National Cancer Institute

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

The Future of Low-Dose Radiation Dosimetry: Methods/Tools and Applications

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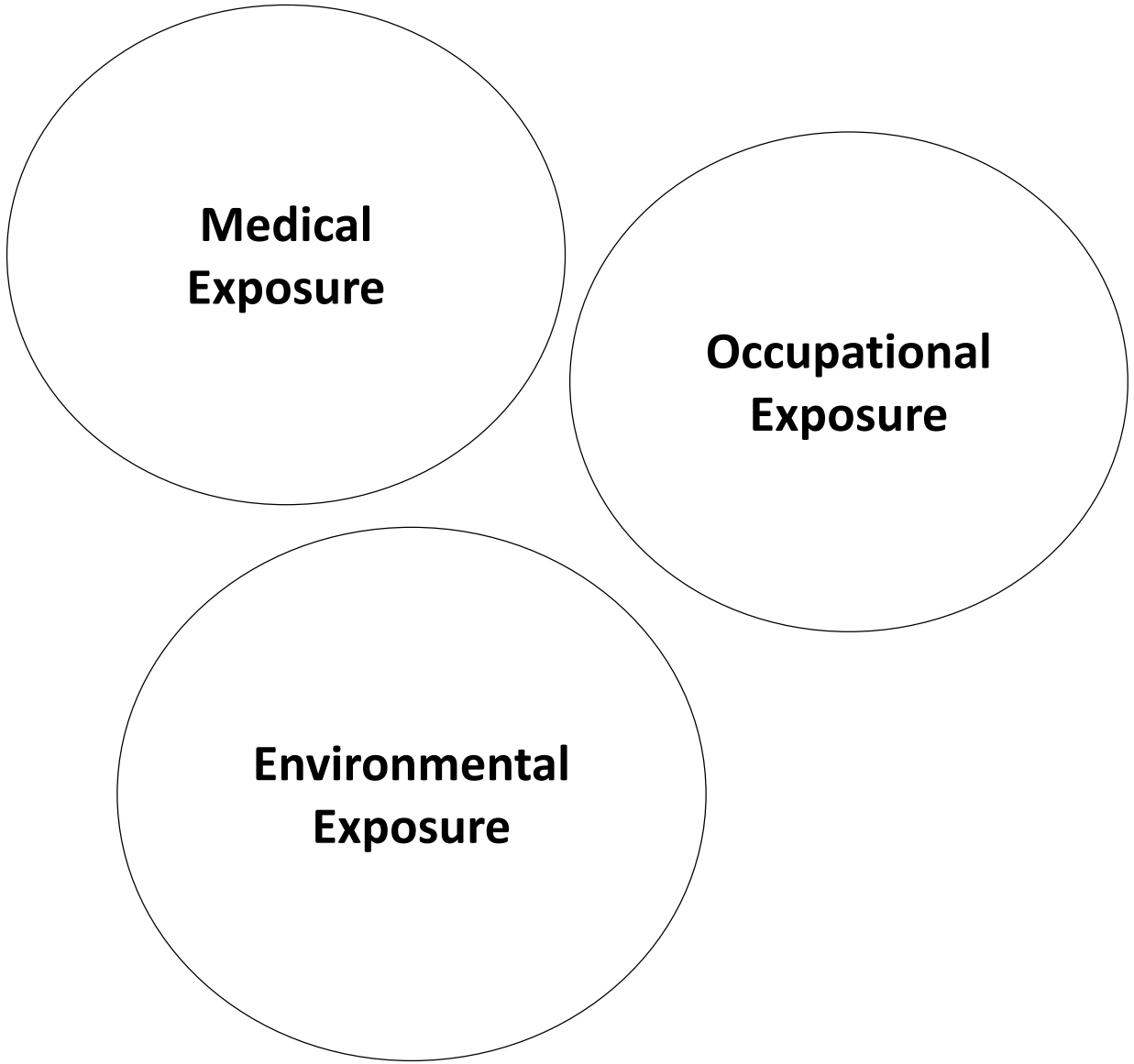
Contents

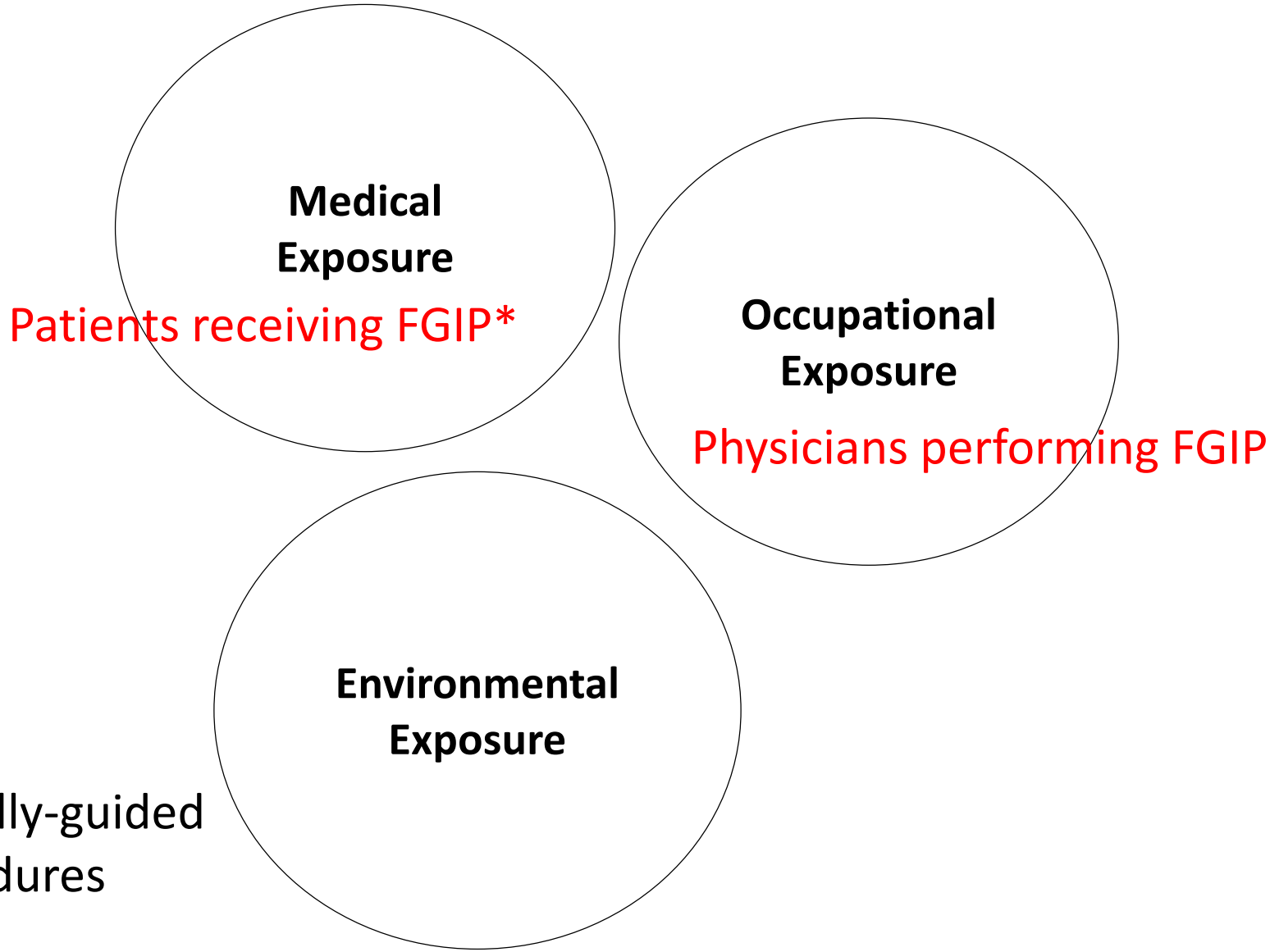
- Dosimetry methods and tools for low dose radiation epidemiology
- Limitations in dosimetry for epidemiology
- Opportunities in dosimetry for epidemiology
- Views on research priorities

DOSIMETRY METHODS AND TOOLS FOR LOW DOSE RADIATION EPIDEMIOLOGY

Type of radiation exposure

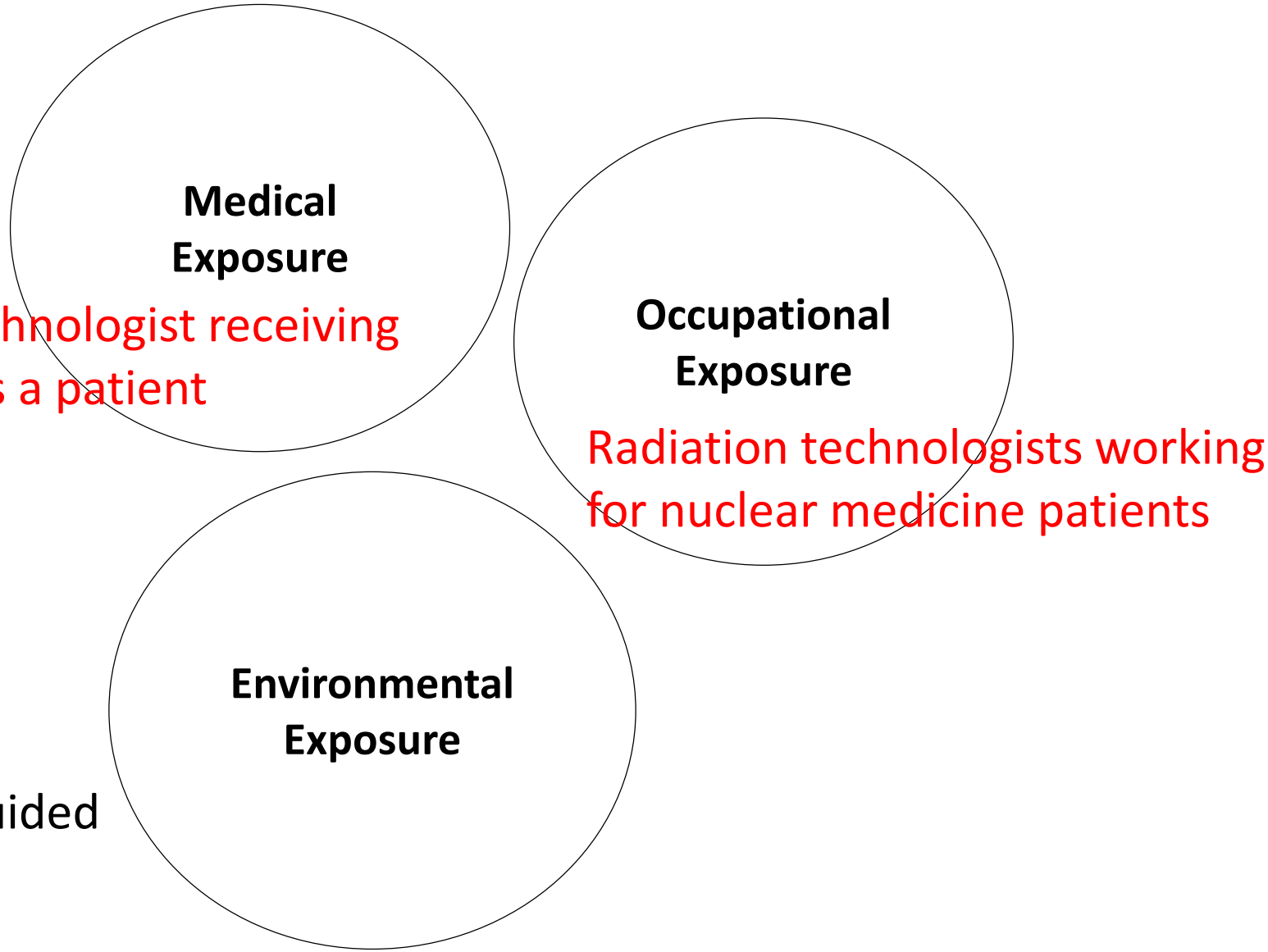


Type of radiation exposure



*FGIP: Fluoroscopically-guided interventional procedures

Type of radiation exposure



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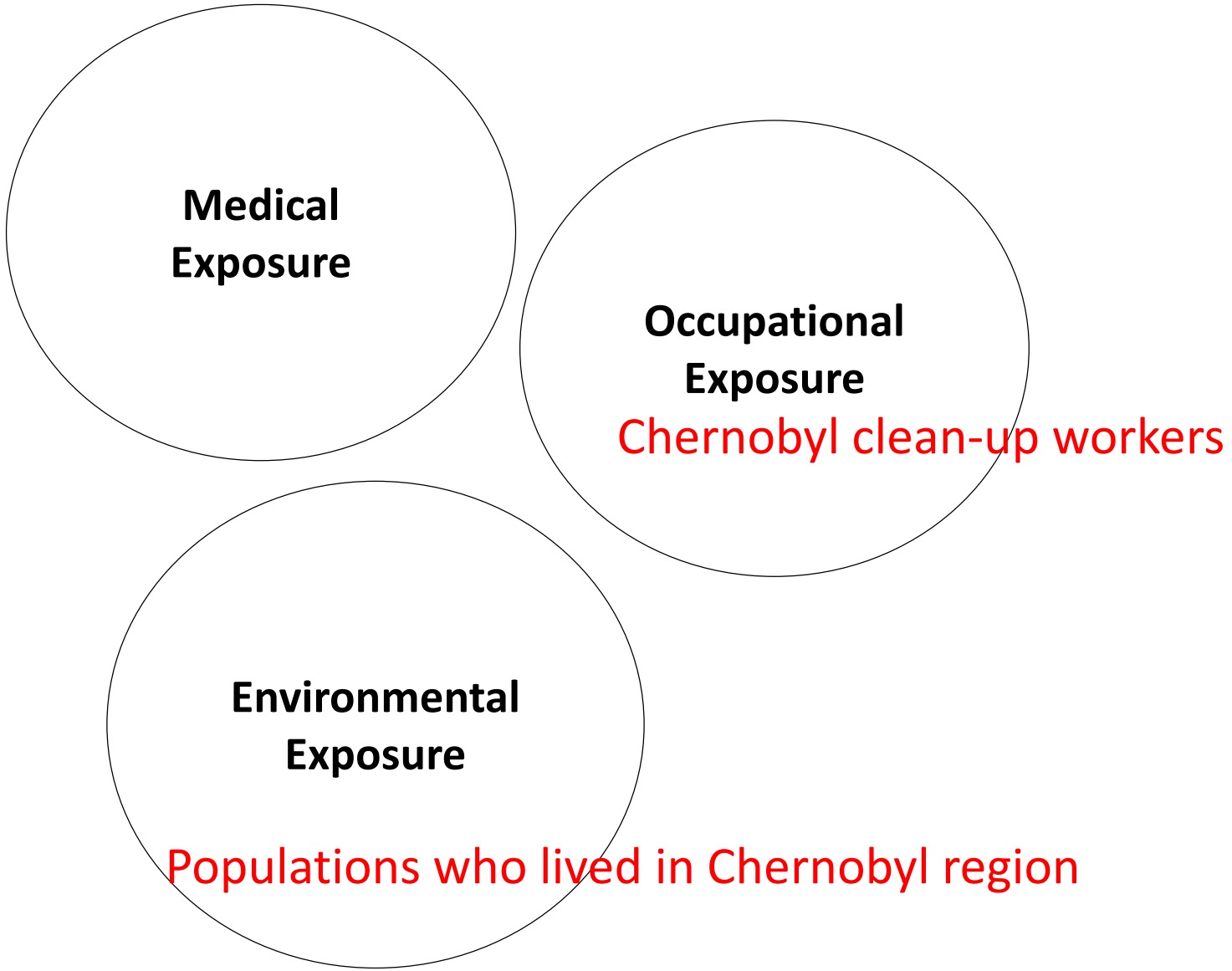

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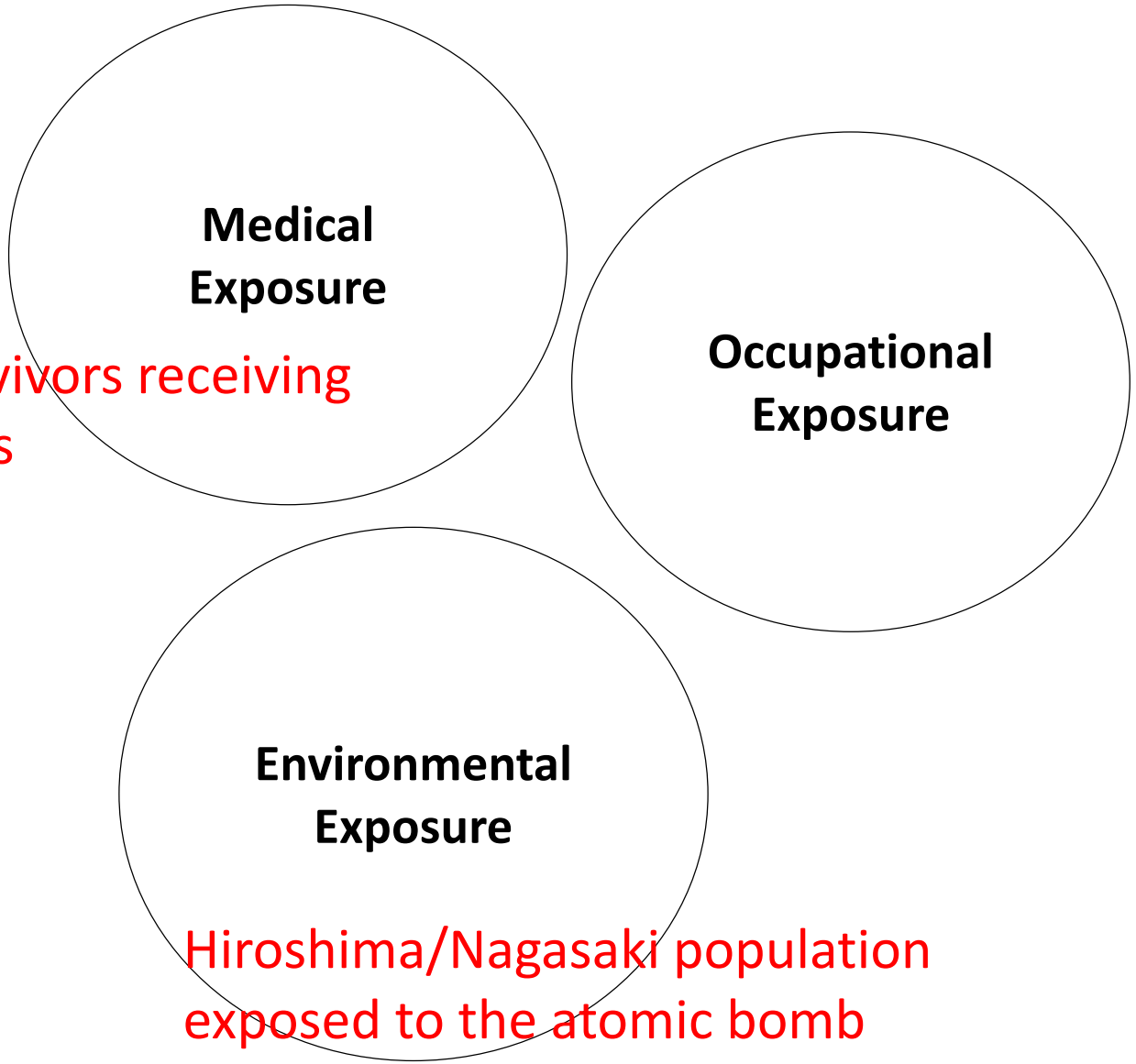
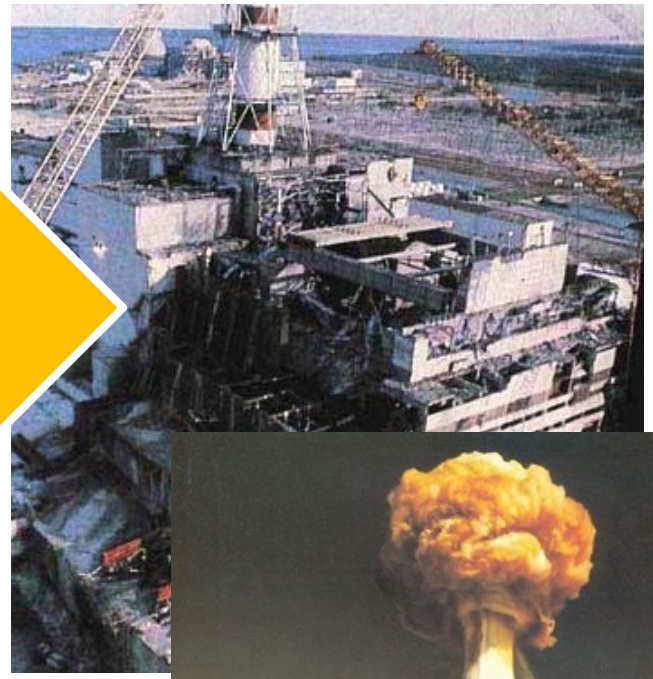


Atomic bomb survivors receiving radiological exams

Hiroshima/Nagasaki population exposed to the atomic bomb

Medical/occupational exposure

Environmental exposure

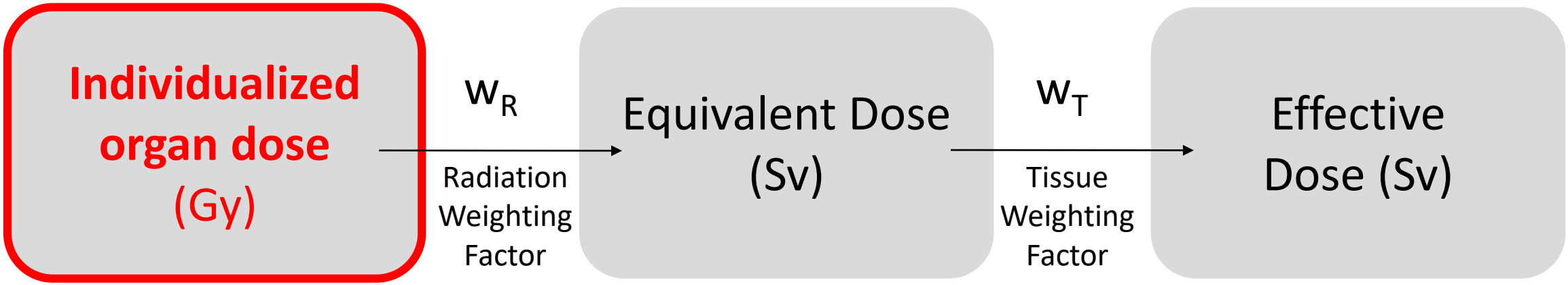


- Planned and controlled
- Relatively well documented

Key consideration in dosimetry for epidemiology

- Individualized organ dose required
- Large size cohorts
- Limited input for retrospective dose reconstruction
- Dosimetric uncertainty

Individualized organ dose required in epidemiology



* ICRP Publication 103 (2007)

General dosimetry approach

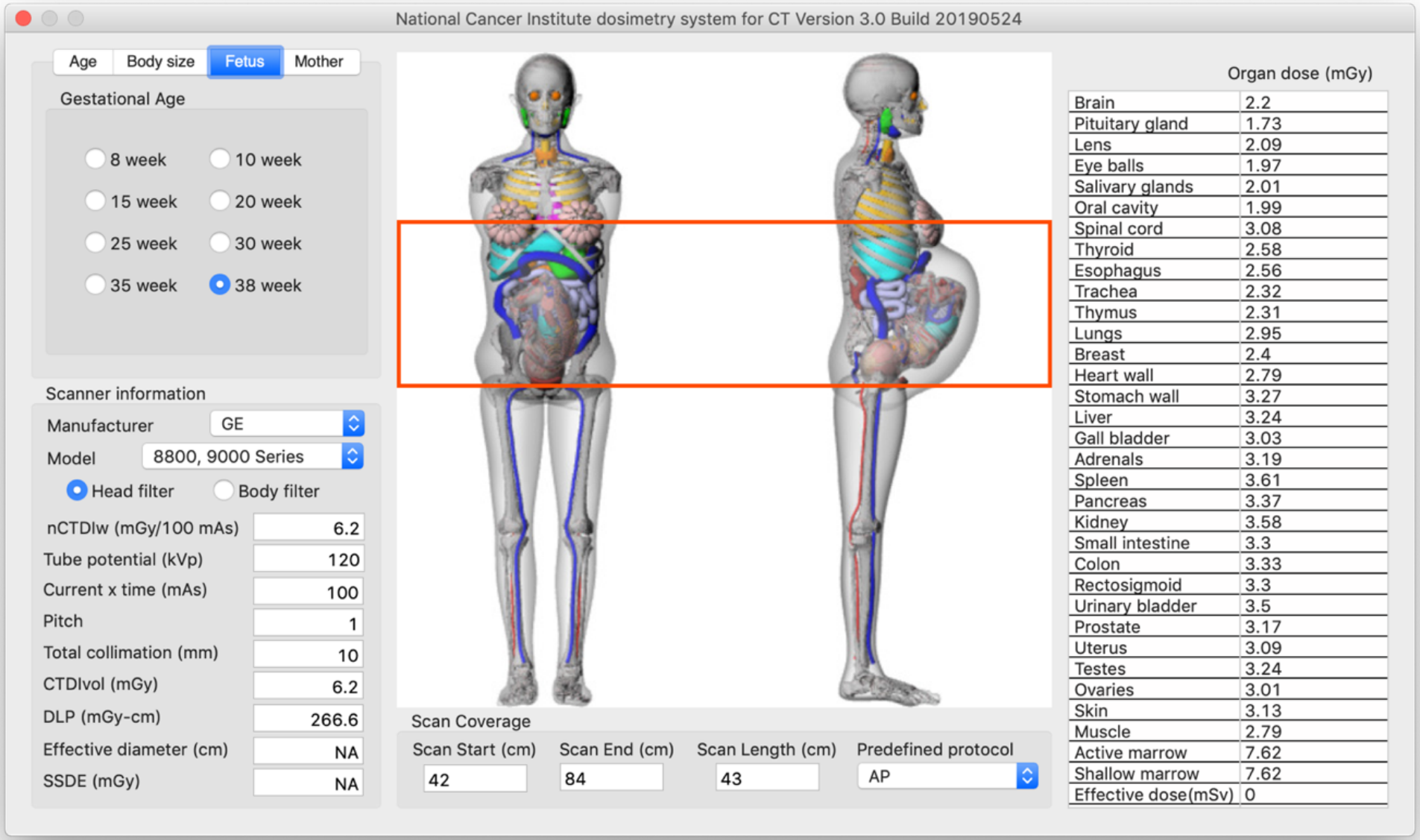
General dosimetry approach

Medical: phantom measurement, dose records, literature
Occupational: film badge, literature, questionnaire
Environmental: survey meter, environment data, questionnaire

General dosimetry approach

Computational human phantoms
Individualization: age, gender, body size, pregnancy
Monte Carlo radiation transport techniques
Computer software to automate conversion

NCI dosimetry system for Computed Tomography: NCICT



Experimental validation
Long et al. MP 2013
Dabin et al. PMB 2016
Giansante et al. JACMP 2019

*Lee et al. JRP (2015), **Lee et al. AJR (2017), ***Lee et al. RSNA (2019)

NCI dosimetry system for Nuclear Medicine: NCINM

National Cancer Institute dosimetry system for Nuclear Medicine 2.0.20210301

INPUT PANEL

NCI phantoms | ICRP phantoms

Phantom Gender: Male | Female

Phantom Age: 0-year | 1-year | 5-year | 10-year | 15-year | Adult

Radionuclide | Radiopharmaceutical

99mTc-ECD

Administered activity (MBq): 585

Administered activity (mCi): 15.81081

Source region	S value export?	Residence Time (h)	Cumulated Activity (MBq-s)
Adipose		0	0
Adrenal L		0	0
Adrenal R		0	0
Adrenal RL		0	0
Blood Body		0	0
Blood Heart		0	0
Blood Body+Heart		0	0
Brain		0.3	6.318e+5
Breast Adip+Gland		0	0
Breast Adipose		0	0
Breast Glandular		0	0
Bronchi		0	0
Colon L C		0.325	6.844e+5
Colon L W		0	0
Colon R C		0.4118	8.673e+5
Colon R W		0	0
Colon Rect C		0.1232	2.595e+5
Colon Rect W		0	0
Cortical Bone Marrow		0	0
Cortical Bone Mineral		0	0
Esophagus Fast		0	0
ET2		0	0
Gall Bladder C		0.19	4.001e+5
Gall Bladder W		0	0
Gonads		0	0
Heart Wall		0	0
Kidney L		0	0
Kidney L Cortex		0	0
Kidney L Medulla		0	0
Kidney L Pelvis		0	0
Kidney R		0	0
Kidney R Cortex		0	0
Kidney R Medulla		0	0
Kidney R Pelvis		0	0
Kidney RL		0.13	2.738e+5
Lenses of Eye		0	0
Liver		0.27	5.686e+5
Lung L		0	0

Export S values (mGy/MBq-s) | Initialize parameters

OUTPUT PANEL

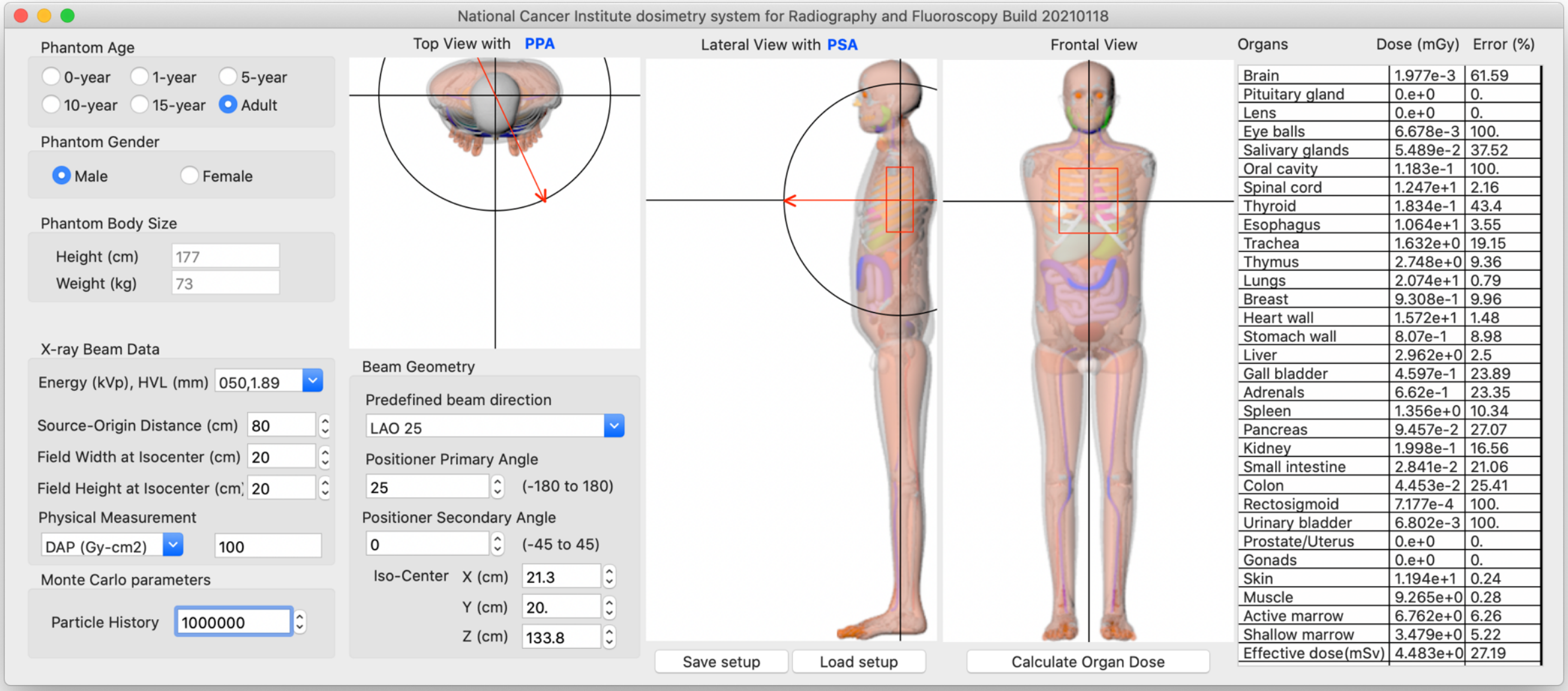
Target region	Organ Mass (g)	Organ Dose (mGy)	Dose per administered activity (mGy/MBq)
Adipose	20471.	1.917e+0	3.276e-3
Adrenal	14.	3.075e+0	5.257e-3
Adrenal L	7.	2.751e+0	4.703e-3
Adrenal R	7.	3.409e+0	5.827e-3
Bronchi	66.3	4.585e+0	7.837e-3
Brain	1449.8	2.667e+0	4.56e-3
Breast adipose	15.	7.275e-1	1.244e-3
Breast glandular	9.98	1.334e+0	2.28e-3
Colon W	369.91	5.386e+0	9.207e-3
Colon W L	149.96	5.042e+0	8.618e-3
Colon W R	149.96	5.644e+0	9.648e-3
ET	39.44	3.783e+0	6.467e-3
Gall bladder W	13.92	1.094e+1	1.87e-2
Gonads	35.	8.976e-1	1.534e-3
Heart W	329.94	1.337e+0	2.285e-3
Kidney	309.98	5.349e+0	9.143e-3
Kidney R	157.	5.567e+0	9.516e-3
Kidney L	152.98	5.131e+0	8.771e-3
Kidney cortex L	107.1	5.051e+0	8.634e-3
Kidney cortex R	109.9	5.48e+0	9.367e-3
Kidney medulla L	38.25	5.287e+0	9.037e-3
Kidney medulla R	39.24	5.713e+0	9.767e-3
Kidney pelvis L	7.63	5.471e+0	9.352e-3
Kidney pelvis R	7.86	6.046e+0	1.034e-2
Lenses of eye	0.38	4.469e-1	7.639e-4
Liver	1799.8	3.793e+0	6.484e-3
Lung	1200.6	1.321e+0	2.258e-3
Lung L	553.25	1.297e+0	2.218e-3
Lung R	647.37	1.34e+0	2.29e-3
Lymph nodes ET	2.26	9.074e-2	1.551e-4
Lymph nodes but ET&Th	129.3	2.328e+0	3.979e-3
Lymph nodes thoracic	6.4	4.098e-1	7.004e-4
Muscle	28996.	6.904e-1	1.18e-3
Nasal passage Ant	11.03	2.52e+0	4.308e-3
Nasal passage Post+pharynx	28.41	3.183e+0	5.441e-3
Oesophagus	40.	1.198e+0	2.049e-3
Oral mucosa	35.83	1.295e+1	2.214e-2

Effective dose ICRP60 (mSv): 6.902e+0

Effective dose ICRP103 (mSv): 7.23e+0

Villoing... Lee, BPEX (2020)

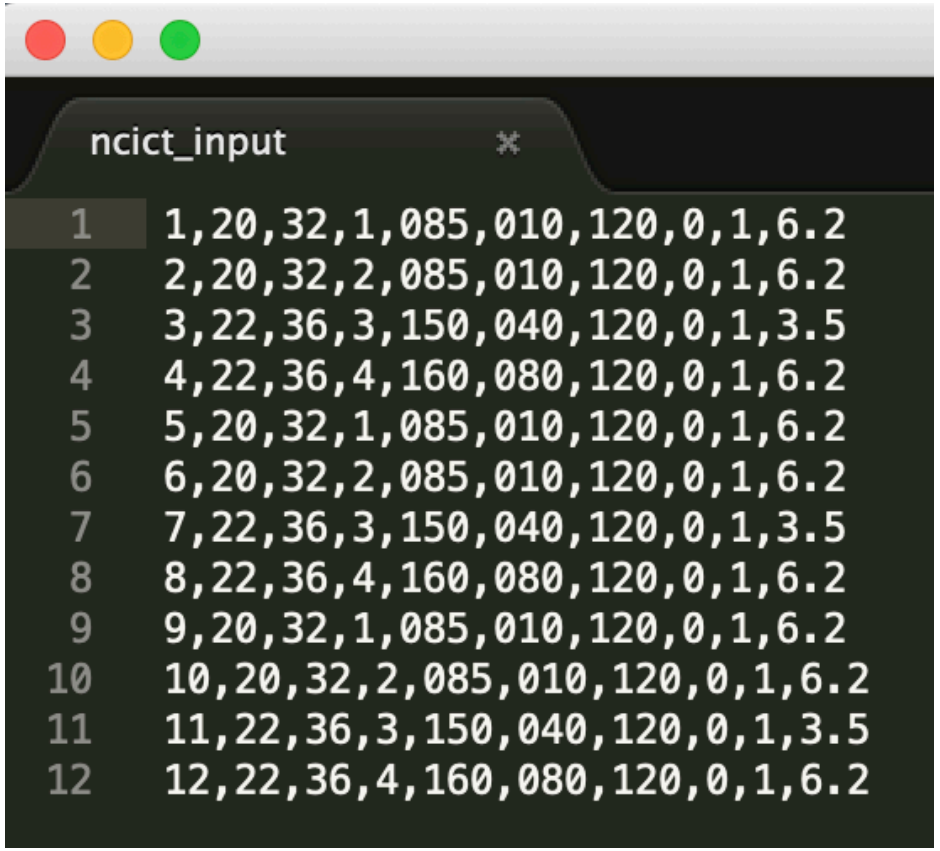
NCI dosimetry system for Radiography and Fluoroscopy: NCIRF

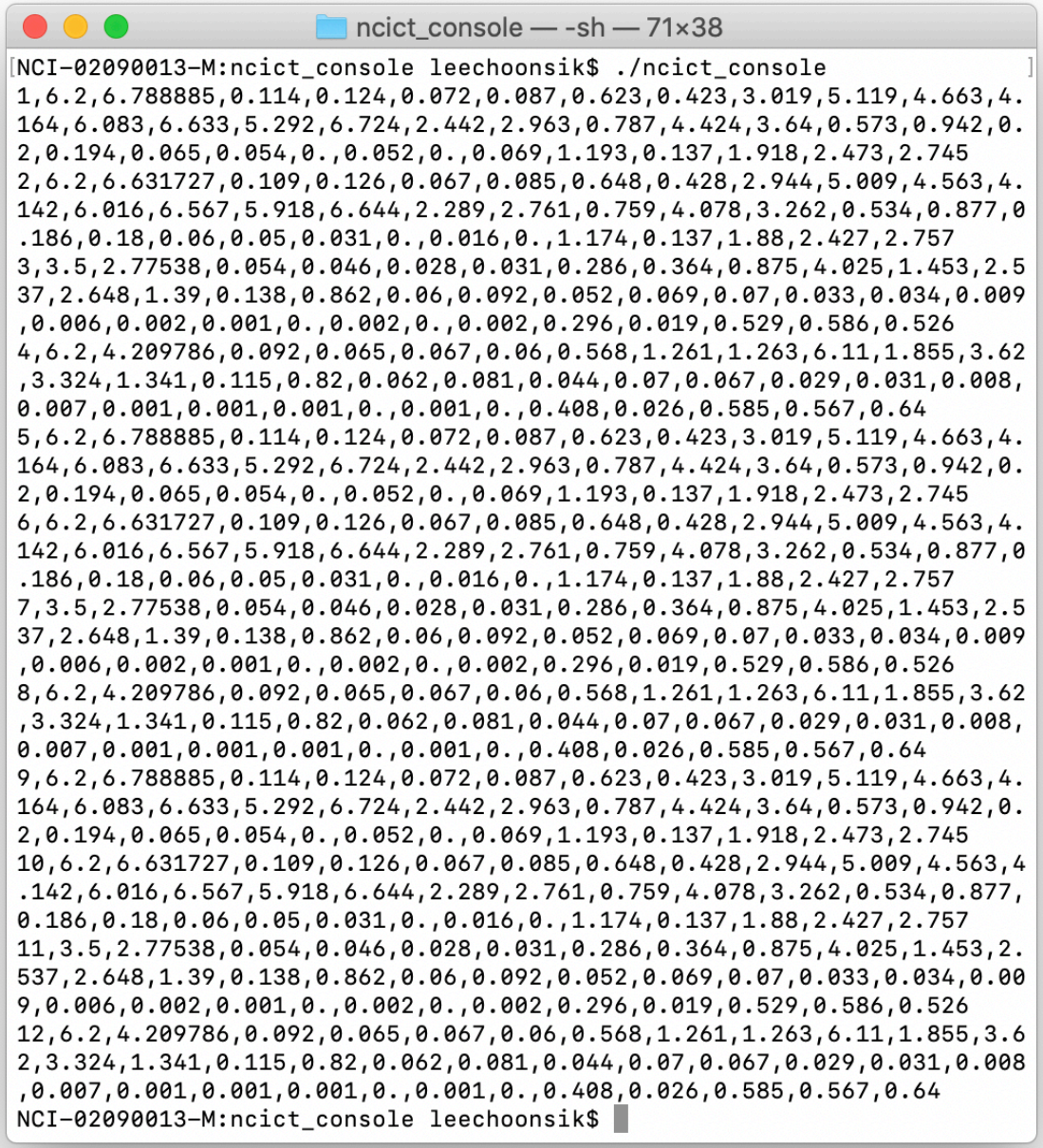


Borrego ... Lee et al. (in preparation)

Batch calculation for large cohorts

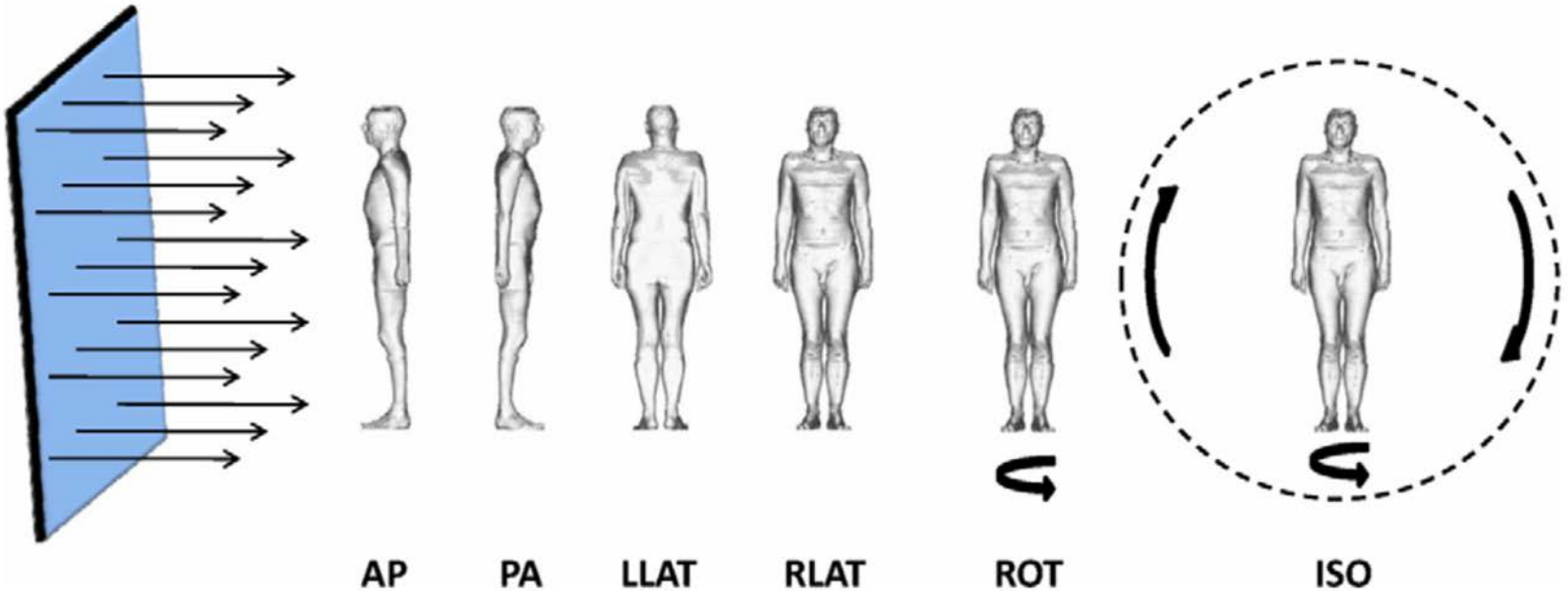
Patient ID, scan start, scan end, phantom_group, height, weight, kVp, TCM strength, filter, make, model, mas, pitch, collimation





Dose conversion methods for occupational exposure

- Dose conversion factors
  - ICRP Publication 116: conversion factors for external exposures
  - Body size-dependent dose conversion factors (Chang et al. 2018)



Dose conversion methods for environmental exposure

- Dose conversion factors
  - ICRP Publication 95: Doses to infants from ingestion of radionuclides in mother's milk
  - ICRP Publication 144: dose coefficients for external exposures to environmental sources

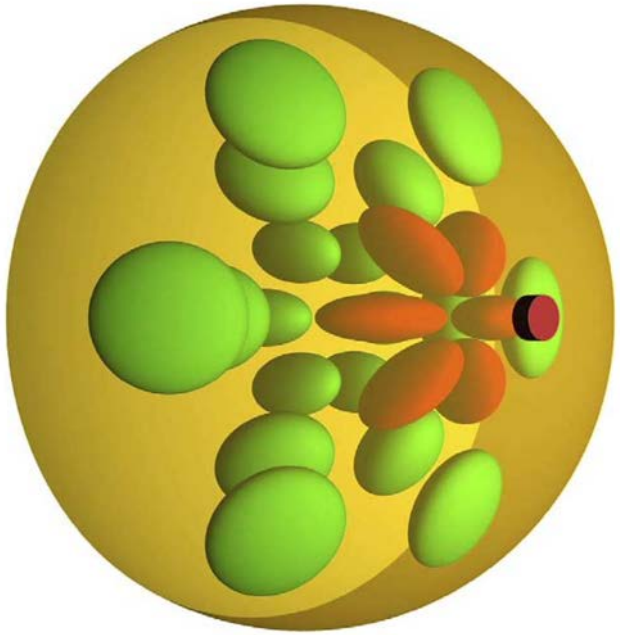
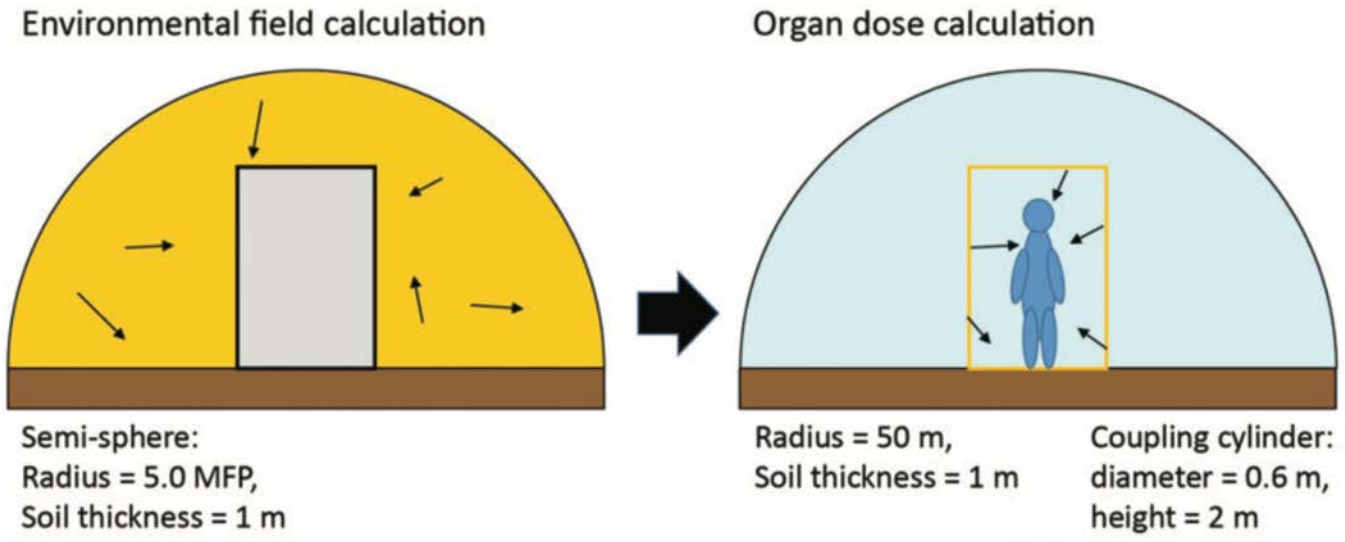
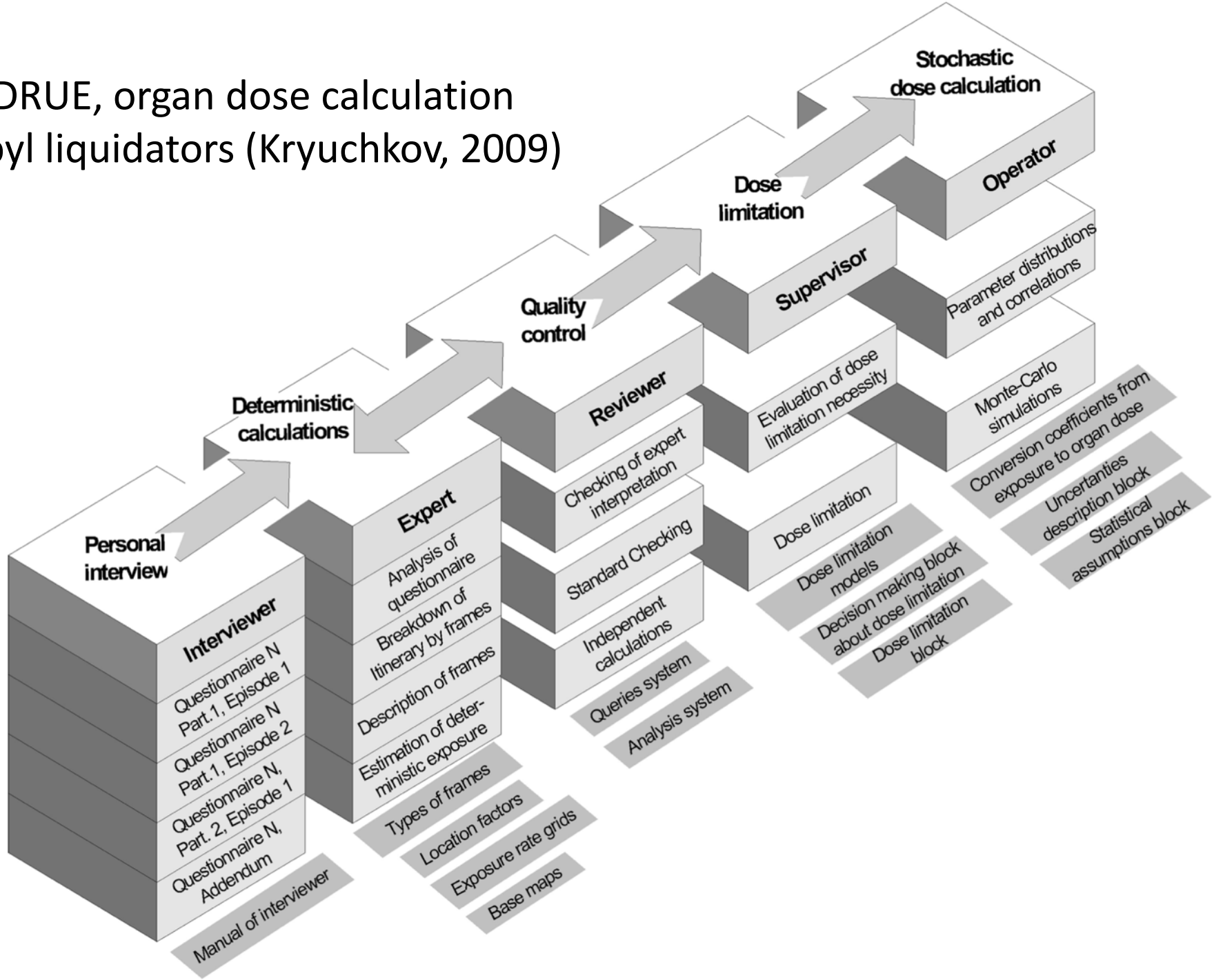


Fig. B.2. Geometric model of the lactating breast. The duct network is not shown.



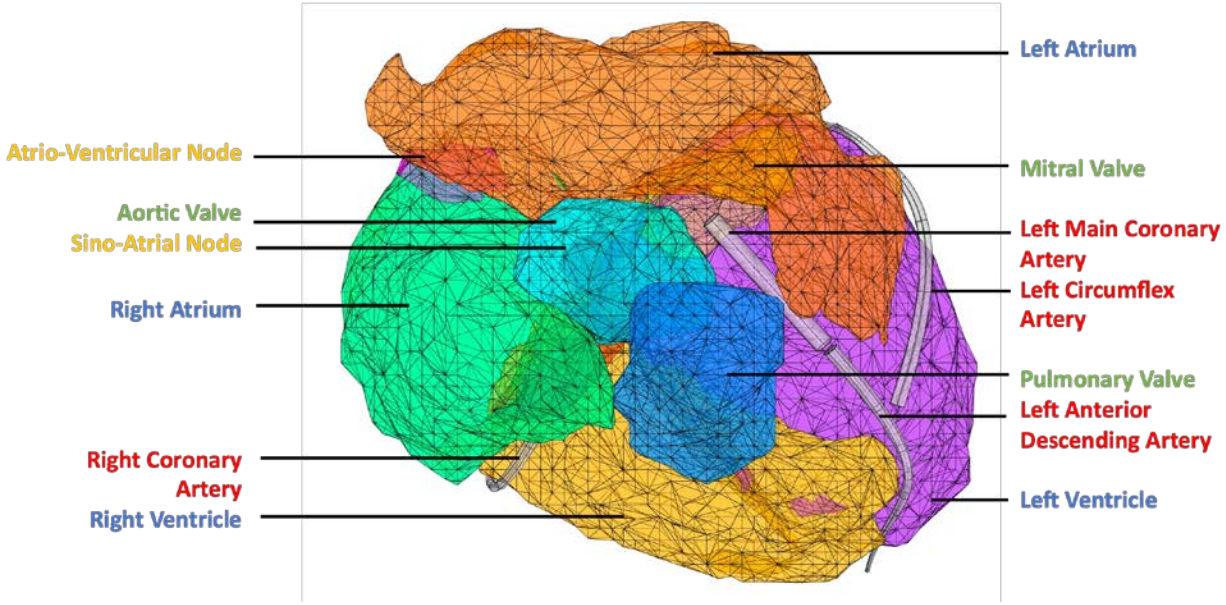
Flowchart for RADRUE, organ dose calculation code for Chernobyl liquidators (Kryuchkov, 2009)



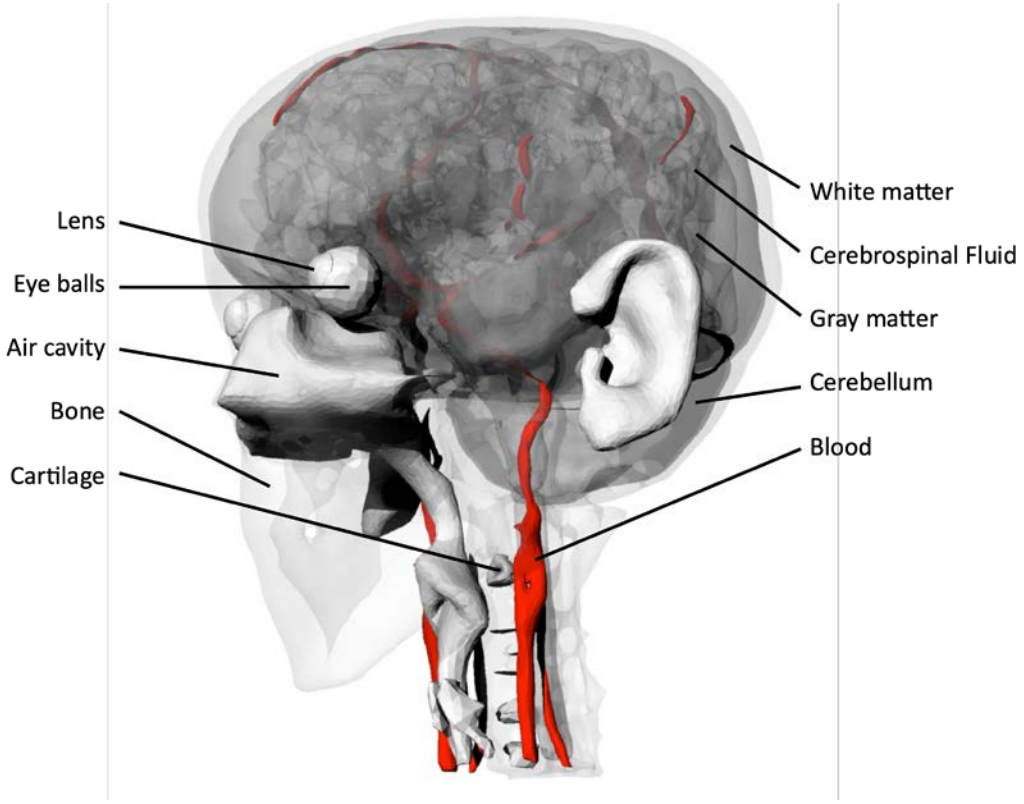
LIMITATIONS/OPPORTUNITIES IN DOSIMETRY FOR EPIDEMIOLOGY

	Limitation	Opportunities
Organ models	Difficult to pinpoint substructure in risk analysis using organ average dose	Develop detailed organ models in phantoms
Dosimetry methods	Dosimetry methods not well established for emerging medical exposures	Develop dosimetry methods for emerging medical exposures
Uncertainty	Dose uncertainty difficult to quantify and implement into risk analysis	Develop methods to quantify uncertainty and implement into risk analysis

Improving organ models for detailed dosimetry 1/2



Detailed heart models used for National Wilms Tumor Study cohort dosimetry (Lee et al. in preparation)



Detailed brain model used for nuclear medicine dosimetry (Villoing et al. 2020)

Improving organ models for detailed dosimetry 2/2

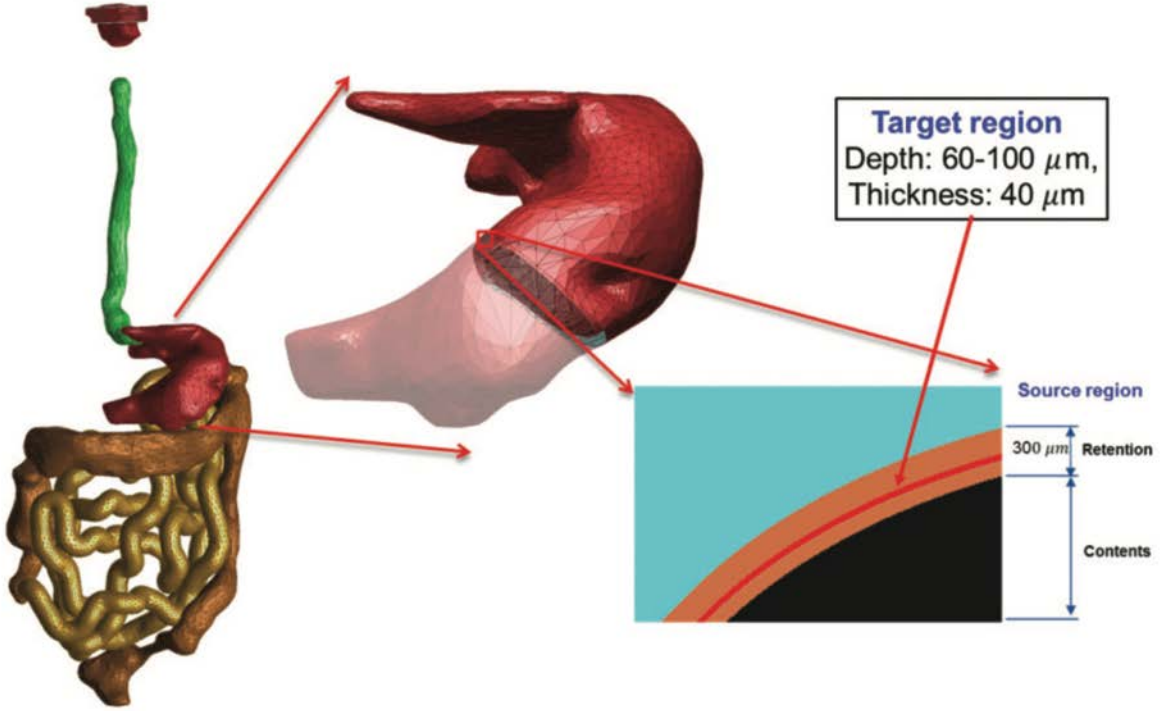


Fig. 5.2. Alimentary tract organs (left) of the male mesh phantom and the enlarged view (right) of the stomach, including the target and source regions.

Detailed ICRP mesh phantoms (ICRP Publication 145, 2020)

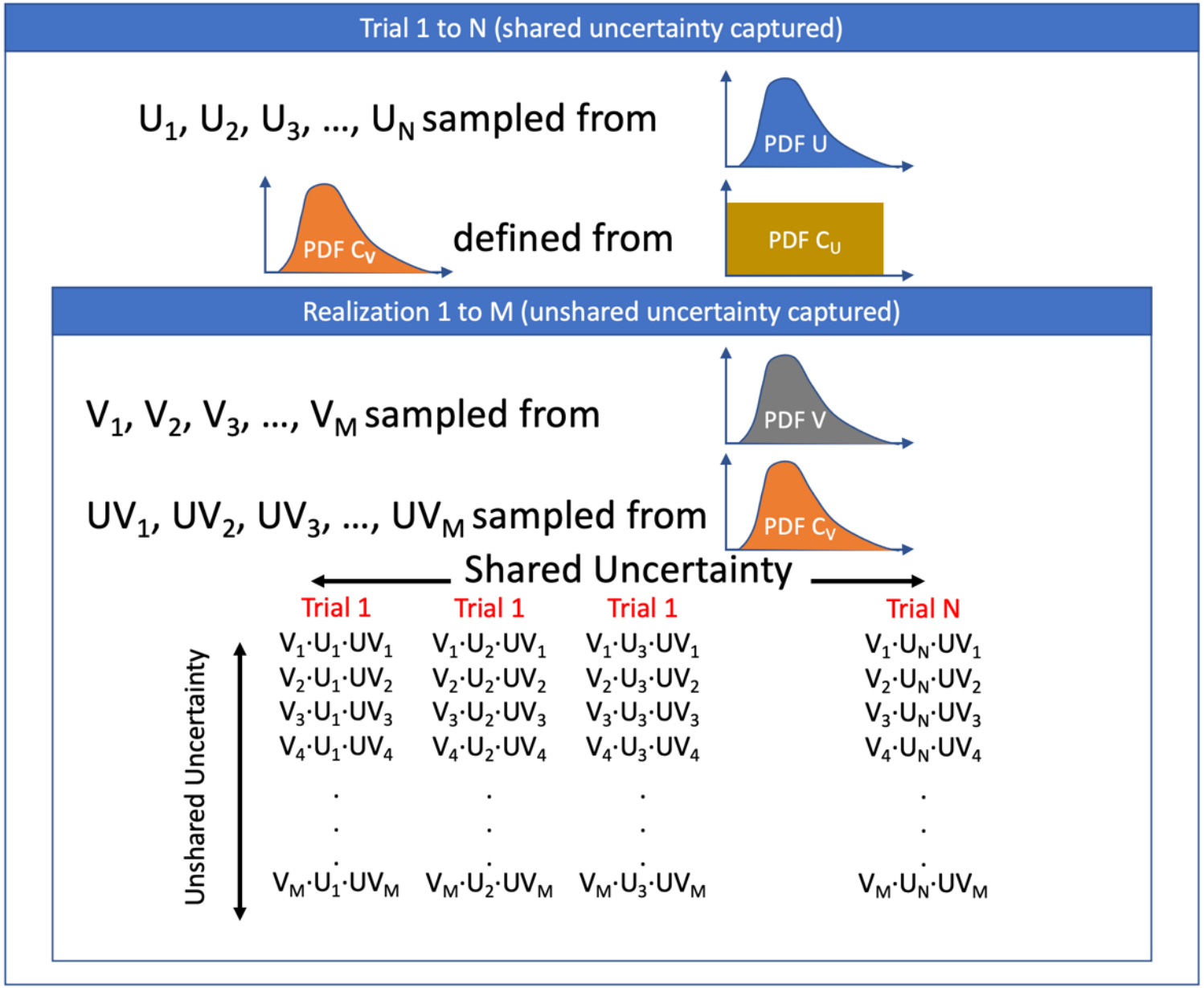
Areas of exposures where dosimetry methods not well established for epidemiology

- Medical
  - Scattered radiation dose to out-of-field region in emerging radiotherapy
  - Imaging dose in radiotherapy
  - Individualized dosimetry for nuclear medicine patients
  - Patient's dose in interventional fluoroscopy
- Occupational
  - Staff dose in interventional fluoroscopy
  - Staff dose in nuclear medicine procedures

Uncertainty quantification and implementation into risk analysis

- It is important:
  - to identify factors contributing uncertainty
  - to quantify dosimetric uncertainties, and
  - to implement them into risk analysis

2-Dimensional Monte Carlo method to calculation multiple doses incorporating uncertainty and variability



*Simon et al. Radiation Research 183:27-41 (2015)

Views on research priorities in dosimetry for epidemiology

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