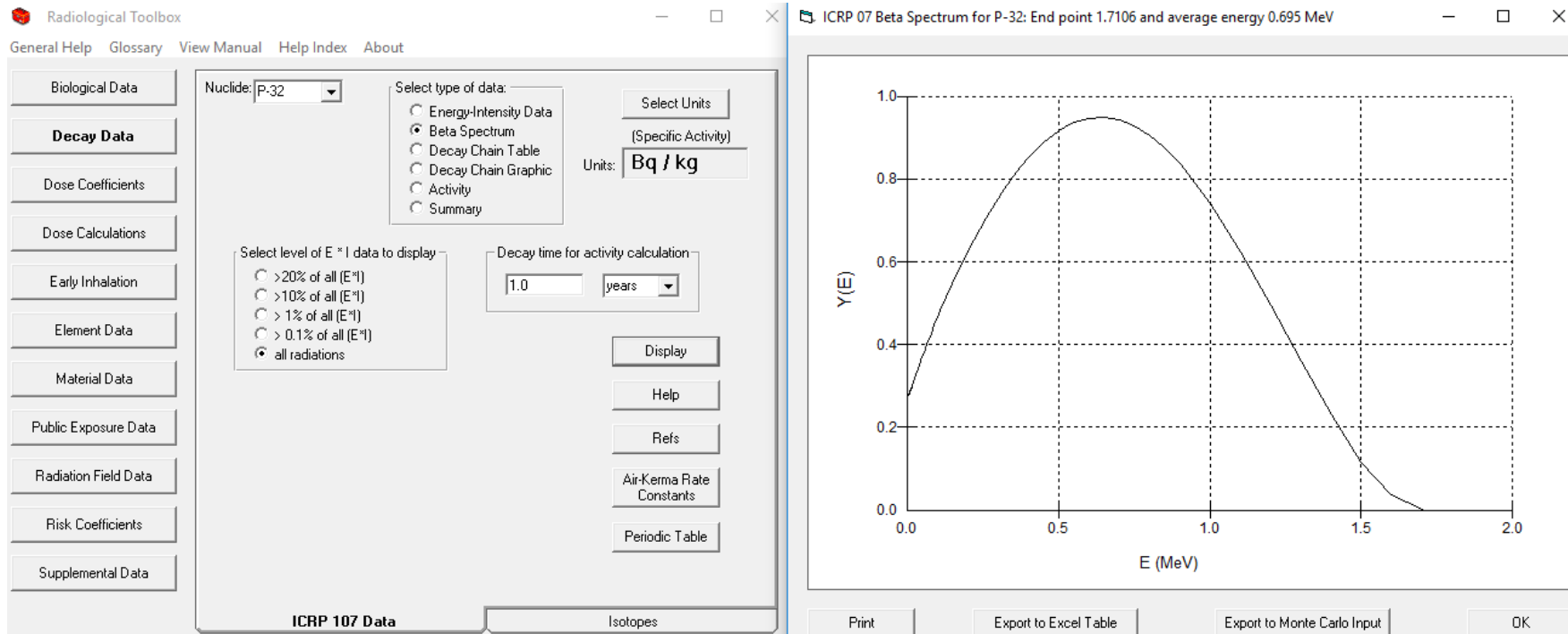
- a) What is the mean energy and the end-point energy of the beta spectrum emitted by ^{32}P ?
- b) What is the CSDA range, gm/cm^2 of electrons with this end-point energy in leaded glass? What fraction of the beta energy is going to be converted to bremsstrahlung radiation?

Question 4 (a)

- a) What is the mean energy and the end-point energy of the beta spectrum emitted by ^{32}P ?
- b) What is the CSDA range, gm/cm^2 of electrons with this end-point energy in leaded glass? What fraction of the beta energy is going to be converted to bremsstrahlung radiation?

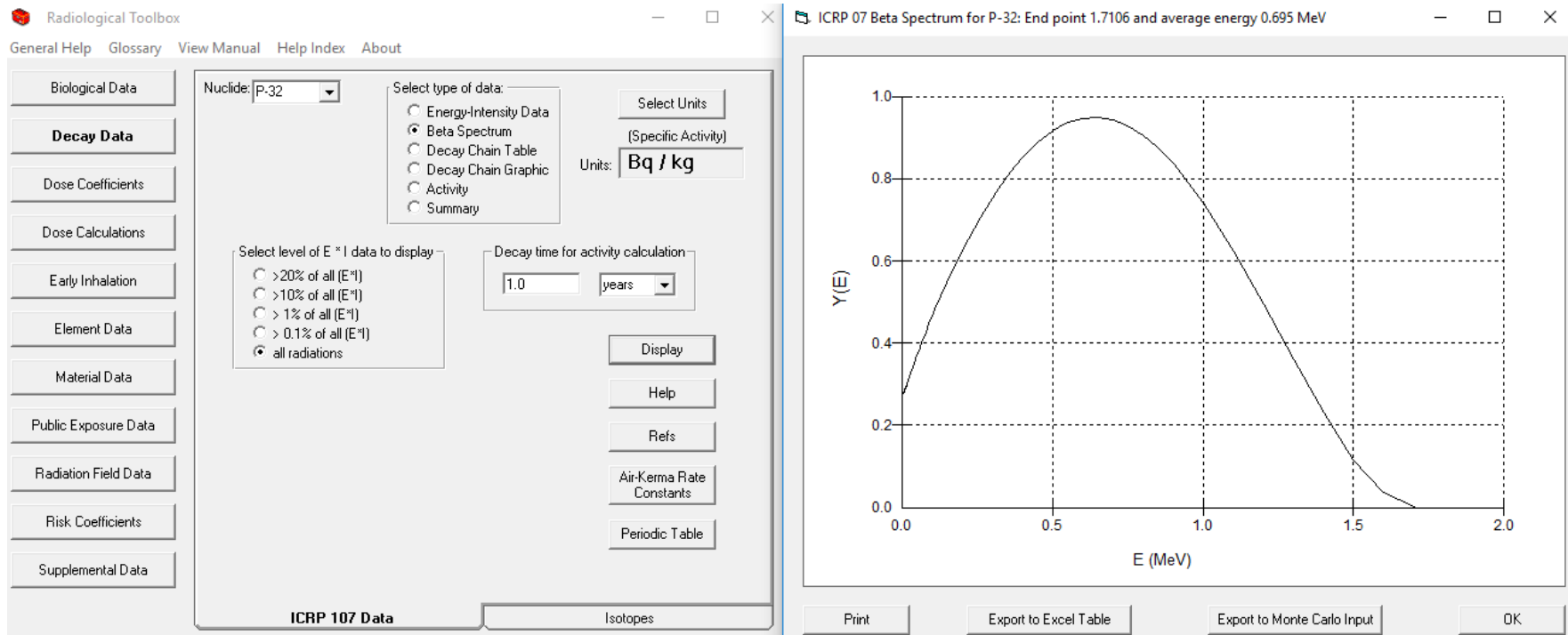
Solving 4 (a)

1. Click the **Decay Data** tab.
2. Select the **ICRP-107 Data** tab.
3. Select **P-32** from the Nuclide drop-down menu.
4. Select the **Beta Spectrum** button.
5. Click **Display**. The average and end-point energies are shown at the top of the beta spectrum.



Solution 4 (a)

- End-point = 1.7106 MeV
- Average = 0.695 MeV



Question 4 (b)

- a) What is the mean energy and the end-point energy of the beta spectrum emitted by ^{32}P ?
- b) What is the CSDA range, gm/cm^2 of electrons with this end-point energy in leaded glass? What fraction of the beta energy is going to be converted to bremsstrahlung radiation?

Solving 4 (b)

1. Click the **Material Data** tab.
2. Select the **Electron Data** tab.
3. Select **Glass, Lead** from the material drop-down menu.
4. Check the **CSDA Range** and the **Yield** buttons.
5. Click **Display**.
6. Read the CSDA and Yield

The screenshot shows the Radiological Toolbox software interface. The left sidebar contains several tabs, with **Material Data** selected. Under **Material Data**, the **Electron Data** sub-tab is active. The main panel displays the material selection as **GLASS, LEAD**. Below this, there are checkboxes for different data types: ☐ Stopping Power - Collision, ☐ Stopping Power - Radiative, ☐ Stopping Power - Total, ☒ CSDA Range, ☒ Radiation Yield, and ☐ Density Effect Delta. The units are set to **MeV cm² / g** for coefficients and **g / cm²** for range. The **Display** button is highlighted. The right panel shows a table of calculated values for Kinetic Energy (MeV), CSDA Range (g/cm²), and Radiation Yield. The table is titled "Electron absorber data for GLASS, LEAD".

Kinetic Energy (MeV)	CSDA Range (g/cm ²)	Radiation Yield
5.00E-01	3.05E-01	3.28E-02
5.50E-01	3.45E-01	3.50E-02
6.00E-01	3.86E-01	3.72E-02
7.00E-01	4.69E-01	4.15E-02
8.00E-01	5.52E-01	4.55E-02
9.00E-01	6.35E-01	4.93E-02
1.00E+00	7.18E-01	5.30E-02
1.25E+00	9.22E-01	6.17E-02
1.50E+00	1.12E+00	6.99E-02
1.75E+00	1.32E+00	7.78E-02
2.00E+00	1.51E+00	8.53E-02
2.50E+00	1.87E+00	9.96E-02
3.00E+00	2.22E+00	1.13E-01
3.50E+00	2.55E+00	1.26E-01
4.00E+00	2.87E+00	1.38E-01
4.50E+00	3.18E+00	1.50E-01
5.00E+00	3.47E+00	1.61E-01
5.50E+00	3.76E+00	1.72E-01
6.00E+00	4.03E+00	1.82E-01
7.00E+00	4.55E+00	2.02E-01
8.00E+00	5.04E+00	2.20E-01
9.00E+00	5.51E+00	2.37E-01
1.00E+01	5.95E+00	2.53E-01
1.25E+01	6.97E+00	2.88E-01
1.50E+01	7.88E+00	3.19E-01
1.75E+01	8.71E+00	3.47E-01
2.00E+01	9.48E+00	3.71E-01
2.50E+01	1.08E+01	4.13E-01
3.00E+01	1.21E+01	4.47E-01

Double-click any column to plot those data.

Export Print OK

Solution 4 (b)

The values at 1.75 MeV may be considered close enough, or interpolation may be used between values at 1.50 and 1.75 MeV.

- CSDA: 1.32 g/cm²
- Yield: 7.78E-2 (7.78%)

Question 5

- a) For an adult worker, what fraction of a 1000 Bq inhalation of a Type S, 5 μm AMAD ^{58}Co aerosol is exhaled immediately after inhalation of that aerosol?
- b) What fraction of the activity is deposited in the thoracic and in the extra-thoracic regions?
- c) What activity in a 24-hour urine sample would you expect to find if the sample is taken 10 days after the intake?

Question 5 (a) and (b)

- a) For an adult worker, what fraction of a 1000 Bq inhalation of a Type S, 5 μm AMAD ^{58}Co aerosol is exhaled immediately after inhalation of that aerosol?
- b) What fraction of the activity is deposited in the thoracic and in the extra-thoracic regions?
- c) What activity in a 24-hour urine sample would you expect to find if the sample is taken 10 days after the intake?

Solving 5 (a) and (b)

- Click the **Biological Data** tab.
- In **Biokinetic Models**, select **Lung Model** and click **Display**.
- Click the **Default Regional Deposition** highlighted text.
- In the table under **AMAD = 5 microns**, add the fractions deposited in the **ET, BB, and BB and AI regions**.

The screenshot displays the Radiological Toolbox software interface. The left sidebar contains a list of tabs: Biological Data (selected), Decay Data, Dose Coefficients, Dose Calculations, Early Inhalation, Element Data, Material Data, Public Exposure Data, Radiation Field Data, Risk Coefficients, and Supplemental Data. The main window is divided into two panes. The left pane, titled 'Biological Data', contains several sections: 'Biokinetic Models' with a 'Display' button and a 'Lung model' dropdown; 'Bioassay Data' with a 'Display' button, 'Am-241' dropdown, and 'Type: M' dropdown; 'Composition of Tissues' with a 'Display' button and 'ADIPOSE TISSUE (ICRP)' dropdown; 'Organ Masses - ICRP 23/89/72' with a 'Display' button, 'Select Units' dropdown, and 'g' dropdown; 'ICRP89 Reference Values' with an 'ICRP 89 Data' dropdown and 'alimentary function' dropdown; and 'Radiation Health Effects' with a 'Display' button and 'Summary of Health Effects' dropdown. The right pane, titled 'Lung Model', contains a text description of particle clearance in the thoracic airways and a diagram of the lung model. The text describes the removal of deposits by extrinsic means, the structure of the thoracic airways (bronchi, bronchioles, alveolar-interstitial region), and the transport of material to the GI tract and regional lymph nodes. The diagram shows a flow from 'Anterior Nasal' and 'Naso-Oropharynx/Larynx' into the 'LN ET' box, which then flows into the 'ET seq' box. A value of 0.001 is shown between these boxes. The 'ET seq' box is labeled 'Extrathoracic' and has an arrow pointing to the 'Anterior Nasal' box.

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Solving 5 (a) and (b)

- Click the **Biological Data** tab.
- In **Biokinetic Models**, select **Lung Model** and click **Display**.
- Click the **Default Regional Deposition** highlighted text.
- In the table under **AMAD = 5 microns**, add the fractions deposited in the **ET**, **BB**, and **BB and AI** regions.

The screenshot shows the Radiological Toolbox software interface. The left sidebar contains a list of tabs: Biological Data (selected), Decay Data, Dose Coefficients, Dose Calculations, Early Inhalation, Element Data, Material Data, Public Exposure Data, Radiation Field Data, Risk Coefficients, and Supplemental Data. The main window displays the Biological Data tab with several sections: Biokinetic Models (Lung model selected), Bioassay Data (Am-241, Type: M), Composition of Tissues (ADIPOSE TISSUE (ICRP)), Organ Masses - ICRP 23/89/72 (g), ICRP89 Reference Values (alimentary function), and Radiation Health Effects (Summary of Health Effects). The right window shows the Lung Model results, including a table of default deposition fractions (AMAD = 5 micron) for an adult worker.

Region	Deposition
AI1	1.596E-02
AI2	3.191E-02
AI3	5.319E-03
bbf	6.569E-03
bbs	4.384E-03
bbseq	7.721E-05
BBf	1.171E-02
BBs	5.921E-03
BBseq	1.243E-04
ET2	3.989E-01
ETseq	1.996E-04
ET1	3.385E-01

Solution 5 (a) and (b)

Deposition in ET = 73.76%

BB = 1.78%

bb = 1.09%

AI = 5.32%

Total Deposition = 81.93%

Amount exhaled = 18.1%

Note: ET1 corresponds to the nasal lings in a nose breather. According to the table, about 34% of the 5 micron aerosol is deposited there. Therefore, if a nose swab is taken, a qualitative idea of the possible intake is probably more than about three times the activity on the swab, depending on how much of the nasal deposit is collected on the swab.

Question 5 (c)

- a) For an adult worker, what fraction of a 1000 Bq inhalation of a Type S, 5 μm AMAD ^{58}Co aerosol is exhaled immediately after inhalation of that aerosol?
- b) What fraction of the activity is deposited in the thoracic and in the extra-thoracic regions?
- c) What activity in a 24-hour urine sample would you expect to find if the sample is taken 10 days after the intake?

Solving 5 (c)

1. Click Biological Data
2. Select 58Co, Type S in Bioassay Data, and click display.
3. Under E_Urine, in the row corresponding to 10 days, read **2.53E-4 (Bq/Bq-Intake)**.

The screenshot shows the 'Radiological Toolbox' application. The 'Biological Data' panel on the left is active. In the 'Bioassay Data' section, 'Co-58' is selected for the isotope and 'S' for the type. The 'Display' button is clicked. The main window displays a table titled 'Bioassay data of occupational inhalation intakes of Co-58 ICRP 68, Absorption Type S'. The table has five columns: Time (days), E_Fecal(t), Cumulative Fecal Excretion, E_Urine(t), and Cumulative Urin Excretion. The row for 10 days (1.00E+01) is highlighted, showing an E_Urine(t) value of 2.53E-04. A tooltip on the right says 'Double-click any column to plot those data.' Below the table are buttons for Help, Export, Print, and OK.

Time (days)	E_Fecal(t)	Cumulative Fecal Excretion	E_Urine(t)	Cumulative Urin Excretion
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E+00	1.09E-01	1.09E-01	5.63E-03	5.63E-03
1.50E+00	1.69E-01	1.95E-01	5.28E-03	7.59E-03
2.00E+00	1.53E-01	2.62E-01	3.10E-03	8.72E-03
2.50E+00	1.14E-01	3.09E-01	1.84E-03	9.43E-03
3.00E+00	7.79E-02	3.40E-01	1.18E-03	9.91E-03
3.50E+00	5.09E-02	3.60E-01	8.39E-04	1.03E-02
4.00E+00	3.25E-02	3.73E-01	6.53E-04	1.06E-02
4.50E+00	2.05E-02	3.81E-01	5.47E-04	1.08E-02
5.00E+00	1.29E-02	3.86E-01	4.81E-04	1.10E-02
5.50E+00	8.14E-03	3.89E-01	4.37E-04	1.13E-02
6.00E+00	5.23E-03	3.91E-01	4.06E-04	1.14E-02
7.00E+00	2.29E-03	3.93E-01	3.55E-04	1.18E-02
8.00E+00	1.19E-03	3.94E-01	3.16E-04	1.21E-02
9.00E+00	7.76E-04	3.95E-01	2.82E-04	1.24E-02
1.00E+01	6.10E-04	3.96E-01	2.53E-04	1.27E-02
1.50E+01	4.35E-04	3.98E-01	1.50E-04	1.36E-02
2.00E+01	3.62E-04	4.00E-01	9.26E-05	1.41E-02
2.50E+01	3.04E-04	4.02E-01	6.08E-05	1.45E-02
3.00E+01	2.57E-04	4.03E-01	4.25E-05	1.48E-02
3.50E+01	2.19E-04	4.04E-01	3.17E-05	1.49E-02
4.00E+01	1.86E-04	4.05E-01	2.49E-05	1.51E-02
4.50E+01	1.59E-04	4.06E-01	2.05E-05	1.52E-02
5.00E+01	1.36E-04	4.07E-01	1.73E-05	1.53E-02
5.50E+01	1.17E-04	4.07E-01	1.51E-05	1.54E-02
6.00E+01	1.01E-04	4.08E-01	1.32E-05	1.54E-02
7.00E+01	7.55E-05	4.09E-01	1.05E-05	1.55E-02
8.00E+01	6.70E-05	4.09E-01	8.44E-06	1.55E-02

Solution 5 (c)

Activity expected in the 24-hour urine sample is:

$$\text{Urine activity} = 1,000 \times 2.53\text{E-}4 = 0.253 \text{ Bq.}$$

This type of calculation is helpful to determine whether the available urine counting protocol and equipment are capable of measuring this level of activity in the sample, given the methods used on site for routine bioassay intervals amounts of urine collected per sample, for example, a 24-hour sample or a “grab” sample. The grab sample is taken from one voiding and therefore usually contains much less activity than a 24-hour sample, and so required greater measurement capabilities to detect a given minimum intake level.

Question 6

- a) What is the air kerma rate free-in-air at a location where the 0.08 MeV photon fluence is $2.24\text{E}8$ photons/cm²?
- b) What is the effective dose rate resulting from exposure to this beam when incident on the body in the AP direction at that location? What is the dose rate if the direction was PA with the same fluence rate? What is the rate if the radiation is isotropic?

Question 6 (a)

- a) What is the air kerma rate free-in-air at a location where the 0.8 MeV photon fluence is $2.24\text{E}8$ photons/cm²?
- b) What is the effective dose rate resulting from exposure to this beam when incident on the body in the AP direction at that location? What is the dose rate if the direction was PA with the same fluence rate? What is the rate if the radiation is isotropic?

Solving 6 (a)

1. Click the **Radiation Field Data** tab.
2. Select the **Operational quantities** button.
3. Click **Display**.

The air kerma column at 0.8 MeV shows a kerma rate of **3.69 pGy-cm²**. This unit may be interpreted as **pGy per photon/cm²** or the **kerma per unit fluence**.

The screenshot displays the Radiological Toolbox software interface. The left sidebar contains various tabs, with 'Radiation Field Data' selected. Under this tab, 'Operational quantities' is chosen. The 'Select Units' dropdown is set to 'pSv cm²'. The 'Display' button is visible. The main window shows a table of PhotonField data for Operational quantities, with the row for 0.8 MeV highlighted. A diagram of a person in an AP (Antero-posterior) geometry is shown on the left side of the table.

Photon Energy (MeV)	Direction Dose Equivalent Conv Coeff (Sv / Gy)	AirKerma Free-in-Air per Fluence (pGy cm ²)	Hp(10) per Air Kerma (Sv / Gy)	Hp(0.07) per Air Kerma (Sv / Gy)
1.00E-02	9.50E-01	7.60E+00	9.00E-03	9.47E-01
1.50E-02	9.90E-01	3.21E+00	2.64E-01	9.81E-01
2.00E-02	1.05E+00	3.21E+00	6.11E-01	1.05E+00
3.00E-02	1.22E+00	7.39E-01	1.11E+00	1.23E+00
4.00E-02	1.41E+00	4.38E-01	1.49E+00	1.44E+00
5.00E-02	1.53E+00	3.28E-01	1.77E+00	1.63E+00
6.00E-02	1.59E+00	2.92E-01	1.89E+00	1.72E+00
8.00E-02	1.61E+00	3.08E-01	1.90E+00	1.73E+00
1.00E-01	1.55E+00	3.72E-01	1.81E+00	1.67E+00
1.50E-01	1.42E+00	6.00E-01	1.61E+00	1.52E+00
2.00E-01	1.34E+00	8.56E-01	1.49E+00	1.43E+00
3.00E-01	1.31E+00	1.38E+00	1.37E+00	1.34E+00
4.00E-01	1.26E+00	1.89E+00	1.30E+00	1.28E+00
5.00E-01	1.23E+00	2.38E+00	1.26E+00	1.24E+00
6.00E-01	1.21E+00	2.84E+00	1.23E+00	1.22E+00
8.00E-01	1.19E+00	3.69E+00	1.19E+00	1.19E+00
1.00E+00	1.17E+00	4.47E+00	1.17E+00	1.17E+00
1.50E+00	1.15E+00	6.12E+00	1.14E+00	
2.00E+00	1.14E+00	7.51E+00	1.13E+00	
3.00E+00	1.13E+00	9.89E+00	1.12E+00	
4.00E+00	1.12E+00	1.20E+01	1.11E+00	
5.00E+00	1.11E+00	1.39E+01	1.11E+00	
6.00E+00	1.11E+00	1.58E+01	1.11E+00	
8.00E+00	1.11E+00	1.95E+01	1.11E+00	
1.00E+01	1.10E+00	2.32E+01	1.11E+00	

Solution 6 (a)

The kerma rate corresponding to the 2.24E8 fluence is:

$$K = 2.24E8 \times 3.69$$

$$= 8.27E8 \text{ pGy}$$

$$= \mathbf{0.827 \text{ mGy}}$$

Question 6 (b)

- a) What is the air kerma rate free-in-air at a location where the 0.8 MeV photon fluence is $2.24\text{E}8$ photons/cm²?
- b) What is the effective dose rate resulting from exposure to this beam when incident on the body in the AP direction at that location? What is the dose rate if the direction was PA with the same fluence rate? What is the rate if the radiation is isotropic?

Solving 6 (b)

1. Click on the **AP button** on the same tab and read the effective dose coefficient (Sv/Gy) for AP, PA, and ISO incidence at 0.8 MeV are:
 - $AP = 1.433$
 - $PA = 1.019$
 - $ISO = 0.749$

Solution 6 (b)

The dose rates are:

$$\begin{aligned} E(\text{AP}) &= 0.827 \text{ (mGy/s)} \times 1.433 \text{ (Sv/Gy)} \times 0.001 \text{ (Gy/mGy)} \\ &= 0.0012 \text{ mSv/s} \\ &= 4.27 \text{ Sv/hr} \end{aligned}$$

$$\begin{aligned} E(\text{PA}) &= 0.827 \text{ (mGy/s)} \times 1.019 \text{ (Sv/Gy)} \times 0.001 \text{ (Gy/mGy)} \\ &= 0.00084 \text{ mSv/s} \\ &= 3.03 \text{ Sv/hr} \end{aligned}$$

$$\begin{aligned} E(\text{ISO}) &= 0.827 \text{ (mGy/s)} \times 0.749 \text{ (Sv/Gy)} \times 0.001 \\ &\text{ (Gy/mGy)} \\ &= 0.00062 \text{ mSv/s} \\ &= 2.23 \text{ Sv/hr} \end{aligned}$$

Question 7

- What is the risk resulting from continuous submersion for a year in a cloud of ^{133}Xe with a constant concentration of $1\text{E}3 \text{ Bq/m}^3$?

Solving 7

1. Click the **Risk Coefficients** button.
2. Select **Xe-133** from the **Nuclides** list.
3. Click **Display**.

The risk coefficients are:

Mortality = $6.59\text{E-}17 \text{ m}^3/\text{Bq}\cdot\text{s}$

Morbidity = $9.86\text{E-}17 \text{ m}^3/\text{Bq}\cdot\text{s}$

The screenshot shows the 'Radiological Toolbox' application with the 'Risk Coefficients' window open. The 'Nuclide' list on the left has 'Xe-133' selected. The 'Select intake mode' section has 'Air Submersion' selected. The 'Display' button is highlighted. The main window displays a table of risk coefficients for Xe-133 from FGR 13.

Nuclide	Xe-133			
Cancer	mortality	morbidity		
esophagus	9.23E-19	1.03E-18		
stomach	4.44E-18	4.93E-18		
colon	9.26E-18	1.68E-17		
liver	1.70E-18	1.79E-18		
lung	1.29E-17	1.36E-17		
bone	4.87E-19	6.96E-19		
skin	4.96E-19	4.96E-19		
breast	9.47E-18	1.89E-17		
ovary	1.10E-18	1.57E-18		
bladder	2.51E-18	5.03E-18		
kidney	6.19E-19	9.52E-19		
thyroid	4.81E-19	4.81E-18		
leukemia	6.01E-18	6.07E-18		
residual	1.55E-17	2.18E-17		
Total	6.59E-17	9.86E-17		

The 'Total' row is highlighted in blue. The units are $\text{m}^3 / \text{Bq s}$.

Solution 7

The integrated duration of exposure is:

$$\begin{aligned} X &= 1\text{E}3 \text{ (Bq/m}^3\text{)} \times 8760 \text{ (h/y)} \times 3600 \text{ (s/h)} \\ &= 3.154\text{E}10 \text{ (Bq-s/m}^3\text{)} \end{aligned}$$

Mortality risk

$$\begin{aligned} &= 6.59\text{E-}17 \text{ (m}^3\text{/Bq-s)} \times 3.154\text{E}10 \text{ (Bq-s/m}^3\text{)} \\ &= 2\text{E-}6 \end{aligned}$$

Morbidity risk

$$\begin{aligned} &= 9.86\text{E-}17 \text{ (m}^3\text{/Bq-s)} \times 3.154\text{E}10 \text{ (Bq-s/m}^3\text{)} \\ &= 3\text{E-}6 \end{aligned}$$

Questions?



Lectern - Mr. Scott Moore, Deputy Director NMSS Table (left to right) - Dr. Hertel, Dr. Dewji, Dr. Zanzonico, Peter Crane, JD, and Ms. Stephanie Coffin (moderator, Deputy Director, - Division of Systems Analysis in RES)