OAK RIDGE National Laboratory

PHYSICS & ENGINEERING
FRANCIS MARION UNIVERSITY

Challenges and Opportunities for Dosimetry in Low-Dose Radiation Research

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Presentation to the National Academies Committee on Developing a Long-Term Strategy for Low-Dose Radiation Research in the United States

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U.S. DEPARTMENT OF ENERGY

Overview

- Recent advances in internal dosimetry
- Opportunity for low-dose radiation research
- Present and future challenges for low-dose dosimetry
- Research needs

Radiation Dosimetry 101

$$\text{Dose} = \text{Source term} \times \text{Energy absorption term}$$

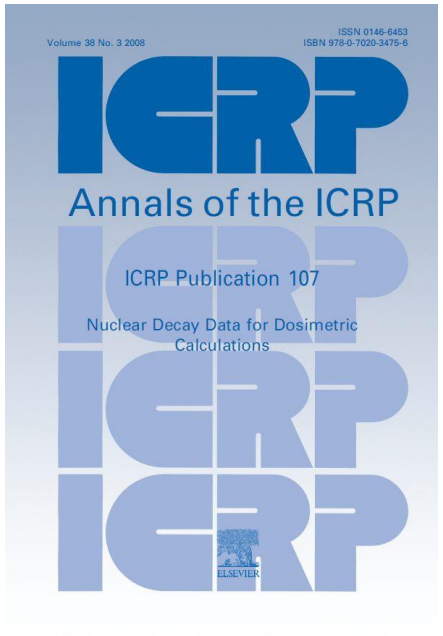
External

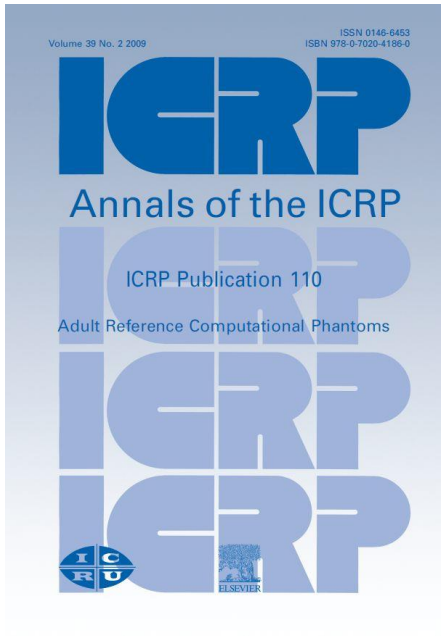
$$D_T = \int_0^{\infty} \Phi\left(\mathbf{r_0}, E\right) \times d_T\left(E\right) dE$$

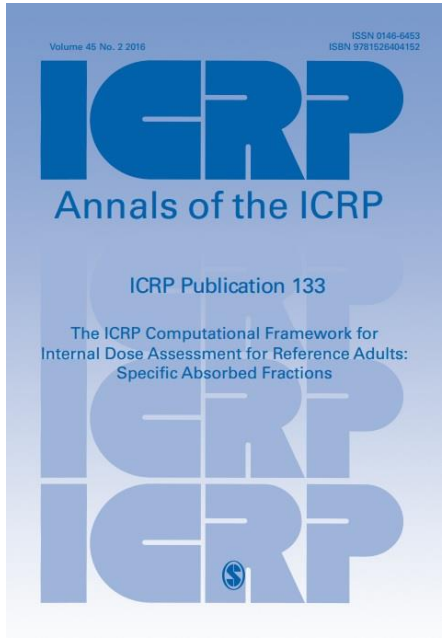
Internal

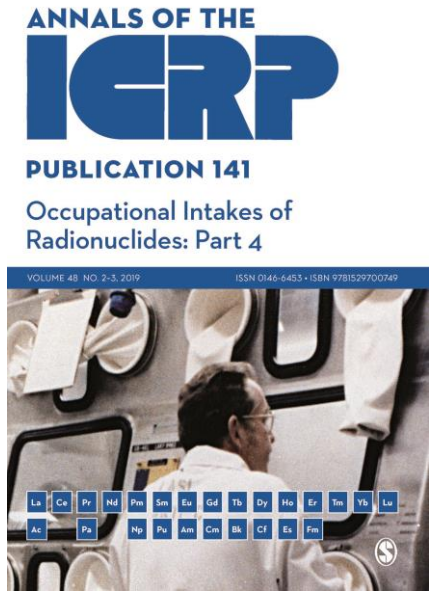
$$D_T = \int_{t_0}^{t_0+\tau} A_S\left(t\right) \times S_w\left(r_T \leftarrow r_S, t\right) dt$$

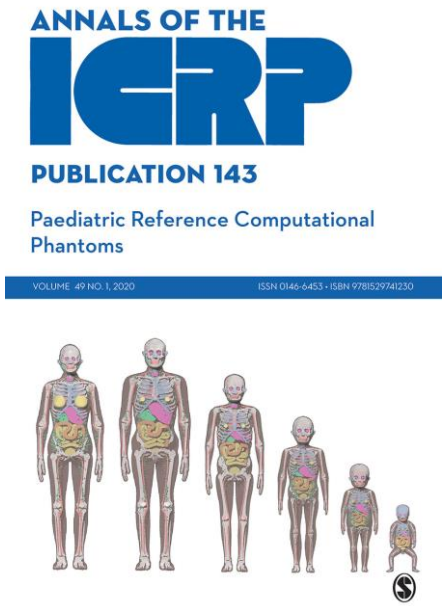
Recent advances in internal dosimetry











- Use of whole-body, non-hermaphrodite voxel phantoms
- Improved energy-absorption models for charged particles in the alimentary tract, gall bladder, and skeleton
- Improvements to biokinetic models
- Inclusion of whole-body blood as a source region
- Independent biokinetics for members of a decay chain $^{125}\mathrm{Cs} \rightarrow {}^{125}\mathrm{Xe} \rightarrow {}^{125}\mathrm{I} \rightarrow$
- Improved nuclear decay data

Opportunity for Low-Dose Radiation Research

- Improvements to reference individual dosimetry reduce/remove the conservatism in the models
- Without the conservatism, these internal dosimetry models can be used with greater confidence in dose reconstruction
- Internal doses in cohorts result in chronic doses with non-uniform dose rates across the body

DOE Russian Health Studies

"Good quality studies in radiation epidemiology include a scientifically sound and transparent scientific approach to dosimetry or dose estimation, preferably at the level of the individual study participant."
UNSCEAR 2017 Report on Sources, Effects and Risks of Ionizing Radiation

NCRP REPORT No. 163

RADIATION DOSE RECONSTRUCTION: PRINCIPLES AND PRACTICES

NCRP

NCRP REPORT No. 164

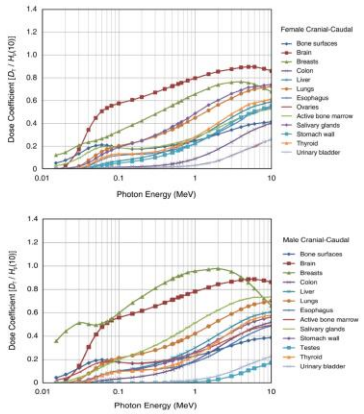
UNCERTAINTIES IN INTERNAL RADIATION DOSE ASSESSMENT

NCRP

NCRP REPORT No. 178

DERIVING ORGAN DOSES AND THEIR UNCERTAINTY FOR EPIDEMIOLOGIC STUDIES

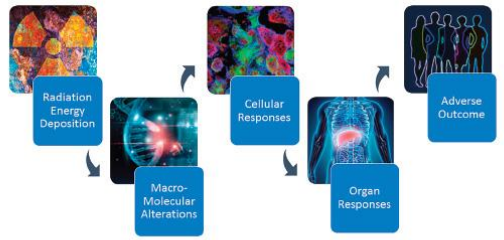
(With a Focus on the One Million U.S. Workers and Veterans Study of Low-Dose Radiation Health Effects)



National Council on Radiation Protection and Measurements

NCRP REPORT No. 186

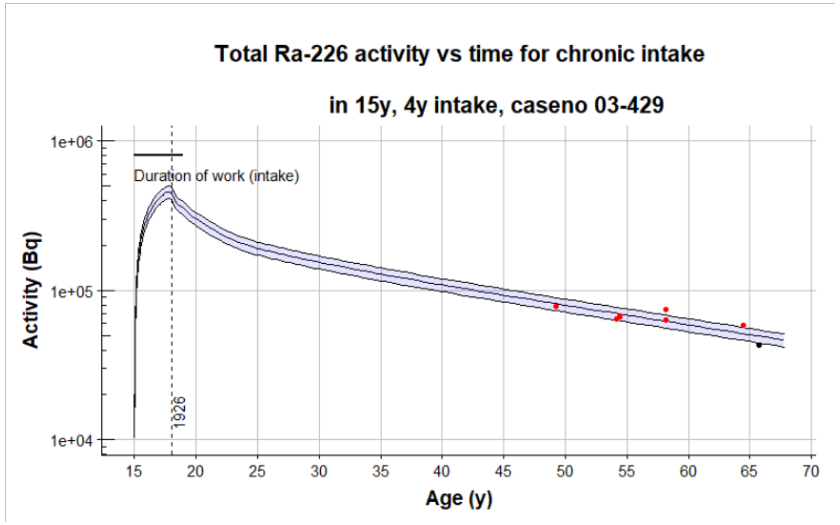
APPROACHES FOR INTEGRATING INFORMATION FROM RADIATION BIOLOGY AND EPIDEMIOLOGY TO ENHANCE LOW-DOSE HEALTH RISK ASSESSMENT

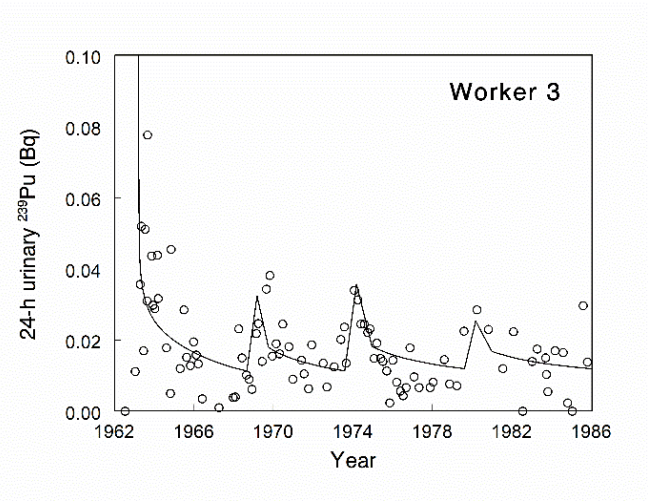


National Council on Radiation Protection and Measurements

Challenge #1 – Quality and Quantity of Measurements

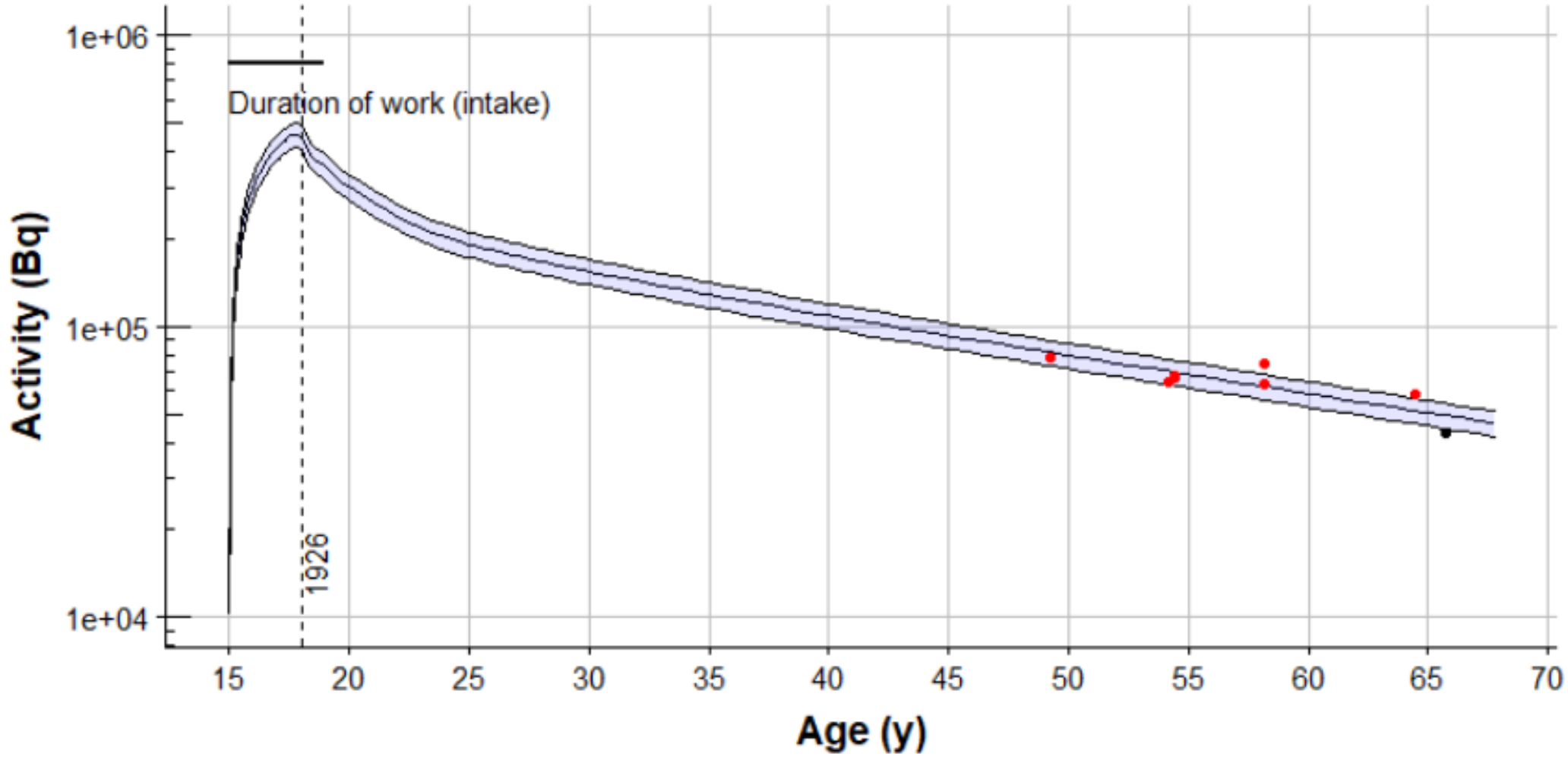
- The quality and quantity of the measurements used to inform dose reconstruction vary by cohort, and even within a cohort
- Some measurements are very good while others are limiting
- Examples: Radium Dial Painters, Rocky Flats





Total Ra-226 activity vs time for chronic intake

in 15y, 4y intake, caseno 03-429



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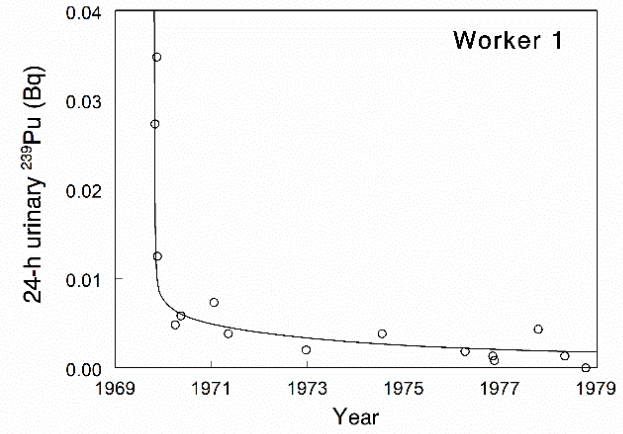
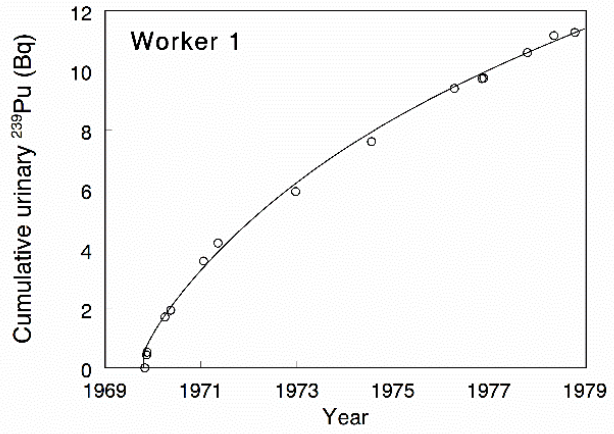
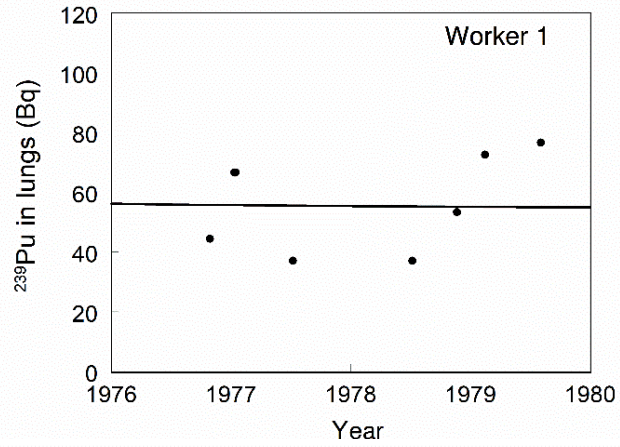
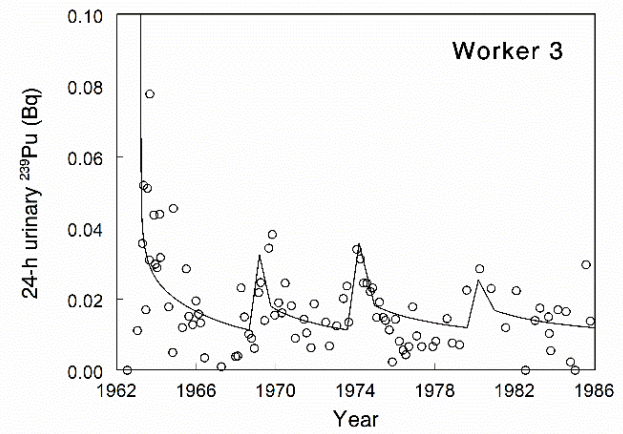
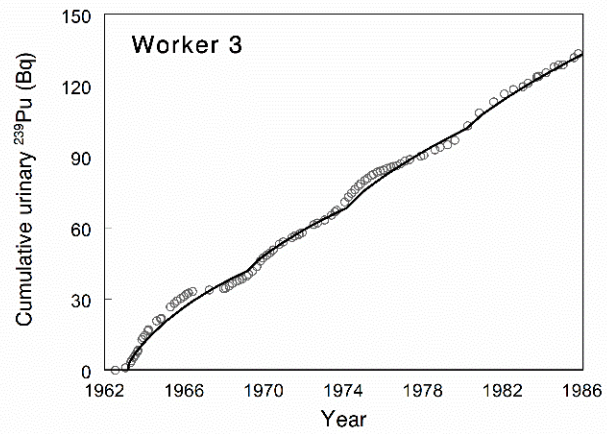
Rocky Flats

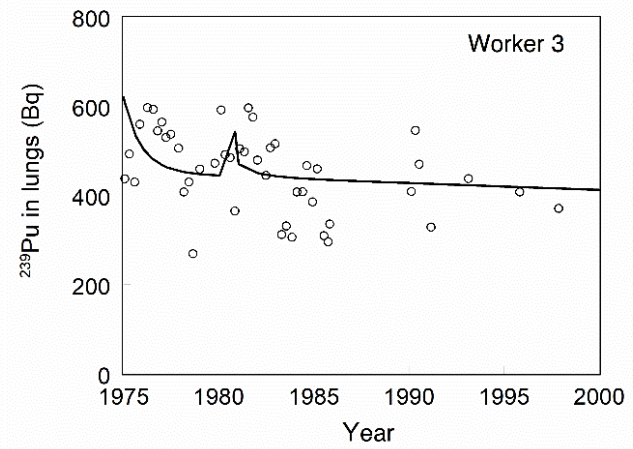

Worker 1
24-h urinary ^{239}Pu (Bq)
Year
0.04
0.03
0.02
0.01
0.00
1969
1971
1973
1975
1977
1979


Worker 1
Cumulative urinary ^{239}Pu (Bq)
Year
12
10
8
6
4
2
0
1969
1971
1973
1975
1977
1979


Worker 1
^{239}Pu in lungs (Bq)
Year
120
100
80
60
40
20
0
1976
1977
1978
1979
1980


Worker 3
24-h urinary ^{239}Pu (Bq)
Year
0.10
0.08
0.06
0.04
0.02
0.00
1962
1966
1970
1974
1978
1982
1986


Worker 3
Cumulative urinary ^{239}Pu (Bq)
Year
150
120
90
60
30
0
1962
1966
1970
1974
1978
1982
1986


Worker 3
^{239}Pu in lungs (Bq)
Year
800
600
400
200
0
1975
1980
1985
1990
1995
2000

Challenge #2 – What's the target and do we have a model for it?

- We're still learning more
  most appropriate dosim
  responses.
- New targets will likely no
  biokinetics or energy ab
- Examples:
  - HATM, HRTM geometries
  - Skeleton
  - Cognition
  - Cardiovascular disease

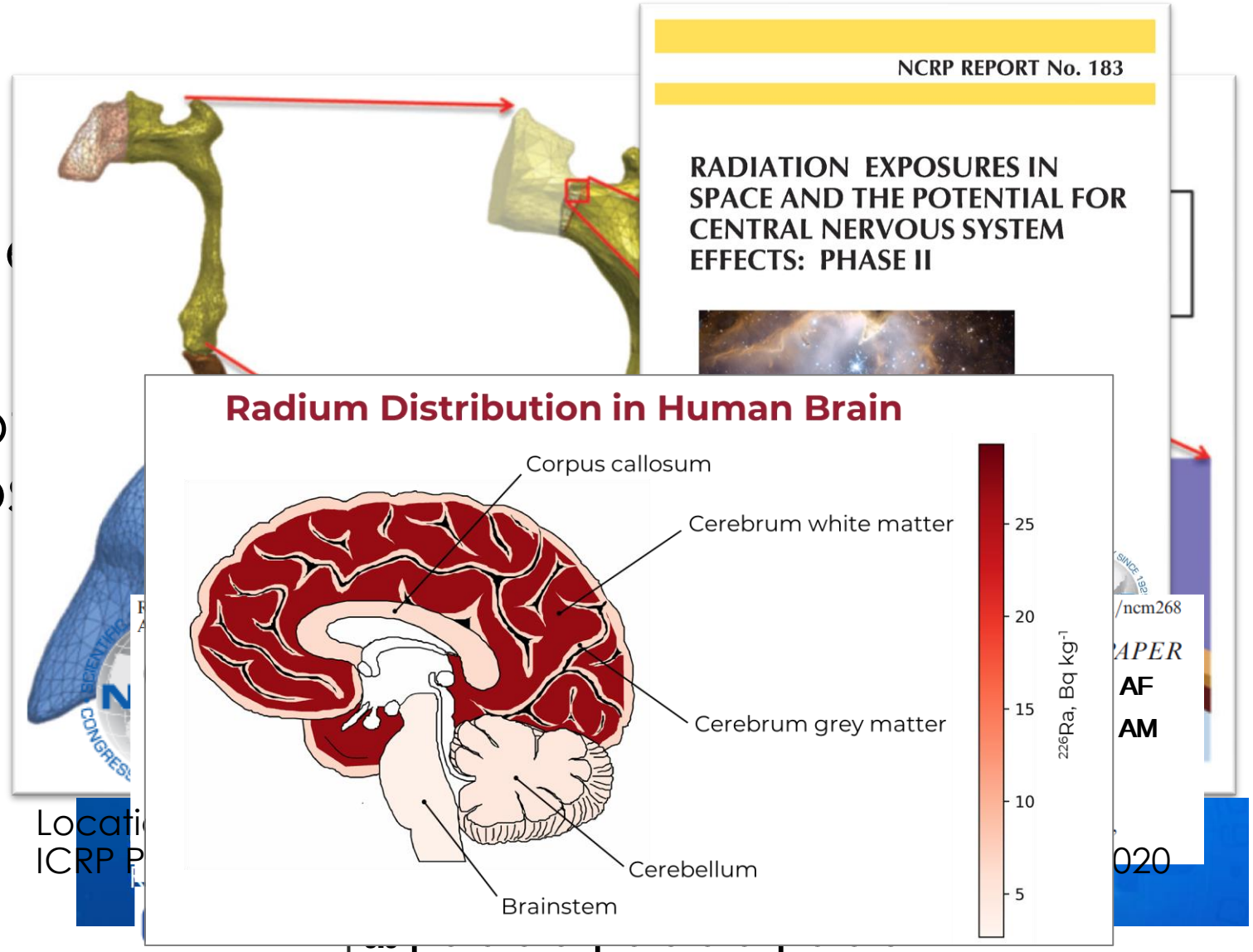


Image courtesy of Martin Sefl, USTUR, Washington St. Univ.

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Challenge #3 – Continuing to improve biokinetic modeling

- Age-dependency after reaching adulthood
  - Current models used in radiation protection model an adult's biokinetic transfer rates as constant from age 20 or 25 years through end of life
- Sex-dependent systemic biokinetics
  - Although we have sex-specific energy absorption data, we don't have sex-specific systemic biokinetics.
  - Systemic biokinetics of the male are applied to the female

INTERNATIONAL JOURNAL OF RADIATION BIOLOGY
https://doi.org/10.1080/09553002.2021.1917785

Taylor & Francis
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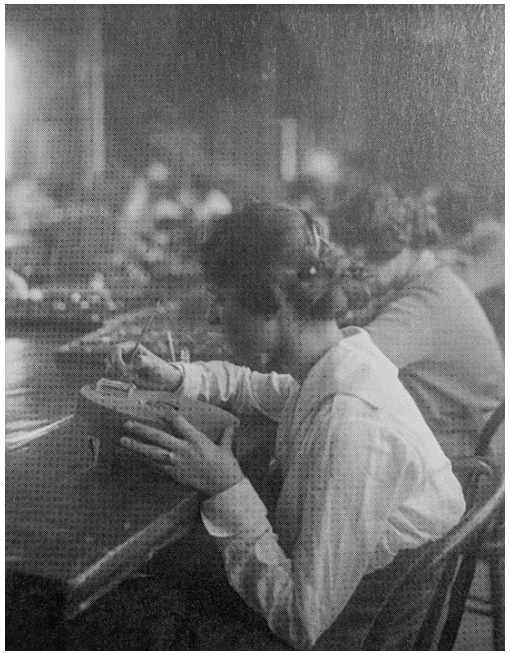
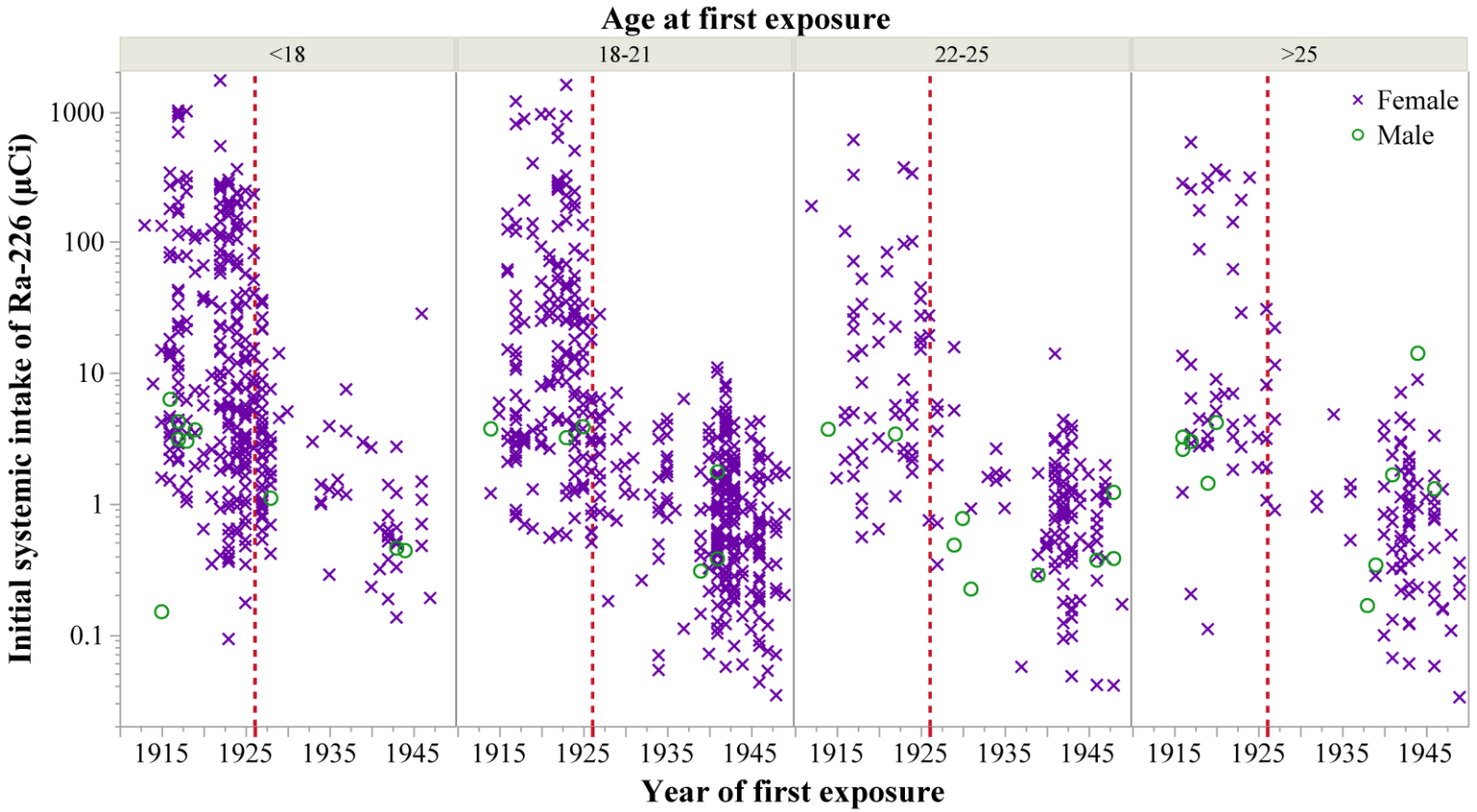
REVIEW

Radium dial workers: back to the future

Nicole E. Martinez[a,b], Derek W. Jokisch[b,c], Lawrence T. Dauer[d], Keith F. Eckerman[b], Ronald E. Goans[e], John D. Brockman[f], Sergey Y. Tolmachev[g], Maia Avtandilashvili[g], Michael T. Mumma[h,i], John D. Boice, Jr.[i,j], and Richard W. Leggett[b]



from Jim Riddings's *Illustrated History of Ottawa's Radium Dial Scandal*



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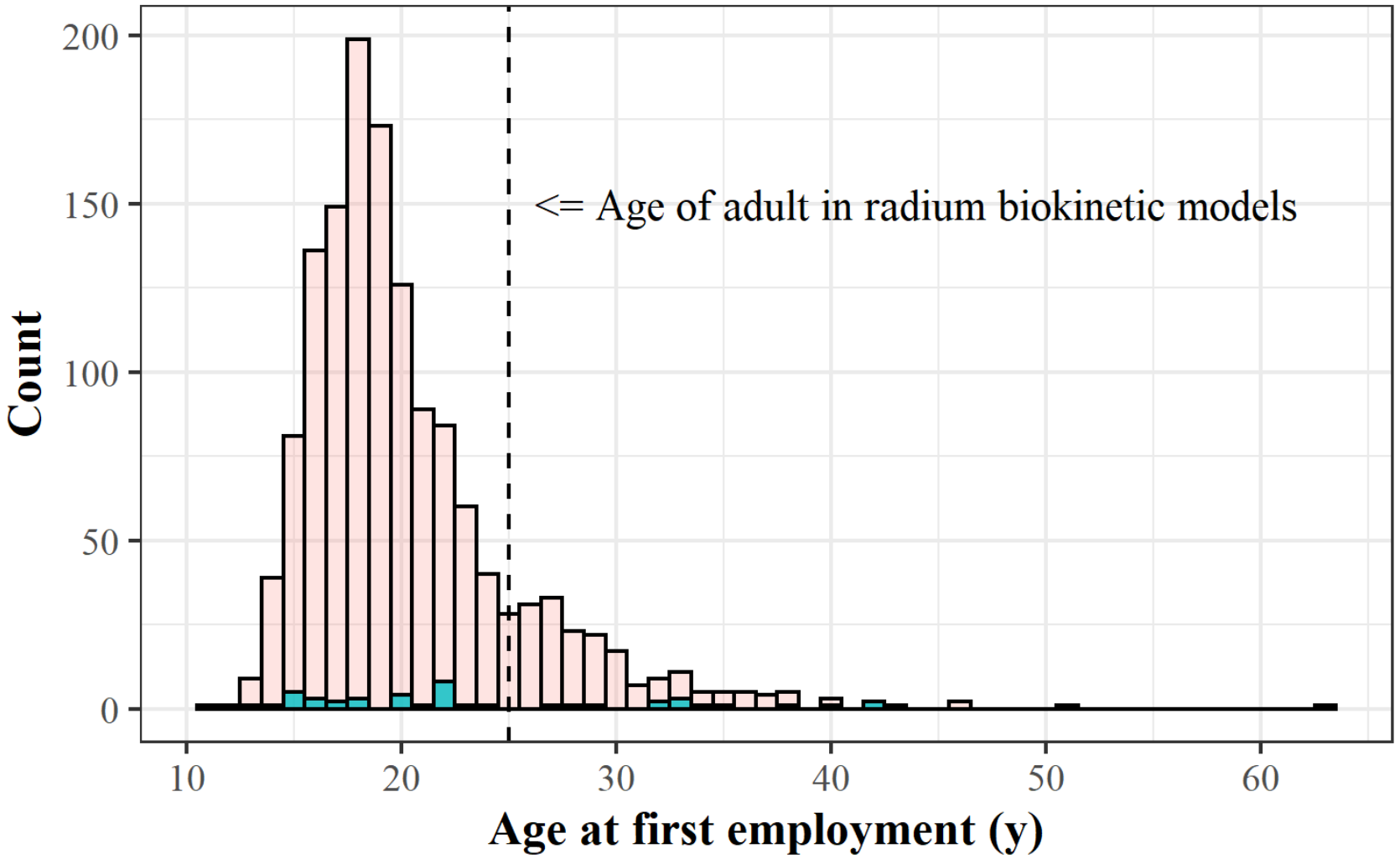
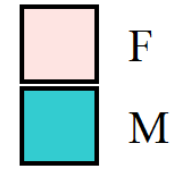
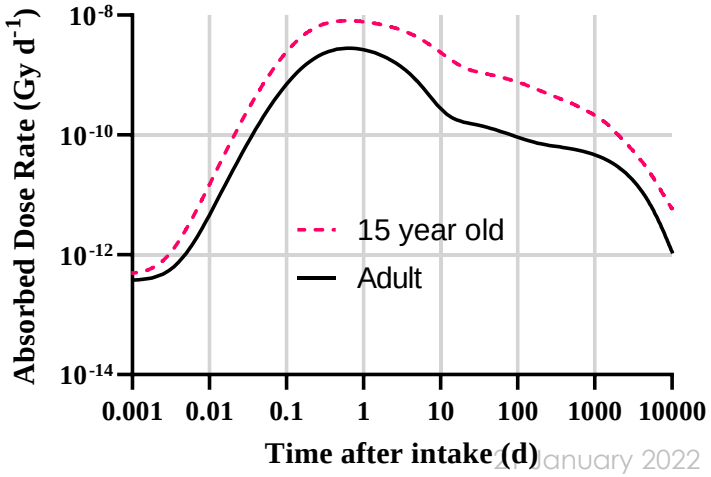




1 Bq ingestion of Ra-226
bone endosteum (intake at age 15y vs. 25y)



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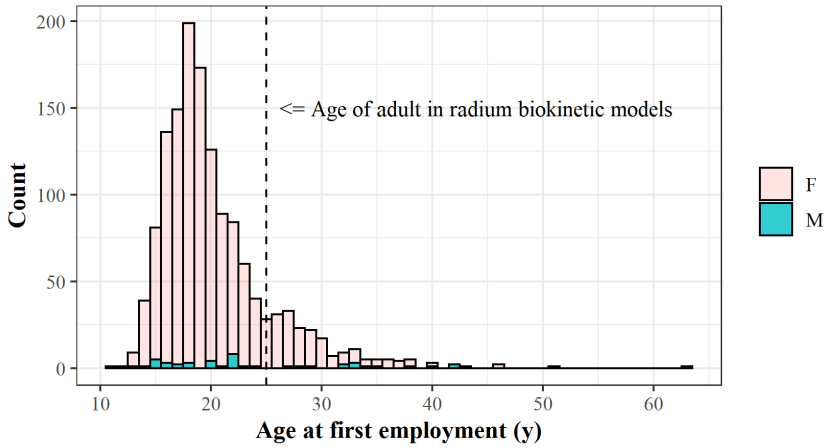
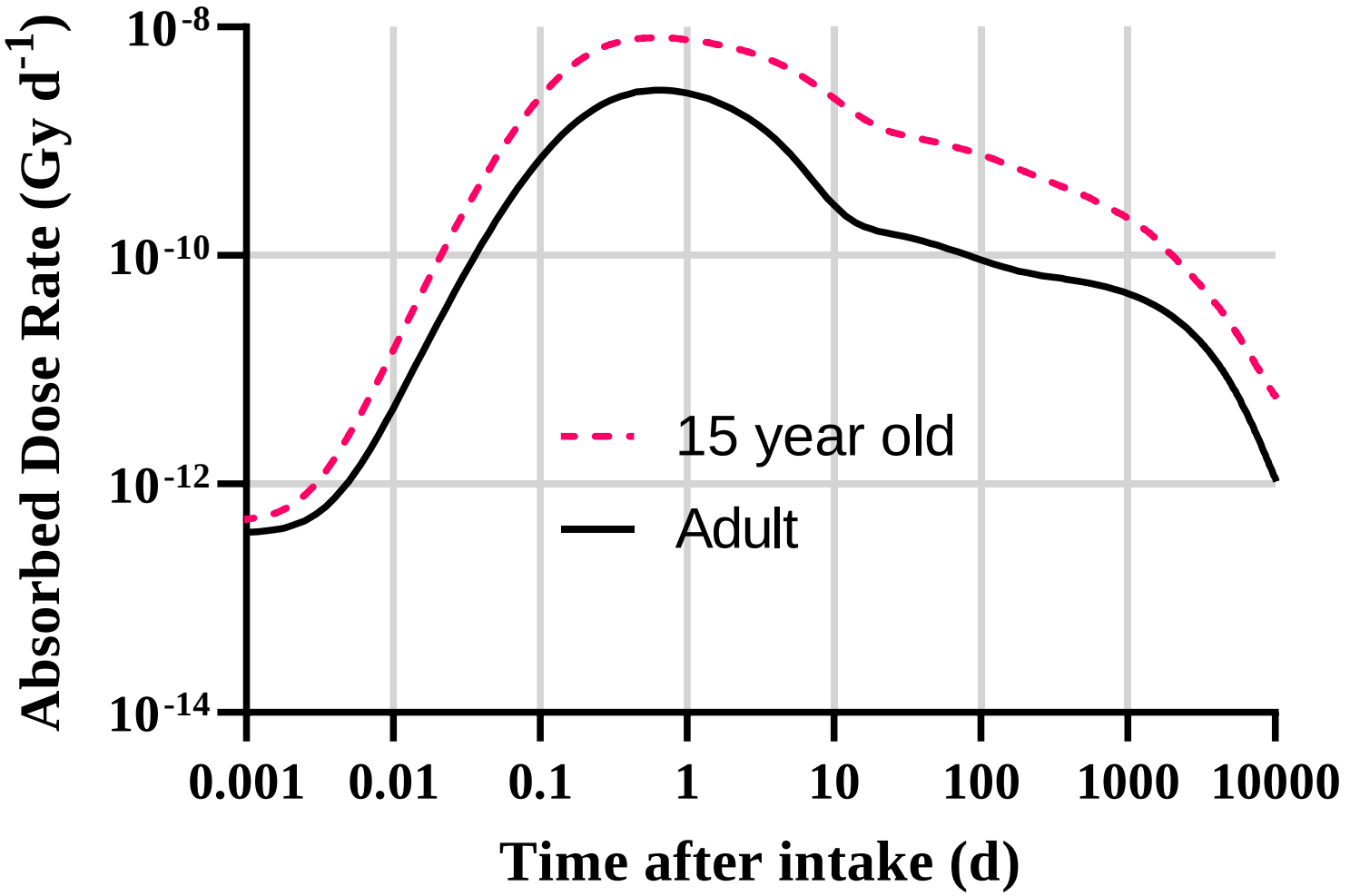


1 Bq ingestion of Ra-226 bone endosteum (intake at age 15y vs. 25y)



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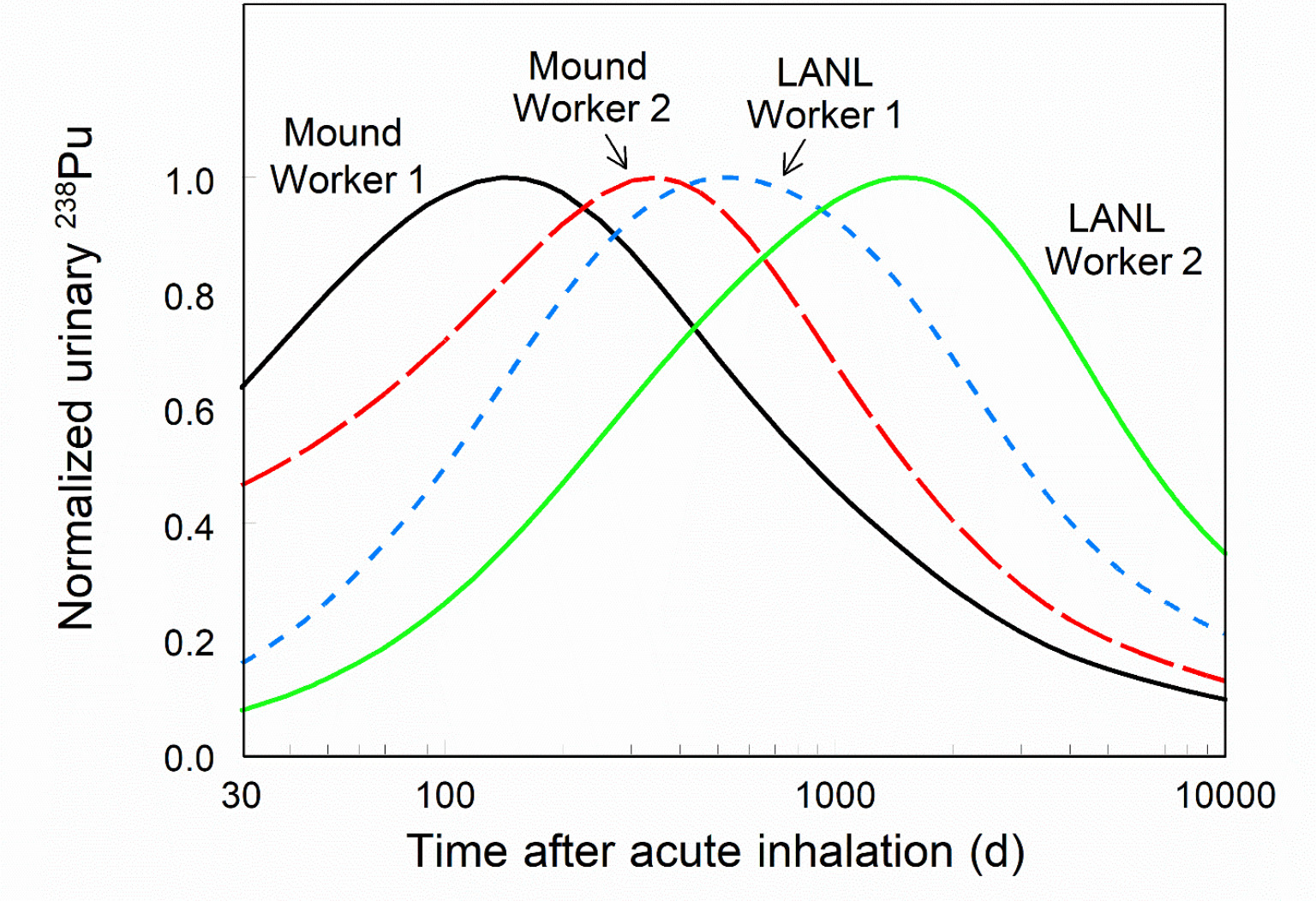
Challenge #4 – Biological Variability in Biokinetic Models

- For dose reconstruction we need to address biological variability by either:
  - Choosing custom models to match each member of a cohort
  - Or, using the variability to quantify uncertainty in each term
- We have lots-o-phantoms which can be used to address the energy absorption term
- We need to expand the data and tools which can be used to address variability in the biokinetic term
  - TR LaBone 2021, "*Bayesian Calibration of the ICRP Zirconium Biokinetic Model and Use of Canned Priors for the Evaluation of Bioassay.*" University of South Carolina

Mound (Ohio) and Los Alamos – Pu-238 inhalation Individual and Site Variability in Biokinetics



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Research Needs in Dosimetry…in support of low-dose research

- Sex-specific biokinetic modeling
- Age-dependent biokinetic modeling beyond adulthood
- Biokinetic modeling based on growing experimental data and knowledge of mammalian/human physiology with an emphasis in quantifying variability
- Energy absorption data for new source-target combinations

Center for Radiation Protection Knowledge





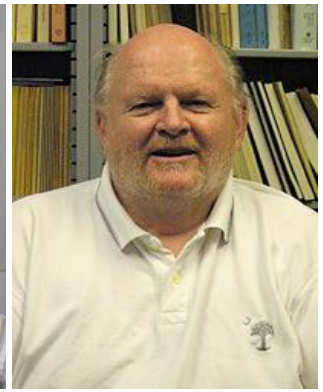
ORNL / Y12

Left to right
Rich Leggett
Caleigh Samuels
Scott Schwahn
Amber Harshman
Ken Veinot



Joint Faculty Appointees

Derek Jokisch (Francis Marion)
Nicole Martinez (Clemson)
Nolan Hertel (Georgia Tech)

Consultants *ORNL Retirees*

Clay Easterly
Keith Eckerman