ICRP Task Group 113: Reference Organ and Effective Dose Coefficients for Common X-Ray Imaging Examinations

Challenges of Radiological Protection in Research and Society referring to the Medical Field

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University of Dundee

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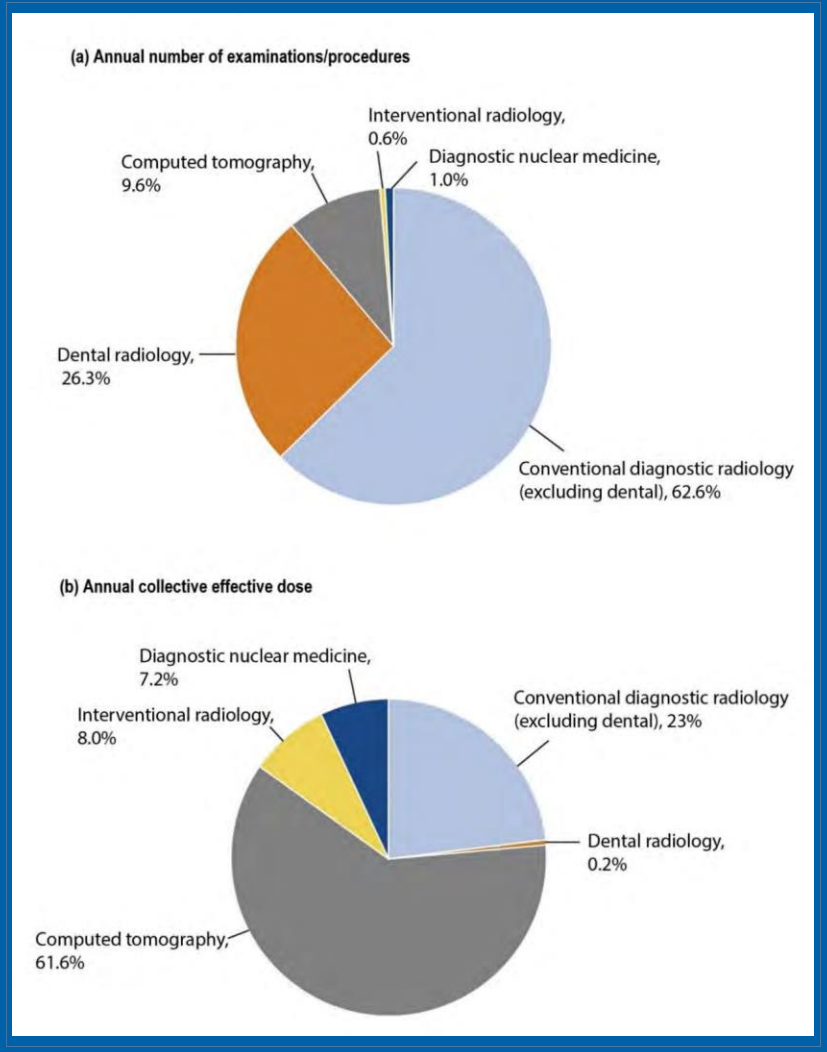
ICRP

Background

- For many years, the ICRP has produced reference dose coefficients for common diagnostic nuclear medicine procedures (Report 36 et seq.).
- Coefficients relating absorbed or equivalent dose to organs at risk and measurable quantities commonly used in X-ray imaging procedures have been calculated using Monte Carlo methods for the last 40 years.
- Because there is no gold standard and no agreed set of phantoms, results are not directly comparable.
- The ICRP has established TG113 to provide reference dose coefficients for radiographic, CT and fluoroscopic x-ray imaging procedures.

Aims



- The aim of the Task Group is to perform Monte Carlo radiation transport simulations on a series of reference imaging examinations and to report the resulting organ absorbed dose and effective dose coefficients.
- Four plus one different projects.

Stream	Scope
Radiography	Adult & Paediatric
Computed Tomography	Adult & Paediatric
Fluoroscopically Guided Interventions	Adult
Diagnostic Fluoroscopy	Paediatric
Other	Pregnant & Non-Reference Patients

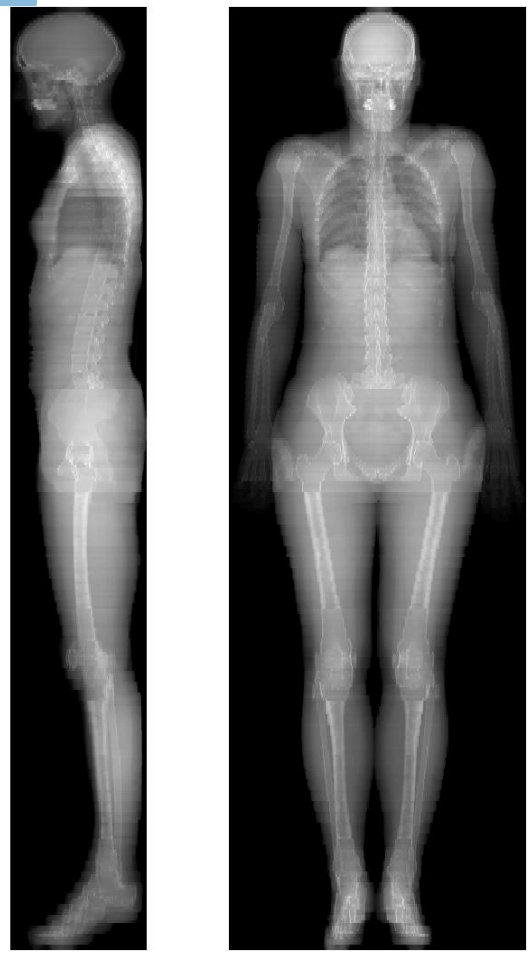
Task Group 113 Scope

- The scope of this work includes the use of the reference voxel computational phantoms of the ICRP , male and female new-born, 1-year-old, 5-year-old, 10-year-old, 15-year-old, and adult. See ICRP Reports 110 & 143.
- The work of the Task Group will lead to publications and electronic material covering adult and paediatric organ and effective dose coefficients within well-defined imaging protocols in radiography, CT and paediatric diagnostic fluoroscopy.
- However, in the case of Interventional Fluoroscopy (FGI) it is not possible to define a reference examination, or probably a reference patient.

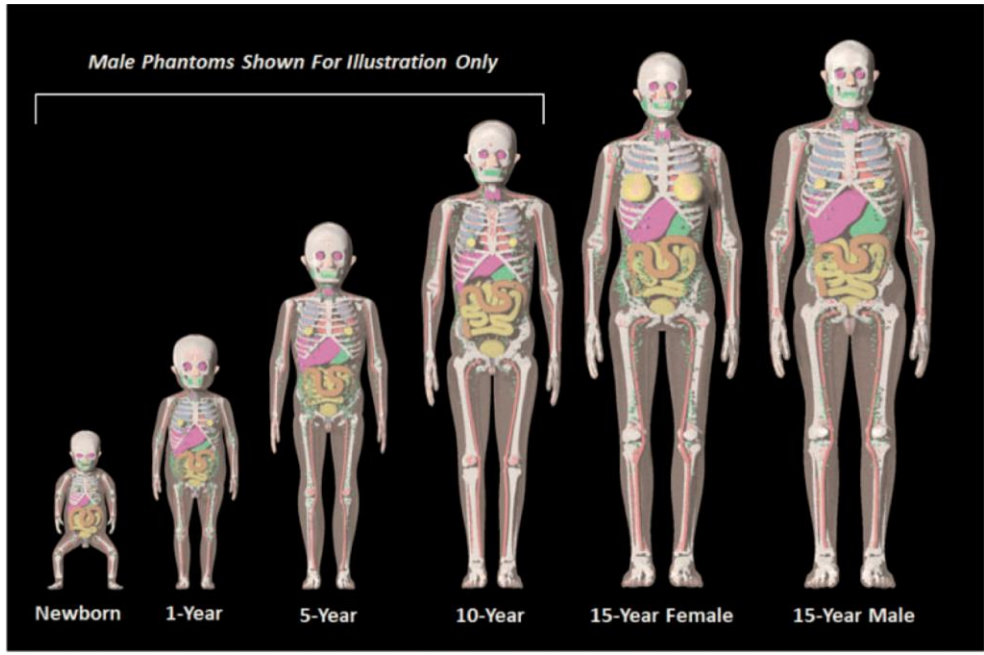
Organs for which dose coefficients are provided

- Red bone marrow
- Colon
- Lung
- Stomach
- Gonads
- Bladder
- Oesophagus
- Liver
- Thyroid
- Skeletal endosteum
- Brain
- Salivary glands
- Skin
- Remainder tissues: adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa pancreas, prostate, small intestine spleen, thymus, uterus/cervix
- Lens of the eye
- E_{103} (male or female contribution)

Radiography– Adult & Paediatric

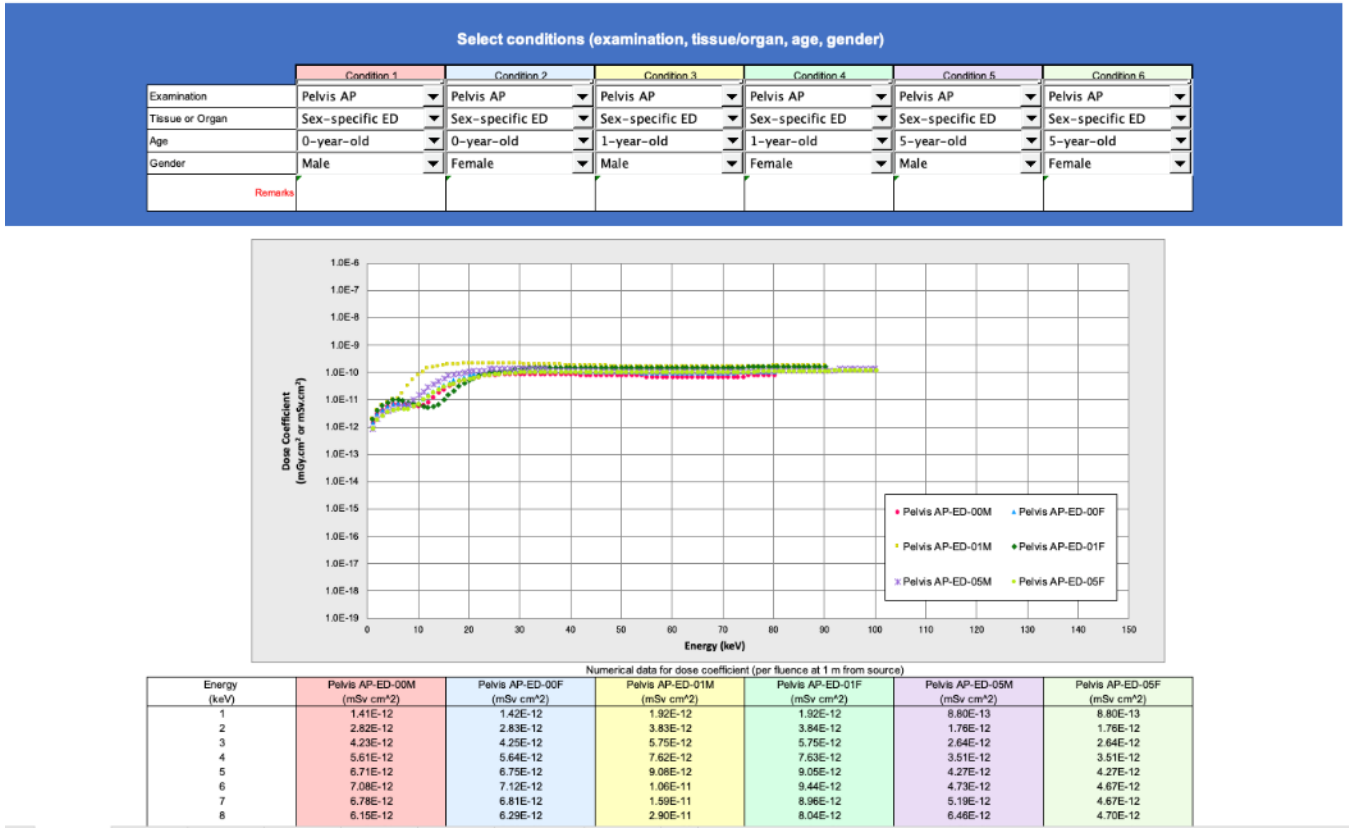


Examination Type -Adult	Projections Modelled
Chest/ Thorax	PA, AP, LLat, RLat
Pelvis & hip	AP
Abdomen	AP Supine
Lumbar spine (inc.LSJ)	AP, LLat, RLat, Oblique
Cervical spine	AP, Lat, RLat
Thoracic spine	AP, RLat, LLat
Examination Type -Paediatric	**Projections Modelled**
Chest	PA and AP
Pelvis	AP
Abdomen	AP
Lumbar Spine	AP, LLat, RLat
Thoraco-Lumbar Spine (new-born, 1 year only)	RLat, LLat
Scoliosis (new-born, 1 year only)	AP, RLat, LLat
Scoliosis (5,10,15 year only)	PA, RLat, LLat
Skull	AP, PA, Lat



Organ and effective dose coefficients are available for a range of beam qualities (e.g. 80 kV, 3 mm Al) and at 1 keV intervals for those who wish to obtain more finely tuned results using convolution. For spectral beams, coefficients are normalised to KAP and kerma free-in-air at a reference plane.

Radiography: Report in publication cycle.



Select conditions (examination, tissue/organ, age, gender)

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Examination	Pelvis AP	Pelvis AP	Pelvis AP	Pelvis AP	Pelvis AP	Pelvis AP
Tissue or Organ	Sex-specific ED	Sex-specific ED	Sex-specific ED	Sex-specific ED	Sex-specific ED	Sex-specific ED
Age	0-year-old	0-year-old	1-year-old	1-year-old	5-year-old	5-year-old
Gender	Male	Female	Male	Female	Male	Female
Remarks						

Numerical data for dose coefficient (per fluence at 1 m from source)

Energy (keV)	Pelvis AP-ED-00M (mSv cm^2)	Pelvis AP-ED-00F (mSv cm^2)	Pelvis AP-ED-01M (mSv cm^2)	Pelvis AP-ED-01F (mSv cm^2)	Pelvis AP-ED-05M (mSv cm^2)	Pelvis AP-ED-05F (mSv cm^2)
1	1.41E-12	1.42E-12	1.92E-12	1.92E-12	8.80E-13	8.80E-13
2	2.82E-12	2.83E-12	3.83E-12	3.84E-12	1.76E-12	1.76E-12
3	4.23E-12	4.25E-12	5.75E-12	5.75E-12	2.64E-12	2.64E-12
4	5.61E-12	5.64E-12	7.62E-12	7.63E-12	3.51E-12	3.51E-12
5	6.71E-12	6.75E-12	9.08E-12	9.05E-12	4.27E-12	4.27E-12
6	7.08E-12	7.12E-12	1.06E-11	9.44E-12	4.73E-12	4.67E-12
7	6.78E-12	6.81E-12	1.59E-11	8.96E-12	5.19E-12	4.67E-12
8	6.15E-12	6.29E-12	2.90E-11	8.04E-12	6.46E-12	4.70E-12

ICRP Dose viewer

Select ICRP internal dose coefficients

Effective Dose ICRP Publ. 60

Members of the public

Diagnostic nuclear medicine

Effective Dose ICRP Publ. 103

Occupational intake

Diagnostic X-ray Imaging Examinations

ICRP downloadable material

Educational material

App operated by Martin Andersson

Click for questions or review

Ver. 1.01

All data will be available in an electronic supplement.

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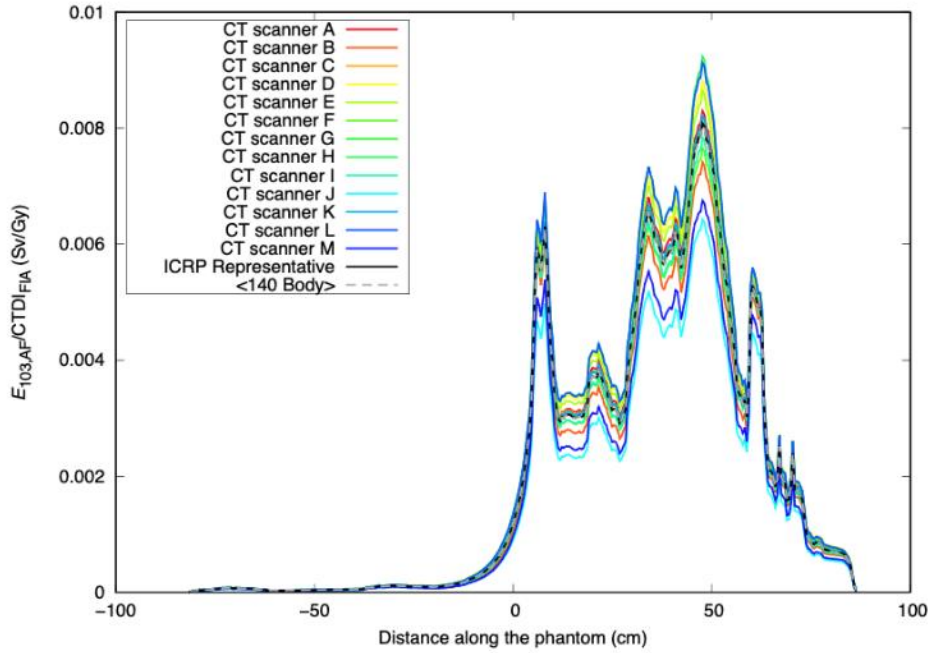
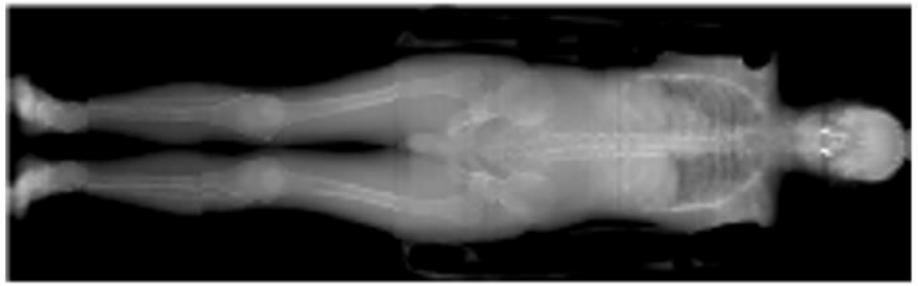
Computed Tomography – ICRP Representative Scanner

- Modelled 102 separate operating conditions for 13 CT scanners from 4 manufacturers on Adult Male and Adult Female phantoms and derived organ dose and effective dose coefficients per phantom slab.
- Using the results from the 102 models we have defined a representative ‘ICRP scanner’ for which organ and effective dose coefficients can be determined for adult and paediatric phantoms.
- Users can match to their own scanner using $CTDI_{vol}$.

ICRP Representative Scanner – Some detail

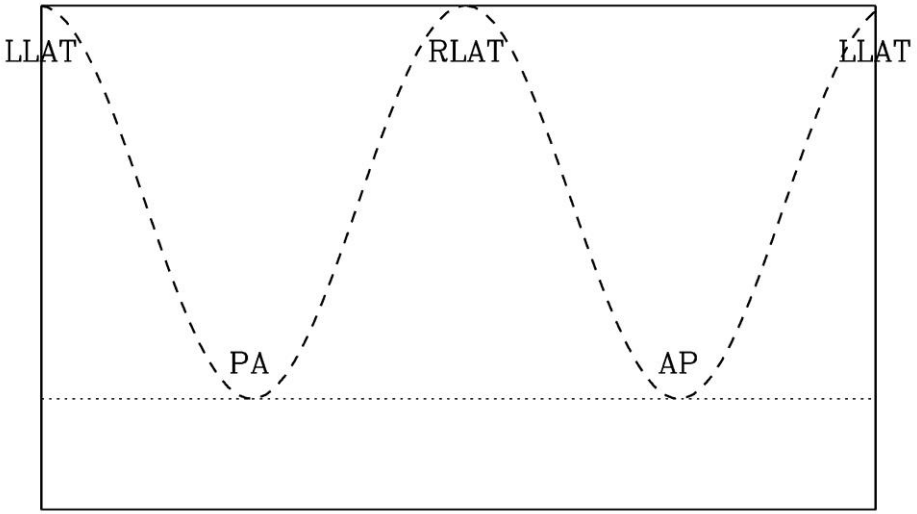
- **Operates with**
  - Tube voltage 80, 100, 120, or 140 kV and
  - Body or Head beam shaping filter
- **CT scanner is distributable and implemented in various Monte Carlo codes.**
- **ICRP scanner shows satisfactory dosimetric behaviour when compared to the simulated CT scanners.**





ATCM in the ICRP representative scanner

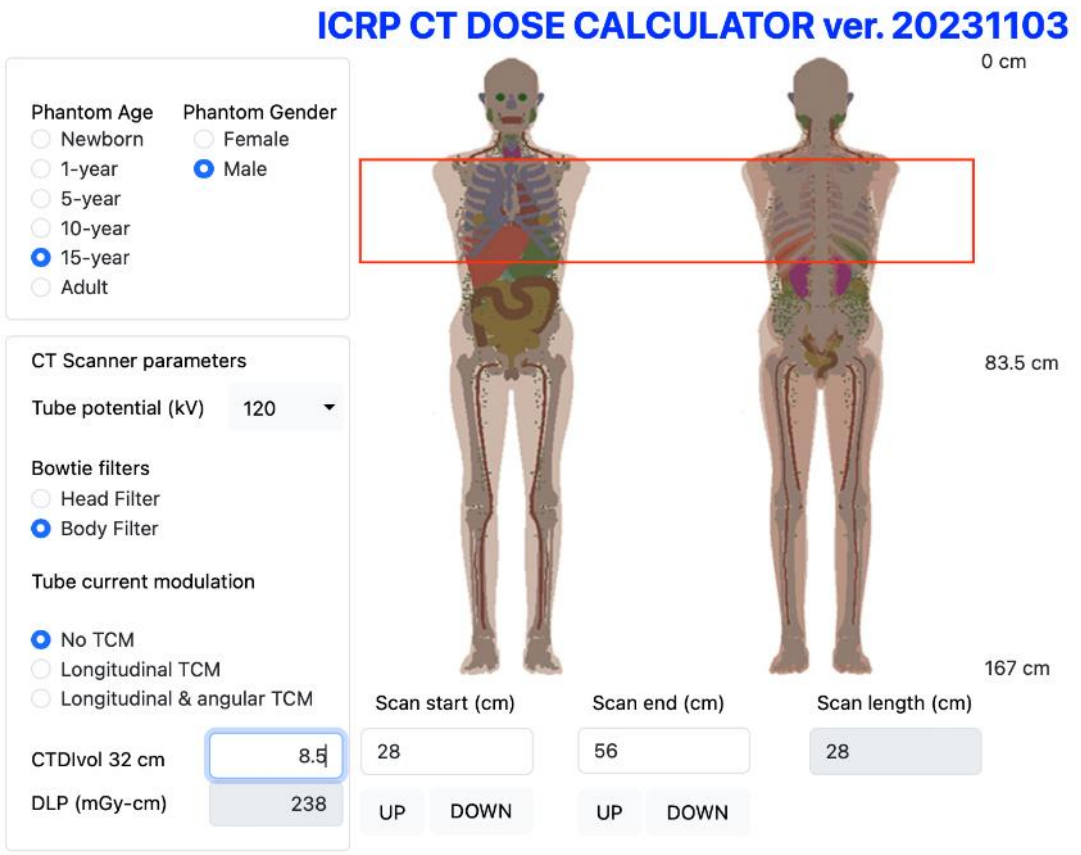
- Manufacturers do not disclose the details of their ATCM implementation.
- Even for the same manufacturer, there are differences in ATCM implementation.
- Often, tube current is not only depending on vendor-specific settings, but also on the image quality setting chosen by the operator.
- We have decided to provide dose coefficients for a simple “physics-based” cosine model of ATCM.
- This is an educational / optimisation tool, to enable the study of the impact of a relatively easy to understand angular and longitudinal TCM on organ doses.



- Each slab (slice): sinusoidal angular tube current modulation
- Based on localiser radiographs in AP and RLAT direction
- $\boldsymbol{I_i(\varphi) \propto \left(A_i^{\mathrm{AP}}\right)^q + \frac{\left(A_i^{\mathrm{RLAT}}\right)^q - \left(A_i^{\mathrm{AP}}\right)^q}{2}(1+\cos 2\varphi) \qquad (\varphi = 0\text{: RLAT})}$
- Modulation strength: $\boldsymbol{q = 0.75}$ (a compromise)
- $\left(D_{\mathrm{org}}/\mathrm{CTDI_w}\right)_i = \frac{\left(D_{\mathrm{org}}/\mathrm{CTDI_w}\right)_{i,0} + \zeta_i \left(D_{\mathrm{org}}/\mathrm{CTDI_w}\right)_{i,1}}{1+\zeta_i}$ with $\zeta_i = \frac{1}{2}\left(\frac{\left(A_i^{\mathrm{RLAT}}\right)^q}{\left(A_i^{\mathrm{AP}}\right)^q} - 1\right)$
- For multi-slice: sum using a weighting by AP attenuation
- $\left(D_{\mathrm{org}}/\mathrm{CTDI_{vol}}\right)_{P_A} = \frac{\sum_{i=n}^{m} \tau_i \left(D_{\mathrm{org}}/\mathrm{CTDI_w}\right)_{i,0}}{\sum_{i=n}^{m} \tau_i}(n-m+1)$ with $\tau_i \sim \left(A_i^{\mathrm{AP}}\right)^q$

Computed Tomography - GUI

CT organ and effective doses will be accessible in electronic files and also via a Graphical User Interface



Organ	Dose (mGy)
Testes	0.02
UB-wall	0.0638
Oesophagus	10.7982
Liver	11.3045
Thyroid	3.7771
Endost-BS	2.6396
Brain	0.108
S-glands	0.5637
Skin	2.0664
Adrenals	11.8965
ET	0.2485
E103M (mSv)	6.358814

Viewer prototype

- Bespoke GUI.
- Web based.
- Maintained on ICRP domain.

Fluoroscopically Guided Interventions

- **Issues**
  - All FGI procedures are tailored to the individual patient.
  - Organ dose is dependent on:
    - Patient size.
    - Procedure complexity (lesion type and anatomy).
    - Operator factors (knowledge and experience), and
    - Equipment factors.
  - There is a considerable range of KAP for every FGI procedure type.
- It is not possible to define a reference examination.

Fluoroscopically Guided Interventions

The Task Group is using Radiation Dose Structured Report data from multiple cases of the same procedure to estimate representative doses for each of 11 commonly performed procedures.

- Angiography, carotid artery, bilateral
- Angiography, abdomen-pelvis, visceral arteries
- Percutaneous biliary drainage placement
- Artery embolization, abdomen-pelvis, viscera
- Tumour arterial embolization, liver
- Tumour arterial embolization, head-neck
- Gastrostomy catheter placement
- Nephrostomy placement
- Transjugular biopsy, abdomen, liver
- Gastrojejunostomy tube placement
- Peritoneal catheter placement, tunneled

FGI procedures included, based on a review of procedure numbers from the US ACR fluoroscopy Dose Index Registry Pilot, and excluding procedures known to be very low-dose (e.g., central line placement)

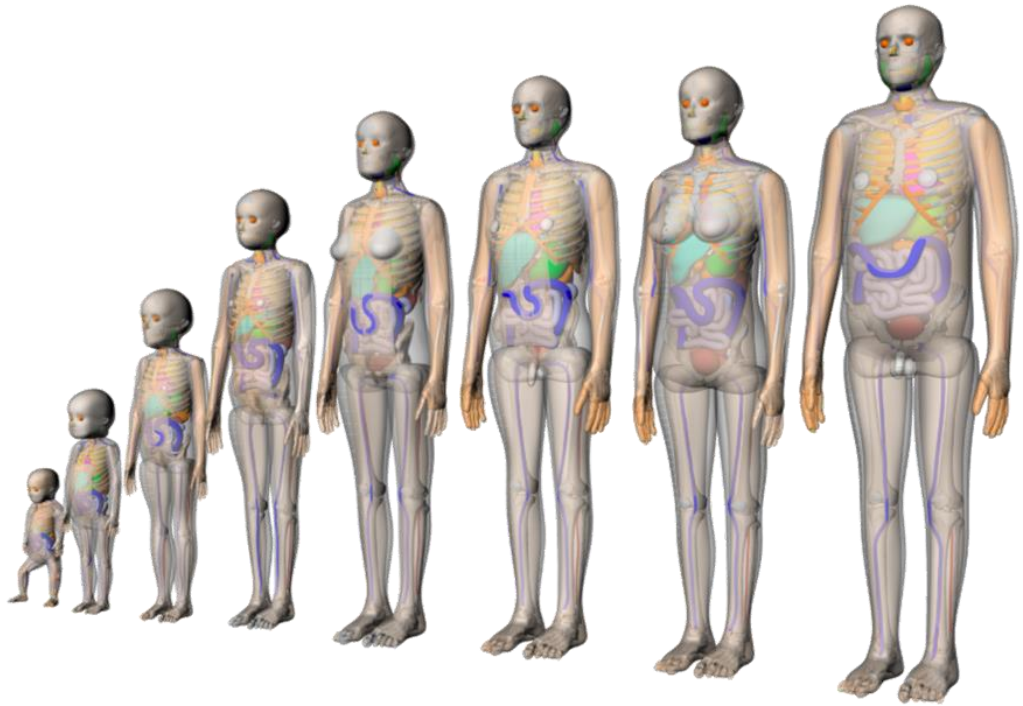
Data collection

- Radiation Dose Structured Reports (RDSR) data (11 common FGI procedures) have been collected from three health care institutions in the United States.
- N=2899

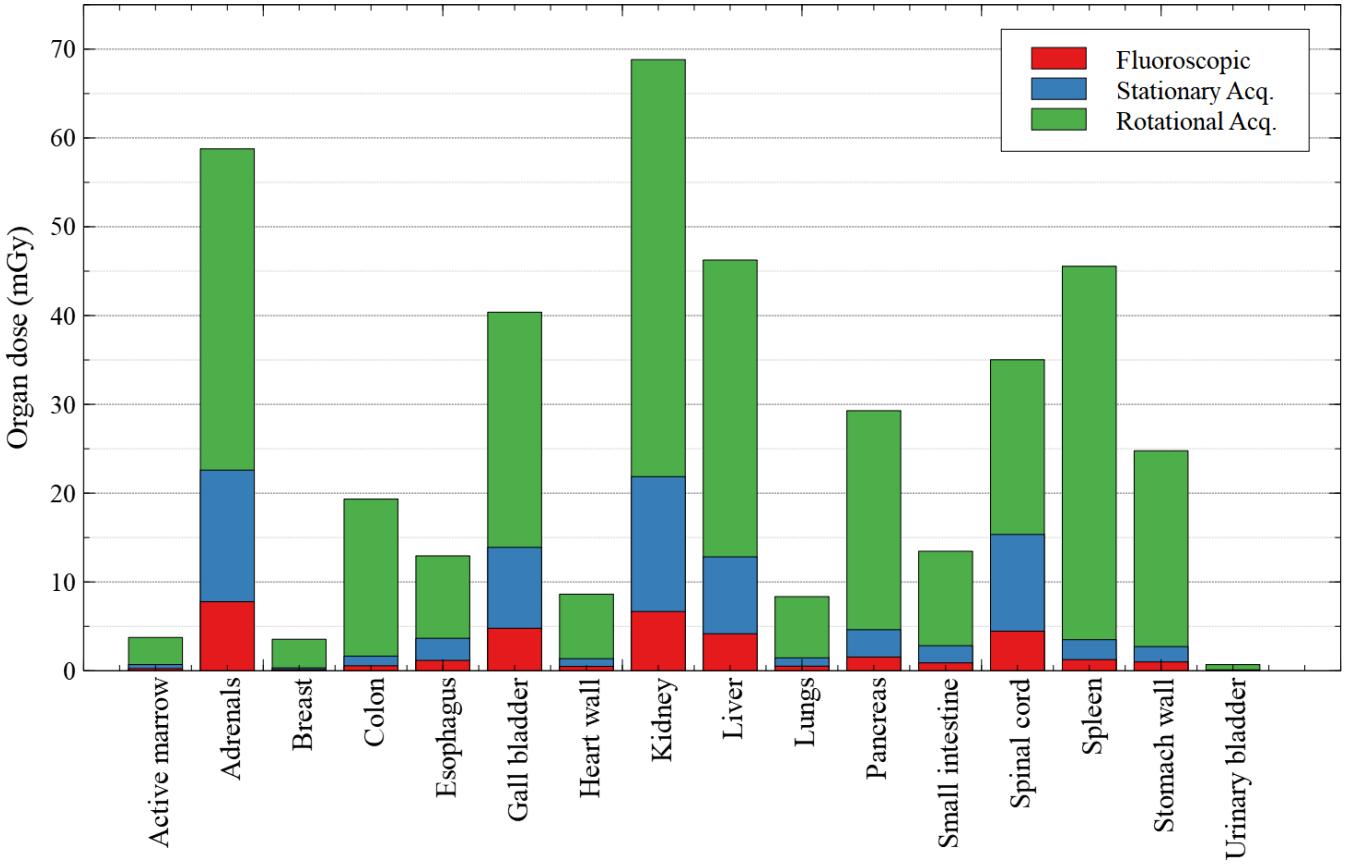
	C1	C2	C3	Total
Angiography, carotid artery, bilateral	116	0	2	118
Angiography, abdomen-pelvis, visceral arteries	100	100	50	250
Percutaneous biliary drainage placement	130	100	99	329
Artery embolization, abdomen-pelvis, viscera	120	74	116	310
Tumour arterial embolization, liver	148	100	28	268
Tumour arterial embolization, head-neck	0	25	0	25
Gastrostomy catheter placement	146	100	73	319
Nephrostomy placement	148	100	313	561
Trans-jugular biopsy, abdomen, liver	148	100	35	283
Gastrojejunostomy tube placement	135	100	15	250
Peritoneal catheter placement, tunnelled	87	98	1	186
Totals	**1278**	**897**	**732**	**2899**

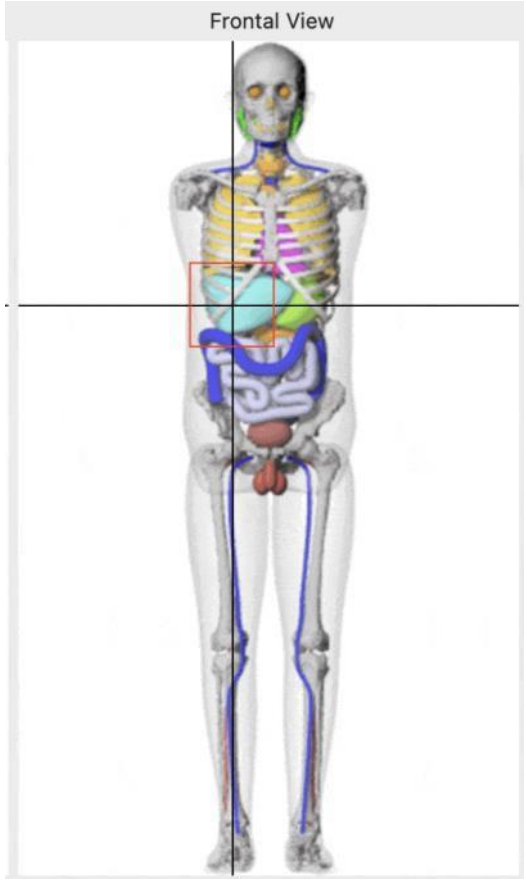
Data analysis

- RDSR data have been translated to the input data for Monte Carlo simulations combined with the NCI library of body size-dependent computational human phantoms for phantom and event-specific organ dose calculations.
- Selection from 193 adult phantoms based on patient sex, height, and weight
- From the resulting data, “typical” or “average” organ and effective doses will be estimated per FGI procedure.
- A pilot is underway – Liver chemoembolisation and Percutaneous biliary drainage.



Results: percutaneous biliary drainage





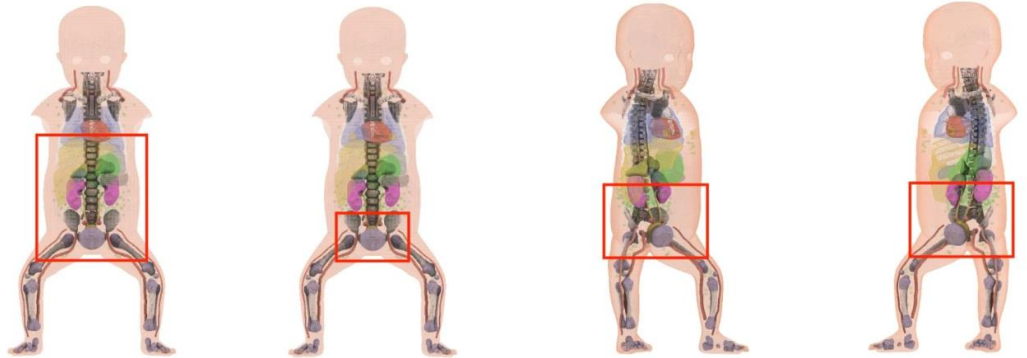
Organ absorbed dose broken down into dose from fluoroscopic, stationary, and rotational acquisition modes for one example patient procedure.

Common Paediatric Diagnostic Fluoroscopic Examinations

- Goal: To develop ICRP reference dose coefficients for common paediatric diagnostic fluoroscopic examinations for normal and selected abnormal conditions.
- The examinations being considered are Voiding cystourethrogram (VCUG), Lower GI series (contrast enema), Upper GI series and Modified barium swallow.

VCUG exam - newborn

Outlines encompass the same physical organ landmarks that would be viewed during typical fluoroscopy examination and are meant to be indicative of the standard of practice worldwide.



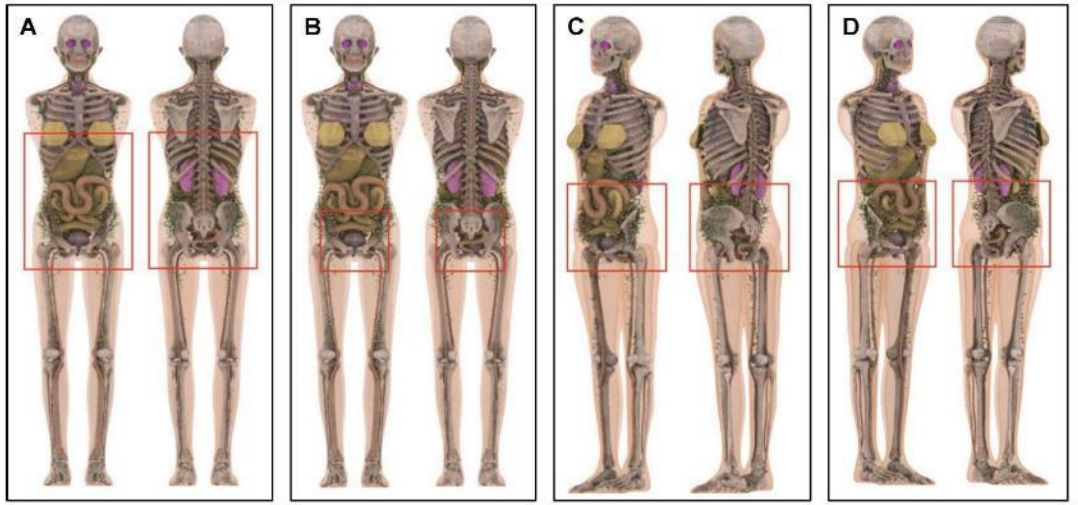
PA Scout | PA View | RPO View (reflux). | LPO View (reflux)

Four fields are simulated for this procedure – AP scout, AP to investigate urinary bladder and ureters, RPO & LPO to search for reflux.

Common Paediatric Diagnostic Fluoroscopic Examinations

- In all, fifty-nine diagnostic fluoroscopy protocol outlines, encompassing 545 total x-ray fields, have been developed for the clinical protocols.
- Dose Coefficients will be normalised to KAP or kerma free in air at a reference plane.

VCUG exam – 15 yr old female

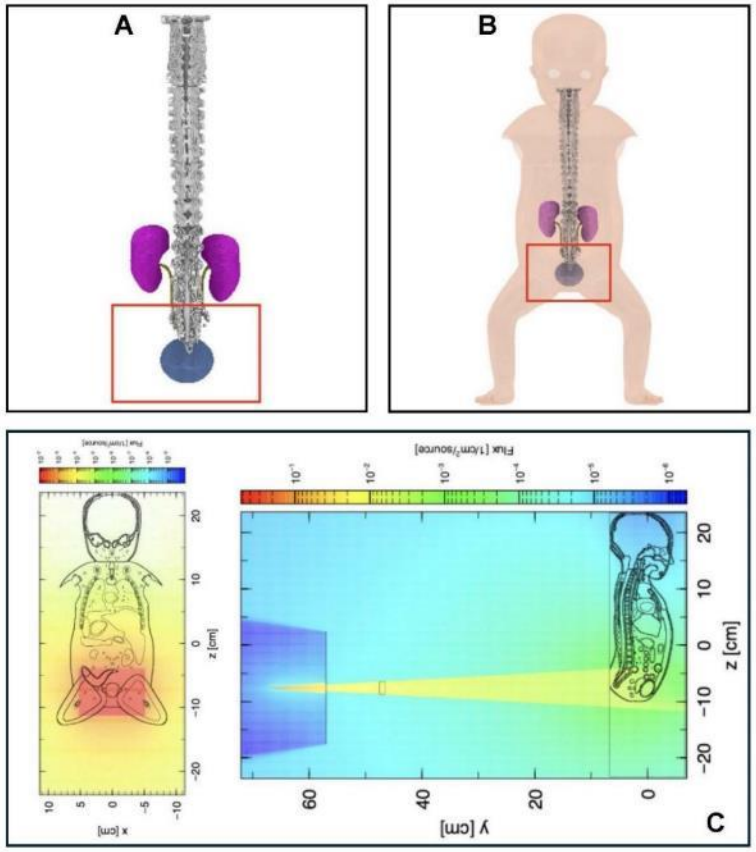


PA Scout PA View RPO View (reflux). LPO View (reflux)

Four fields are simulated for this procedure – AP scout, AP to investigate urinary bladder and ureters, RPO & LPO to search for reflux.

Image From : Impact of contrast agents on organ dosimetry in pediatric diagnostic fluoroscopy: the voiding cystourethrogram. WW Smither, EL Marshall, D Borrego, KE Applegate, WE Bolch. Phys Med Biol. 2024. 69(17).

Example: PA field definition - VCUG (newborn)



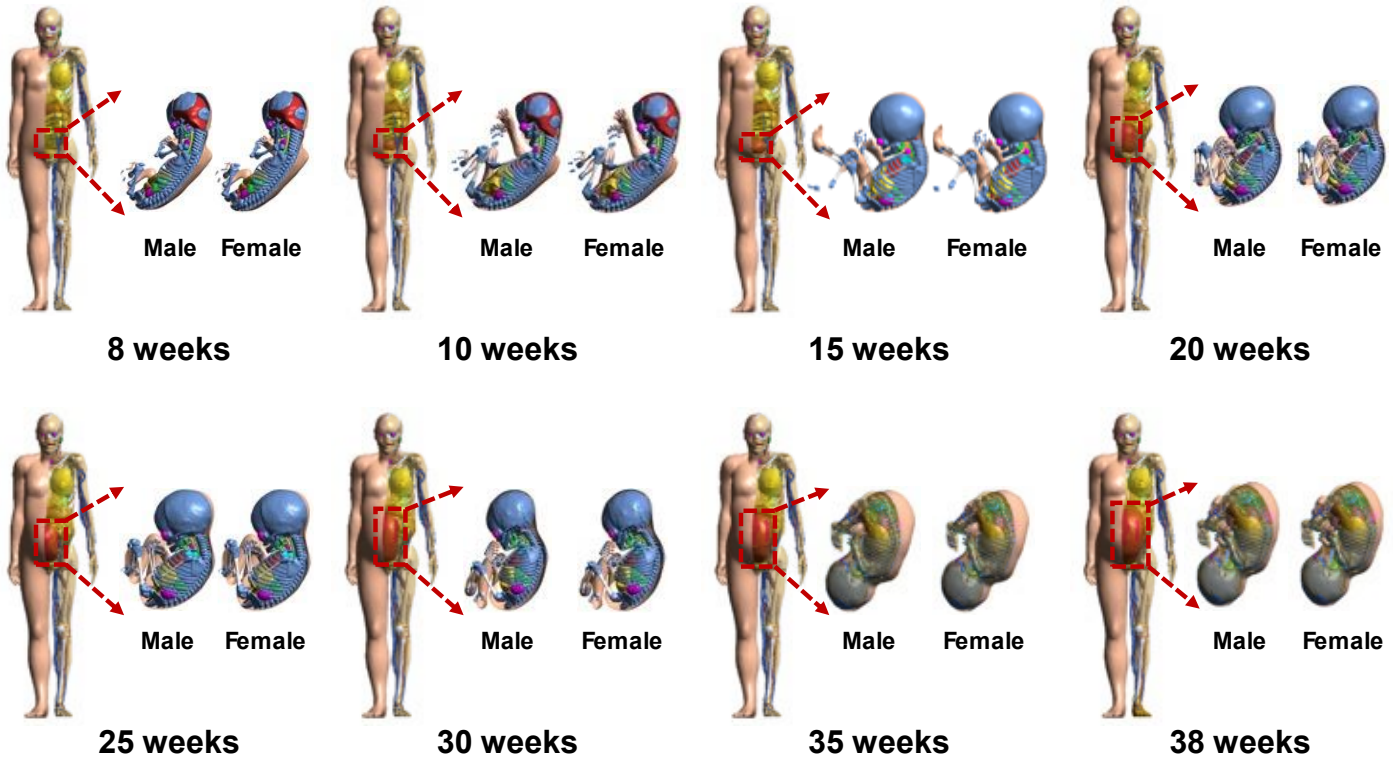
Four fields are simulated for this procedure – AP scout, AP to investigate urinary bladder and ureters, RPO & LPO to search for reflux

- **A - Using organ-of-interest for field designations based on bony landmarks.**
- **B -Phantom with the organ-of-interest and the skin layer for field designations with field outlined in red.**
- **C- Radiation transport model generated x-ray photon fluence tally in the coronal and sagittal planes for field of view geometry confirmation ahead of the dose calculation.**

From : Impact of contrast agents on organ dosimetry in pediatric diagnostic fluoroscopy: the voiding cystourethrogram. WW Smither, EL Marshall, D Borrego, KE Applegate, WE Bolch. Phys Med Biol. 2024. 69(17).

CT and Radiography: ICRP Pregnant female Mesh type phantoms

- **Pilot study:**
- **Using ICRP Representative Scanner.**
- **Determine dose coefficients for 10-week fetal age phantom and pregnant female, at 120 kV and body filter.**



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Thank you for your attention

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