PU-239 ORGAN SPECIFIC DOSIMETRIC MODEL APPLIED TO NON-HUMAN BIOTA

M. Kaspar[1]

M. Johansen[2]

A. Brandl[1]

[1]Environmental and Radiological Health Sciences Colorado State University, Fort Collins, CO
[2] Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Lucas Heights, Australia

Introduction/Abstract

- Three items of interest
  - Effectiveness of Aquatic Model in ERICA-Tool at Internal Dosimetry
    - ERICA Tool vs MCNPX
  - Compared 4 organ scaling factors
    - Ellipsoidal and spherical
  - Calculated organ dose due to Pu-239 to a small sample of Rabbits from the Maralinga nuclear test site

Outline:

- Introduction & Background
  - Motivations for Investigation
  - Site History
  - Site Characteristics
  - Exposure Pathways
  - Rabbit Biology & Physiology
  - Raw Environmental Samples
  - Computer Modeling Principles
  - Methodology & Dosimetric Approaches
- Results & Discussion
- Conclusion

Motivations for Investigation

- Increased awareness has stressed the need for increased environmental protection (ICRP's)
  - Environmental protection is not clearly defined…
  - Long-lived contaminates (Pu-239) may persist in the environment for thousands of years
- Opportunity to study the long-term effects of chronic low-dose exposures
  - Radiation damage studied extensively at the cellular level
  - Organs/tissues are more complex
  - Organ structure plays a vital role in radiation response
  - Different tissues have different responses.
- Natural populations are chronically exposed
  - Bioaccumulation in specific organs.
  - May effect the overall health of the population.
- Environmental Risk from Ionizing Contaminates Assessment Tool
  - ERICA Tool may have limited use in organ dosimetry
  - Already scientifically accepted software
  - Assumptions are based on organ data
  - Database is continuously updated.

Site History and Characteristics

- United Kingdom
  - Above ground testing (50's – 60's) at Maralinga
  - All involved radioactive materials (Pu-239)
- "Major Trials"
  - 7 of 9 nuclear detonations occurred at Maralinga
  - Ranging from 1 to 27 kilotons of TNT equivalent
- "Minor Trials"
  - Development trials designed to test the integrity of nuclear devices
  - All involved nuclear materials
  - Taranaki is considered to have the highest allotment of plutonium contamination (22 kg of Pu-239)

Site History and Characteristics

- British Cleanup Efforts
  - Three remediation campaigns (’63 – ’67)
  - 470 GBq of Am-241 with 7.2x that of Pu-239 over 130 km^2 remained
- Australian Management & Cleanup
  - In 1986, the Technical Assessment Group (TAG)
    - Found previous remedial efforts were poor…
    - Final cleanup began in 1996 and ended in 2000
    - Site is now considered safe with the exception of 130 km^2
  - Maralinga Tjarutia received control of their land (2009)

Site Characteristics

- Great Victoria Desert
  - 1,200 mi ^{2}
- Soil Characteristics
  - Aeolian Sand
  - Calcretisted Dolomite
  - Mycrophytic crust
- Climate
  - Windy: 10 – 80 mph
  - Temp: 100+ F

Exposure Pathways

- Inhalation
  - Major concern for children - MARTAC (2002)
  - Obligate nose breathers
  - Radiation pneumonitis – premature death
- Ingestion
  - Major concern for children - ARPANSA (2011)
  - Deposition on plants – impact of grazing animals
  - Low absorption but… large quantities
- Wounds/Dermis
  - Skin is an effective barrier
  - Direct access to blood supply, which can circulate throughout the body
  - In humans most can be removed at a clinic, not so for animals
- USDHHS –exposure time
  - Intermediate (15 d < t < 365 d)
  - Chronic (t > 365 d)

Rabbit Biology-Physiology

- Vary greatly in size (1-7 kg) and is environment dependent
- Rabbit is unique in that, the intestine is 10x its body length and is the largest of any animal relative to size
- Non-ruminant animals, simular to horses and cows
  - Most food passes through quickly without being digested.
  - Routinely eat their own feces
  - Rely on the microflora in the cecum for nutrient intake
- Require between 50-120 mL/kg body mass of water per day.

Rabbit Biology-Physiology: Australia Specific

- Thought to have originated from Spain, leaving them ill-suited for life in arid Australia
  - Young are severely stunted as result
  - Larger kidneys, and smaller livers as a result of high salt, heat, and lack of water
- In food and water shortages, rabbits will lose 22-50% of body mass
  - Young often do not live through such events
- Actively seek plants like chenopods, that are high in protein and water but low in salt

Raw Environmental Samples

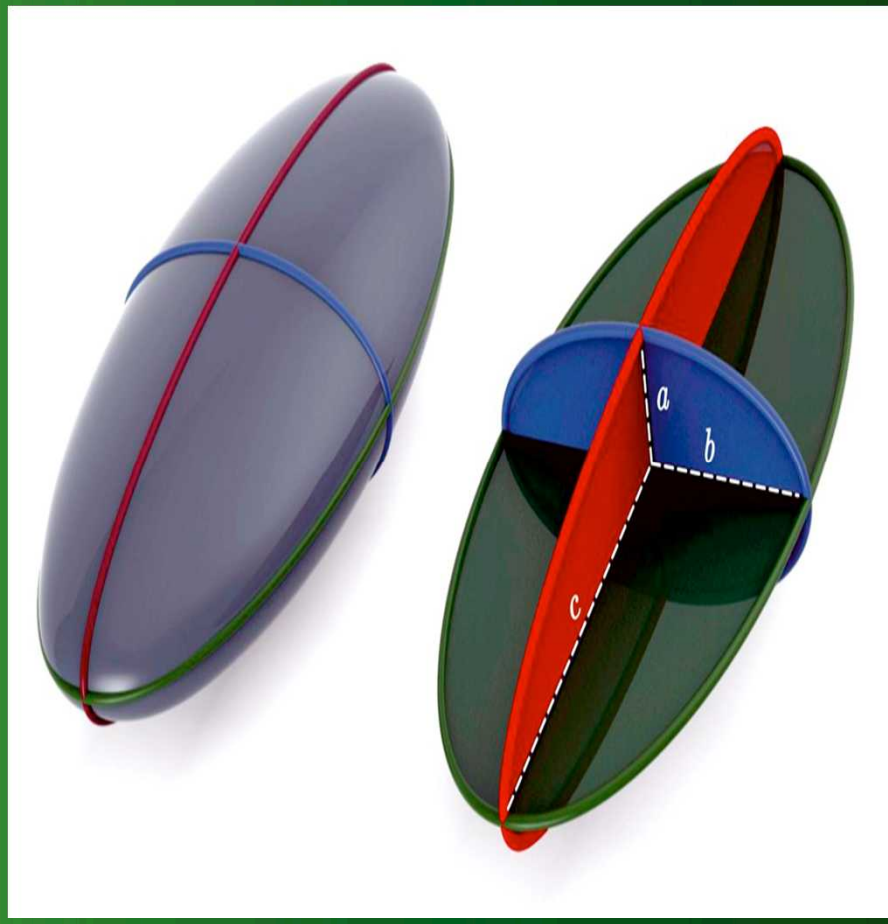
- Sample Collection
  - Six live rabbit samples collected in 2011 from the Taranaki plume
  - Two samples were collect 10 km to the SE
  - Followed ANSTO's animal handling protocols
- Pu-239 Analysis
  - Australian National Tandem Research Accelerator (ANTERES), an atomic mass spectrometer
  - Improved atomic measurements for long-lived actinide elements over traditional alpha-spectrometry, by 3 orders of magnitude
  - Subsamples were removed and concentrated by David Childs

Computer Modeling Principles

- ERICA-Tool
  - Environmental Risk from Ionising Contaminants: Assessment & Management
  - Software to assist with the management of radionuclide contaminants by assessing concerns with biota and whole ecosystems
  - Doses are given in units of µGy/h
  - Essentially a lookup table
  - Aquatic model, used and develop by Ulanovsky and Prohl but used since the 1970's
    - Surrounding medium and organism are identical (approximately)
    - Infinite surrounding medium
    - Organisms treated as simple shapes, simular to ICRP 108

Computer Modeling Principles

- MCNPX
  - Monte Carlo N-Particle
  - Statistics based physics software program
  - Wide variety of applications including internal dosimetry
  - Requires user supplied problem data
    - geometry, materials, starting particles and particle interactions
  - Based on cross-sectional data supplied with the software



Methodology & Dosimetric Approaches

- Absorbed dose, or amount of energy absorbed per unit mass, is generally considered appropriate
- Animal dosimetry is expressed as a dose rate
- Concerned about the population not the individual
- Organs treated as simple spheres and ellipsoids and normalized to ICRP literature
  - Multiple geometries for the same organ

Methodology & Dosimetric Approaches

- Organ Mass Determination
  - Used Jelenko et al (1971) organ information
  - Calculated using ICRP 108's reference duck, simular to Taranenko et al (2004) and other European biological assessment programs

ICRP 108 Duck/Rabbit Organ Mass

Organ/Tissue	Organ Weight (%)	Organ Weight (g)
Blood	6.25%	78.75
Heart	0.24%	3.024
Large Intestine	2.81%	35.406
Small intestine	2.98%	37.548
Kidney [one]	0.41%	5.103
Liver	4.51%	56.826
Lung [one]	0.32%	4.032
Muscle	55.86%	703.836
Skeleton	6.13%	77.238
Skin	12.97%	163.422
Spleen	0.08%	1.008
Stomach	0.84%	10.584
Total	93.40%	1176.777

Methodology & Dosimetric Approaches

- Organ Dimension Scaling
  - Multiple organ geometries were used for the same organ
  - All organ length dimensions were scaled using simple ratio's
    - Body length
    - Organ mass
    - Average rabbit intestine data
    - Literature for children height
  - All remaining dimensions were assumed equal
  - Spherical

Methodology & Dosimetric Approaches

Mass = Density × Volume

$$\text{Volume} = \frac{\pi}{6}abc$$

Where a is the diameter calculated below and b = c.

Normalized to ICRP 89 Reference man length/height and ICRP 108 Duck/Rabbit Length

$$\text{Organ Length}_{\text{Rabbit}} = \left(\frac{\text{Organ Length}_{\text{Reference Man}}}{\text{Body Length}_{\text{Reference Man}}}\right) \times \text{Body Length}_{\text{ICRP Rabbit}}$$

$$\text{Organ Length}_{\text{Rabbit}} = \left(\frac{110\ \text{cm}}{176\ \text{cm}}\right) \times 30\ \text{cm}$$

$$\text{Organ Length}_{\text{Rabbit}} = 18.750\ \text{cm}$$

Methodology & Dosimetric Approaches

- Normalized to children's literature from Konus et al (1998)

Liver

$$\text{Organ Length (mm)} = \left(\frac{0.48\ \text{mm}}{\text{cm}}\right) \times (\text{Body Length}_{\text{ICRP Rabbit}}) + 42\ \text{mm}$$

$$\text{Organ Length (mm)} = \left(\frac{0.48\ \text{mm}}{\text{cm}}\right) \times 30\ \text{cm} + 42\ \text{mm}$$

$$\text{Organ Length} = 56.4\ \text{mm} = 5.64\ \text{cm}$$

Normalized to Body Length (cm)

Organ/Tissue	Length	Width	Hight
Heart*	-	-	-
Large Intestine*	18.8	1.9	1.9
Small intestine	47.7	1.2	1.2
Kidney* [one]	1.9	2.3	2.3
Liver*	3.5	5.6	5.6
Lung* [one]	3.1	1.6	1.6
Muscle	-	-	-
Skeleton	854.6	0.4	0.4
Skin	-	-	-
Spleen*	2.0	1.0	1.0
Stomach*	6.3	1.8	1.8

Methodology & Dosimetric Approaches

- Activity Concentration Calculation
  - Data converted from mBq/kg ash to Bq/kg fresh mass for each organ
  - Rabbit-1 had the most complete data
    - Applied to ICRP108 Duck/Rabbit
    - Average whole rabbit concentration was calculated using an organ mass weighted average.
      - Used for “infinite universe” in ERICA and MCNPX

Organ Weighted Activity Concentration

Blood's Contribution

$$\text{Weighted Activity Concentration} = \text{Acitivity Concentration} \times \text{Percent Organ Mass}$$

$$\text{Weighted Activity Concentration} = 4.4\frac{\text{mBq}}{\text{kg}} \times 6.25\ \%$$

$$\text{Weighted Activity Concentration} = 0.277\frac{\text{mBq}}{\text{kg}}$$

Error in Blood's Contribution

$$\sigma_{\text{Organ Activity}} = 0.277\frac{\text{mBq}}{\text{kg}} \times \sqrt{\underbrace{\left(\frac{2.6\ \frac{\text{mBq}}{\text{kg}}}{4.4\frac{\text{mBq}}{\text{kg}}}\right)^2}_{\text{Concentration}} + \underbrace{\left(\frac{1.00\ \%}{6.25\ \%}\right)^2}_{\text{Percent Organ}}}$$

$$\sigma_{\text{Organ Activity}} = 0.166\frac{\text{mBq}}{\text{kg}}$$

Organ Weighted Activity Concentration

Organ/tissue	Activity Concentration(mBq/kg)	SE
Blood	0.28	0.17
Heart	0.004	0.016
Large Intestine	17.36	2.10
Small intestine	18.41	2.04
Kidney (one)	0.03	0.01
Liver	3.17	0.57
Lung (one)	0.87	0.06
Muscle	0.85	0.39
Skeleton	3.13	1.28
Spleen	0.06	0.01
Stomach	5.19	1.29
Universe	50.23	3.52

Methodology & Dosimetric Approaches

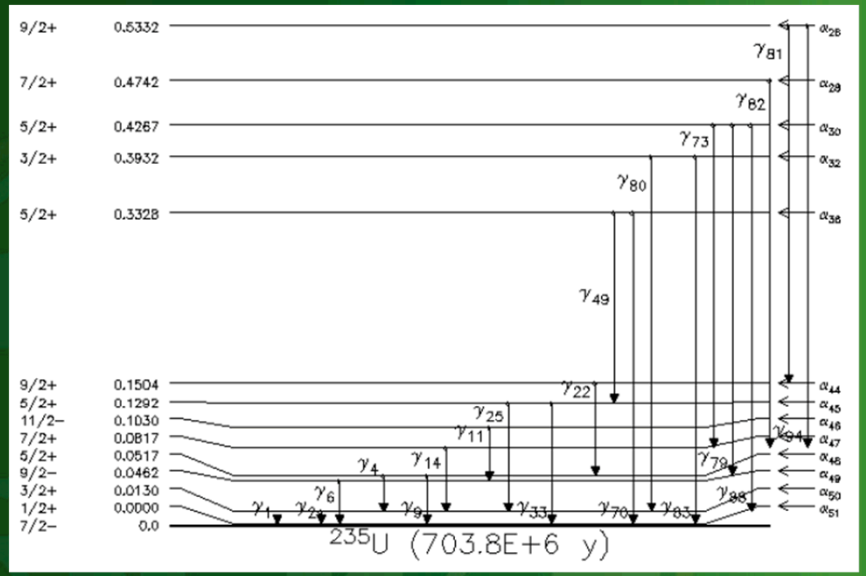
- ERICA Tool
  - Entered as having a normal distribution
  - All organ geometries were compared with like organs
  - Default radiation factors were used
    - Alpha's (10), Beta's (1), and Gamma's (1)
  - Output compared to MCNPX data

Methodology & Dosimetric Approaches

- MCNPX
  - Two models were created
    - Infinite and is relative to the emitted radiation
    - ICRP 108 Duck/Rabbit (more realistic)
    - Checked by using two source distributions (cylindrical and sphereical)
  - ICRU 4-element tissue composition for organ and universe
  - Emitted radiations (next page) were obtained using ICRP 107's DECDATA disk
  - Default particle transport
    - Including energy cutoff's of 1 kev for photons and beta's
  - *F8 energy deposition
  - Relative error < 1% (internal) and < 5% (external)
  - Same radiation weighting factors as ERICA
  - Organs whose geometry fit in the rabbit were compared to infinite universe model
  - Compared to ERICA

Emitted Radiations…

ICRP 38



ICRP 107 DECDATA

Particle	Energy (MeV)	Yeild/nt	Tissue Range (cm)
Alpha-ray	5.148E+00	1.000E+00	5.000E-03
Gamma-ray	6.558E-02	9.758E-04	5.490E+00
X-ray*	3.335E-04	3.042E+00	2.611E-04
IC electron	1.915E-02	3.045E-01	2.000E-03
Auger electron*	6.276E-04	2.590E+00	1.550E-05

Methodology & Dosimetric Approaches

- Rabbit Sample Set Dosimetry
  - All 8 rabbits had varying degrees of Pu-239
  - All had blood, muscle and bone measurements
  - Organ absorbed dose rates were averaged and scaled to each rabbit

Pu-239 Activity Concentrations (mBq/kg)

Rabbit	Blood		Muscle		Bone	
	Mean	S-x	Mean	S-x	Mean	S-x
Rabbit-1*	4.4	2.6	1.5	0.7	48	20
Rabbit-2	252	97	3.9	0.9	49	14
Rabbit-3	3.2	8.0	4.1	1.0	62	10
Rabbit-4	4.9	5.9	-	-	-	-
Rabbit-5	6.5	1.6	4.8	1.1	961	112
Rabbit-6	1.8	2.1	92	6	42	10
Rabbit-7	-60	-74	-0.7	-1.0	32	20
Rabbit-8	-1.3	-0.9	-0.2	-0.2	-	-

Results

- Absorbed Dose Rate ICRP Duck/Rabbit
  - Calculated using ERICA Tool and MCNPX
  - Multiple geometries for the same organ
  - Elliptical geometries were scaled using three parameters
    - Organ Length
    - Organ Mass
    - Literature for children and the average rabbit
  - Sphere

Results

- Comparison between ERICA and MCNPX
  - Absorbed dose rate, % Difference, t-test
    - % Differences ≤ 4%
    - t-score < 0.5
  - Values are essentially identical

Table 12 ERICA Tool and MCNPX absorbed dose rates (μGy/h)

		N2BL			N2OM			N2LI			Round		
Organ	Statistic	ERICA	Infinite	Rabbit	ERICA	Infinite	Rabbit	ERICA	Infinite	Rabbit	ERICA	Infinite	Rabbit
Heart	Mean										4.4E-07	1.1E-07	1.1E-07
	S-x										3.1E-07	6.5E-07	1.6E-06
Large Intestine	Mean	5.1E-04	5.2E-04	5.2E-04	5.0E-04	5.2E-04	5.2E-04	5.1E-04	5.2E-04	-	5.0E-04	5.2E-04	5.2E-04
	S-x	6.2E-05	8.1E-05	8.1E-05	6.4E-05	8.1E-05	8.1E-05	6.3E-05	8.1E-05		6.0E-05	8.1E-05	8.1E-05
Small Intestine	Mean	5.4E-04	5.5E-04	-	5.4E-04	5.5E-04	5.5E-04	5.4E-04	5.5E-04	-	5.4E-04	5.5E-04	5.5E-04
	S-x	5.9E-05	7.7E-05		5.9E-05	7.7E-05	7.7E-05	5.8E-05	7.7E-05		6.0E-05	7.7E-05	7.7E-05
Kidney (one)	Mean	8.8E-07	8.5E-07	8.5E-07	8.8E-07	8.5E-07	8.5E-07	8.8E-07	8.5E-07	8.5E-07	8.9E-07	8.5E-07	8.5E-07
	S-x	3.2E-07	3.2E-07	1.4E-06	3.2E-07	3.2E-07	2.2E-06	3.2E-07	3.2E-07	1.3E-06	3.2E-07	3.2E-07	1.4E-06
Liver	Mean	9.5E-05	9.4E-05	9.4E-05	9.5E-05	9.4E-05	-	9.5E-05	9.4E-05	9.4E-05	9.5E-05	9.4E-05	9.4E-05
	S-x	1.7E-05	2.1E-05	2.1E-05	1.7E-05	2.1E-05		1.7E-05	2.1E-05	2.1E-05	1.7E-05	2.1E-05	2.1E-05
Lung (one)	Mean	2.6E-05	2.6E-05	2.6E-05	2.6E-05	2.6E-05	-				2.6E-05	2.6E-05	2.6E-05
	S-x	1.7E-06	2.1E-06	2.5E-06	1.6E-06	2.1E-06					1.6E-06	2.1E-06	2.5E-06
Muscle	Mean										2.6E-05	2.5E-05	-
	S-x										1.1E-05	1.1E-05	1.1E-05
Skeleton	Mean	9.3E-05	9.3E-05	-	9.4E-05	9.3E-05	-				9.4E-05	9.3E-05	9.3E-05
	S-x	3.8E-05	3.8E-05		3.7E-05	3.8E-05					3.7E-05	3.8E-05	3.8E-05
Skin	Mean										7.1E-03	7.1E-03	7.1E-03
	S-x										7.5E-04	8.9E-04	8.9E-04
Spleen	Mean	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06	1.7E-06
	S-x	2.9E-07	3.6E-07	1.9E-06	2.9E-07	3.6E-07	7.3E-06	2.9E-07	3.6E-07	2.1E-06	2.9E-07	3.6E-07	1.7E-06
Stomach	Mean	1.5E-04	1.5E-04	1.5E-04	1.6E-04	1.5E-04	1.5E-04				1.6E-04	1.5E-04	1.5E-04
	S-x	3.9E-05	5.3E-05	5.3E-05	3.8E-05	5.3E-05	5.3E-05				3.8E-05	5.3E-05	5.3E-05

Comparison: ERICA vs MCNPX

Organ	Statistic*	N2BL Infinite	N2BL Rabbit	N2OM Infinite	N2OM Rabbit	N2LI Infinite	N2LI Rabbit	Round Infinite	Round Rabbit
Heart	% Difference							75.34	75.22
	t-Test							0.46	0.00
Large	% Difference	2.10	2.10	2.33	2.31	1.93	-	2.30	2.30
Intestine	t-Test	0.10	0.00	0.11	0.00	0.10		0.11	0.00
Small	% Difference	2.21	-	2.02	2.01	2.04	-	2.21	2.20
Intestine	t-Test	0.12		0.11	0.00	0.11		0.12	0.00
Kidney	% Difference	3.59	3.62	3.69	3.84			4.03	4.06
(one)	t-Test	0.07	0.00	0.07	0.00			0.08	0.00

Comparison: ERICA vs MCNPX

Organ	Statistic*	N2BL Infinite	N2BL Rabbit	N2OM Infinite	N2OM Rabbit	N2LI Infinite	N2LI Rabbit	Round Infinite	Round Rabbit
Liver	% Difference	1.18	1.18	1.07	-	1.28	1.29	1.39	1.39
	t-Test	0.04	0.00	0.04		0.05	0.00	0.05	0.00
Lung	% Difference	0.23	0.24	0.56	-			0.61	0.62
(one)	t-Test	0.02	0.00	0.05				0.06	0.00
Muscle	% Difference							2.53	-
	t-Test							0.04	
Skeleton	% Difference	0.33	-	1.19	-			1.19	1.20
	t-Test	0.01		0.02				0.02	0.00

Comparison: ERICA vs MCNPX

Organ	Statistic*	N2BL Infinite	N2BL Rabbit	N2OM Infinite	N2OM Rabbit	N2LI Infinite	N2LI Rabbit	Round Infinite	Round Rabbit
Skin	% Difference							0.26	0.27
	t-Test							0.02	0.00
Spleen	% Difference	0.66	0.63	1.19	1.15	0.65	0.63	1.24	1.22
	t-Test	0.02	0.00	0.04	0.00	0.02	0.00	0.05	0.00
Stomach	% Difference	0.09	0.08	1.19	1.20			1.19	1.20
	t-Test	0.00	0.00	0.03	0.00			0.03	0.00

Results

- Comparison between Scaling Parameters
  - Body Length
  - Organ Mass
  - Literature
  - Sphere
  - Statistics were similarly close to zero
    - Potentially indicate geometry is negligible
    - Consider the case of the small intestine
      - Longitudinal Diameter = 855 cm
      - Diameter = 0.4 cm
      - Practically identical to spherical results

Comparison: Scaling Parameters

Organ	Statistic*	N2BL	N2OM	N2LI	Round
Heart	% Difference				-
	t-Test				
Large	% Difference	0.08	0.04	0.12	0.04
Intestine	t-Test	0.01	0.00	0.01	0.00
Small	% Difference	0.27	0.20	0.16	0.12
Intestine	t-Test	0.03	0.02	0.02	0.01
Kidney	% Difference	0.12	0.01	-	0.11
(one)	t-Test	0.00	0.00		0.00

Comparison: Scaling Parameters

Organ	Statistic*	N2BL	N2OM	N2LI	Round
Liver	% Difference	0.06	0.07	0.02	0.04
	t-Test	0.00	0.00	0.00	0.00
Lung	% Difference	0.15	0.14	-	0.04
(one)	t-Test	0.03	0.02		0.01
Muscle	% Difference				-
	t-Test				
Skeleton	% Difference	0.45	0.30	-	0.10
	t-Test	0.01	0.01		0.00

Comparison: Scaling Parameters

Organ	Statistic*	N2BL	N2OM	N2LI	Round
Skin	% Difference				-
	t-Test				
Spleen	% Difference	0.19	0.20	0.18	0.16
	t-Test	0.01	0.01	0.01	0.01
Stomach	% Difference	0.43	0.21	-	0.21
	t-Test	0.02	0.01		0.01

Results

- Absorbed Dose Rate – Maralinga Rabbits
  - 25 % quartile = average for reference rabbit
  - Scaled mean was 17% higher than refference
    - Rabbit-1 had the lowest blood, muscle and bone Pu-239 concentrations
  - Absorbed dose rates < 40 μGy/hr
    - DoE and IAEA guidance based on reproduction rates

Maralinga Rabbit Dose Rates (μGy/hr)

Organ	ICRP Rabbit Mean	Min	25% Quartile	Mean	75% Quartile	Max
Heart	4E-07	2E-07	4E-07	4E-07	1E-06	2E-05
Large Intestine	5E-04	2E-04	5E-04	6E-04	1E-03	3E-02
Small Intestine	5E-04	2E-04	5E-04	6E-04	2E-03	3E-02
Kidney (one)	9E-07	4E-07	9E-07	1E-06	2E-06	5E-05

Maralinga Rabbit Dose Rates (μGy/hr)

Organ	ICRP Rabbit Mean	Min	25% Quartile	Mean	75% Quartile	Max
Liver	9E-05	4E-05	9E-05	1E-04	3E-04	6E-03
Lung (one)	3E-05	1E-05	3E-05	3E-05	7E-05	2E-03
Muscle	3E-05	1E-05	3E-05	3E-05	7E-05	2E-03
Skeleton	9E-05	4E-05	9E-05	1E-04	3E-04	6E-03

Maralinga Rabbit Dose Rates (μGy/hr)

Organ	ICRP Rabbit Mean	Min	25% Quartile	Mean	75% Quartile	Max
Skin	7E-03	3E-03	7E-03	9E-03	2E-02	4E-01
Spleen	2E-06	7E-07	2E-06	2E-06	5E-06	1E-04
Stomach	2E-04	6E-05	2E-04	2E-04	4E-04	9E-03

Conclusion

- Absorbed dose rates were calculated using ERICA and MCNPX
- All organs were treated either as elliptical or spherical
- Everything was composed of ICRU 4-element tissue
- Lack of any statistical difference between computational models
  - ERICA is a viable means of determining internal dosimetry
- Maralinga rabbits absorbed dose rates were 17% higher than from ICRP Rabbit
- All absorbed dose rates were below 40 μGy/hr

Special Thanks!

Alex Brandl

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Tom Johnson

&

John Pinder

Questions?

Extra Slides…

Results

- Absorbed Dose Rate – Bone and Muscle
  - % Differences: 42-100 %
    - Scaled values were between 1-2 orders of magnitude and would underestimate absorbed dose
  - Muscle had the lowest % Differences and t-scores
    - Possible due to less variability in muscle tissue
    - Wide range for blood and bone

Table 17 Organ specific absorbed dose rates (μGy/h) for Maralinga rabbits

			Scaled from ICRP Skeleton				Scaled from ICRP Muscle		
Name	Statistic	Specific*	Blood	Muscle	Bone	ERICA	Blood	Muscle	Bone
Rabbit-1	Mean	1.4E-03	9.3E-05	9.3E-05	9.3E-05	4.6E-05	2.6E-05	2.6E-05	2.6E-05
	S-x	5.9E-04	7.9E-05	6.3E-05	5.8E-05	1.9E-05	2.3E-05	1.9E-05	1.7E-05
Rabbit-2	Mean	1.5E-03	5.3E-03	2.4E-04	9.6E-05	1.2E-04	1.5E-03	6.7E-05	2.6E-05
	S-x	4.4E-04	3.9E-03	1.3E-04	5.1E-05	2.7E-05	1.1E-03	4.0E-05	1.6E-05
Rabbit-3	Mean	1.8E-03	6.8E-05	2.5E-04	1.2E-04	1.2E-04	1.9E-05	7.0E-05	3.3E-05
	S-x	2.9E-04	1.7E-04	1.4E-04	5.7E-05	3.0E-05	4.8E-05	4.3E-05	1.8E-05
Rabbit-5	Mean	2.9E-02	1.4E-04	3.0E-04	1.9E-03	1.4E-04	3.8E-05	8.2E-05	5.1E-04
	S-x	3.3E-03	9.1E-05	1.6E-04	8.7E-04	3.2E-05	2.7E-05	5.0E-05	2.8E-04
Rabbit-6	Mean	1.3E-03	3.8E-05	5.7E-03	8.2E-05	2.7E-03	1.0E-05	1.6E-03	2.3E-05
	S-x	3.0E-04	5.0E-05	2.8E-03	4.2E-05	1.7E-04	1.4E-05	8.8E-04	1.3E-05

*Absorbed dose rate was calculated for the specific rabbit of interest based on body mass and Pu-239 concentration