OpenDose: a Free Online Database of Dosimetric Data for Nuclear Medicine

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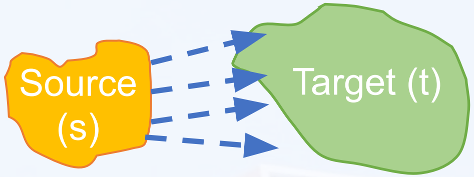
OpenDose

"It aims to provide a free and public resource of robust reference data to enable dosimetry calculations in nuclear medicine, using a variety of Monte Carlo codes through an international collaboration."

Dosimetry in nuclear medicine

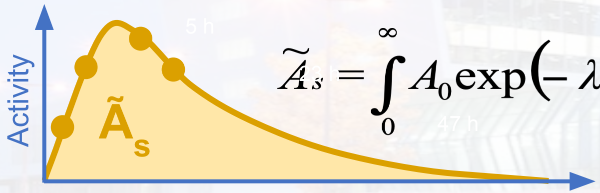
Medical Internal Radiation Dosimetry (MIRD) formalism

Bolch WE. MIRD 21. J Nuc Med. (2009) 50:477-84



$$D_{t \leftarrow s} = \tilde{A}_s \times S_{t \leftarrow s}$$

Cumulated activity



$$\tilde{A}_s = \int_0^{\infty} A_0 \exp\left(-\lambda_{eff}\, t\right) dt$$

- Bio-kinetics and uptake distribution
- Patient-specific

S-value (dose factor)

$$S\left(r_t \leftarrow r_s\right) = \sum_i \frac{\Delta_i \Phi_i\left(r_t \leftarrow r_s\right)}{m_t}$$

- Nuclear decay data
- Source/target geometry

The need

There is no open database of SAFs or S-values available.

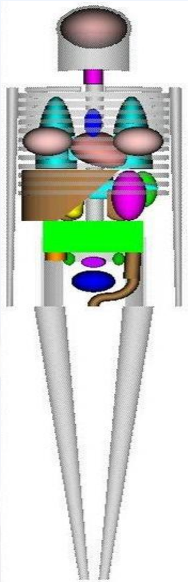
Before…

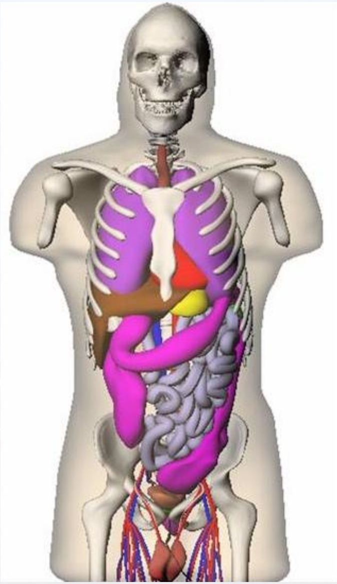
- **OLINDA (v1/v2*) was the only FDA approved dosimetry software and the data was freely available in the RADAR website**

Now…

- **OLINDA is now part of HERMES (expensive)**
- **RADAR data no longer available**
- **Some data is available through IDAC 2.1**

→ Need for an active community to generate, validate and disseminate data to the nuclear medicine community = OpenDose





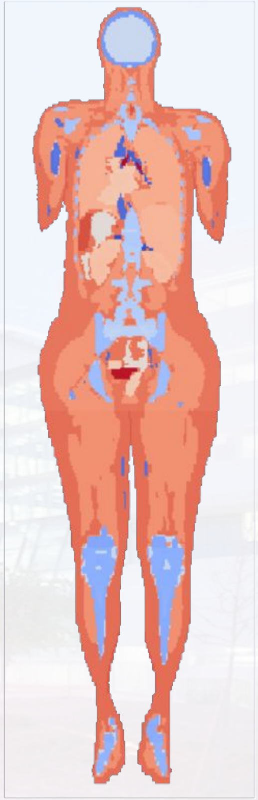
*Stabin et al. JNM 2015

OpenDose

Challenges

- 2 ICRP 110 reference adult phantoms (male and female) and more to come (pediatric and next generation mesh-based phantoms)
- 140 organs (19600 target/source combinations!)
- ICRP 107: ~1200 radionuclides
- MIRD RADTABS source of decay data: ~300 radionuclides

Too big for a single institution !



Proposal

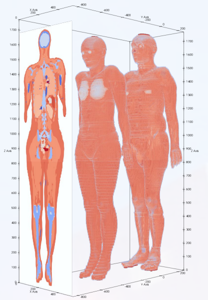
- Collaborative work, everyone is welcome!
- Generate data with different Monte Carlo codes to cross-verify data
- Generate Specific Absorbed Fractions with associated uncertainties
- Traceable and reproducible data
- Create a free database
- Create an easily accessible website
- Compute S-values with uncertainties from SAFs

$$S(r_t \leftarrow r_s) = \sum_i \frac{\Delta_i \Phi_i (r_t \leftarrow r_s)}{m_t}$$

OpenDose framework

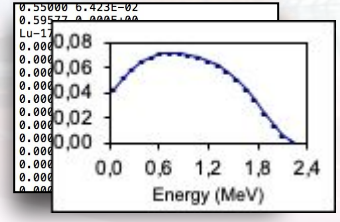
Input data

Computational Phantoms



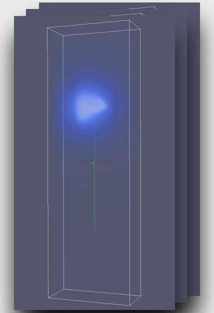
141 segmented regions
53 material compositions

Isotope data



Monte Carlo Simulations: GATE/Geant4, FLUKA, PENELOPE, MCNP, EGS

Absorbed Dose Maps (+ uncertainties)



per voxel

+

SAF tables (+ uncertainties)

Energy_MeV	target000	target001	target002
0.005	0.0	8.607745631331213e-06	0.0
0.0055	0.0	7.162995573859466e-06	0.0
0.006	0.0	5.944192504359427e-06	0.0
0.0065	0.0	1.8604394367445052e-06	0.0
0.007	0.0	5.547282091043621e-06	0.0
0.0075	0.0	6.55714264717551e-06	0.0
0.008	0.0	6.8806313600648625e-06	0.0
0.0085	0.0	8.099165671727396e-06	0.0

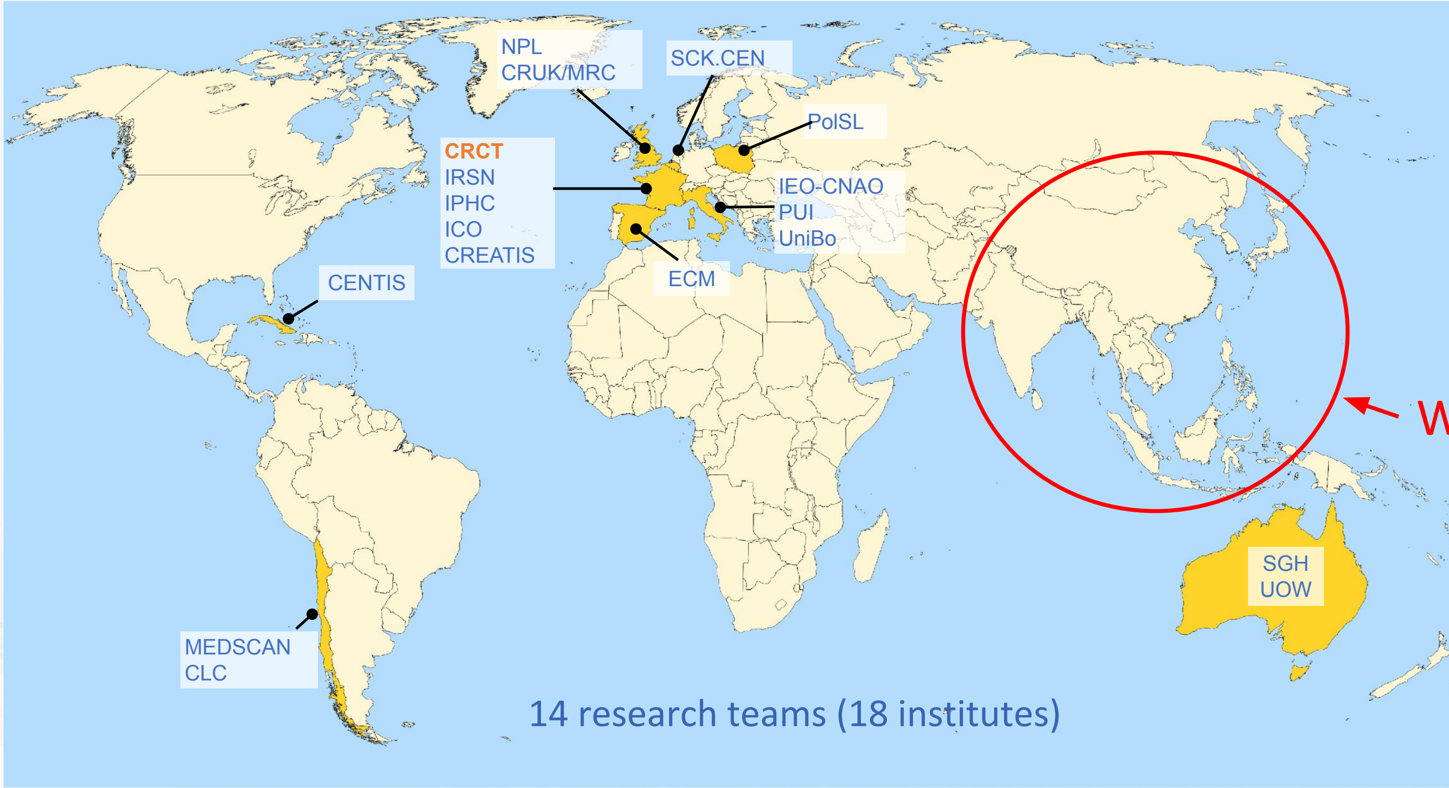
per target (region of voxels)

For each Source, Particle type, Energy

Web database

S-values
+ uncertainties

The OpenDose Collaboration



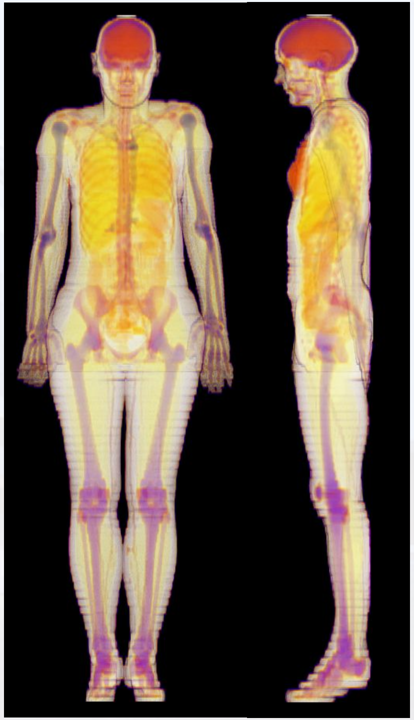
We need you !

OpenDose: initial comparisons

→ Check-point simulations:

- Adult female phantom (ICRP 110 v1.2)
- Sources: liver, blood (trunk)
- Targets: 140
- Seven energies: 0.05, 0.1, 0.2, 0.5, 1, 2 and 5 MeV
- Electrons and photons
- 10^8 histories

2 (sources) × 2 (particles) × 7 (energies) = 28 simulations
CPU computation time ~1 week (1 core)

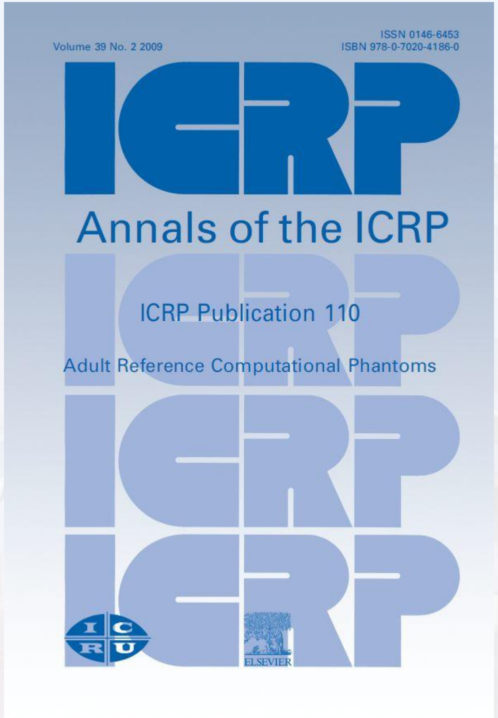


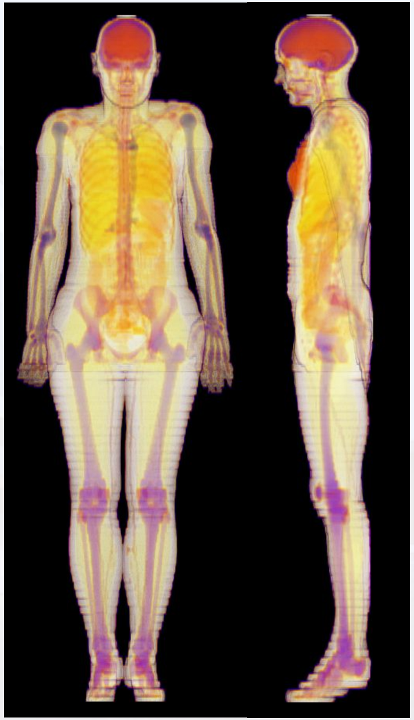
→ Complete set of simulations:

2 (models) × 140 (sources) × 2 (particles) × 91 (energies) = 50960 simulations

ICRP 110 phantoms

- Developed to evaluate internal and external radiation doses
- Generated from tomographic data, but adjusted to ICRP 89 (2002)
- Female phantom (‘Laura’):
  - Height: 1.63 m
  - Mass: 60 kg
  - No. of voxels: 299 × 137 × 346(+2*)
  - Voxel size: 1.775 × 1.755 × 4.84 mm
  - Voxel volume: 15.25 mm^3
  - Number of organs: 141
  - Number of media: 53





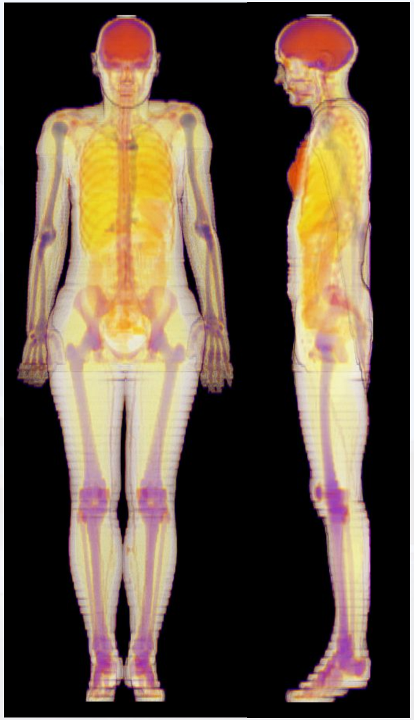
ICRP 110 phantoms

141

Organs and tissues of the adult female reference computational phantom			
Organ ID	Organ	Tissue number	Density
1	Adrenal, left	43	1.03
2	Adrenal, right	43	1.03
3	Anterior nasal passage (ET1)	45	1.03
4	Posterior nasal passage down to larynx (ET2)	45	1.03
5	Oral mucosa, tongue	29	1.05
6	Oral mucosa, lips and cheeks	29	1.05
7	Trachea	45	1.03
8	Bronchi	45	1.03
9	Blood vessels, head	28	1.06
10	Blood vessels, trunk	28	1.06
11	Blood vessels, arms	28	1.06
12	Blood vessels, legs	28	1.06
…	…	…	…

53

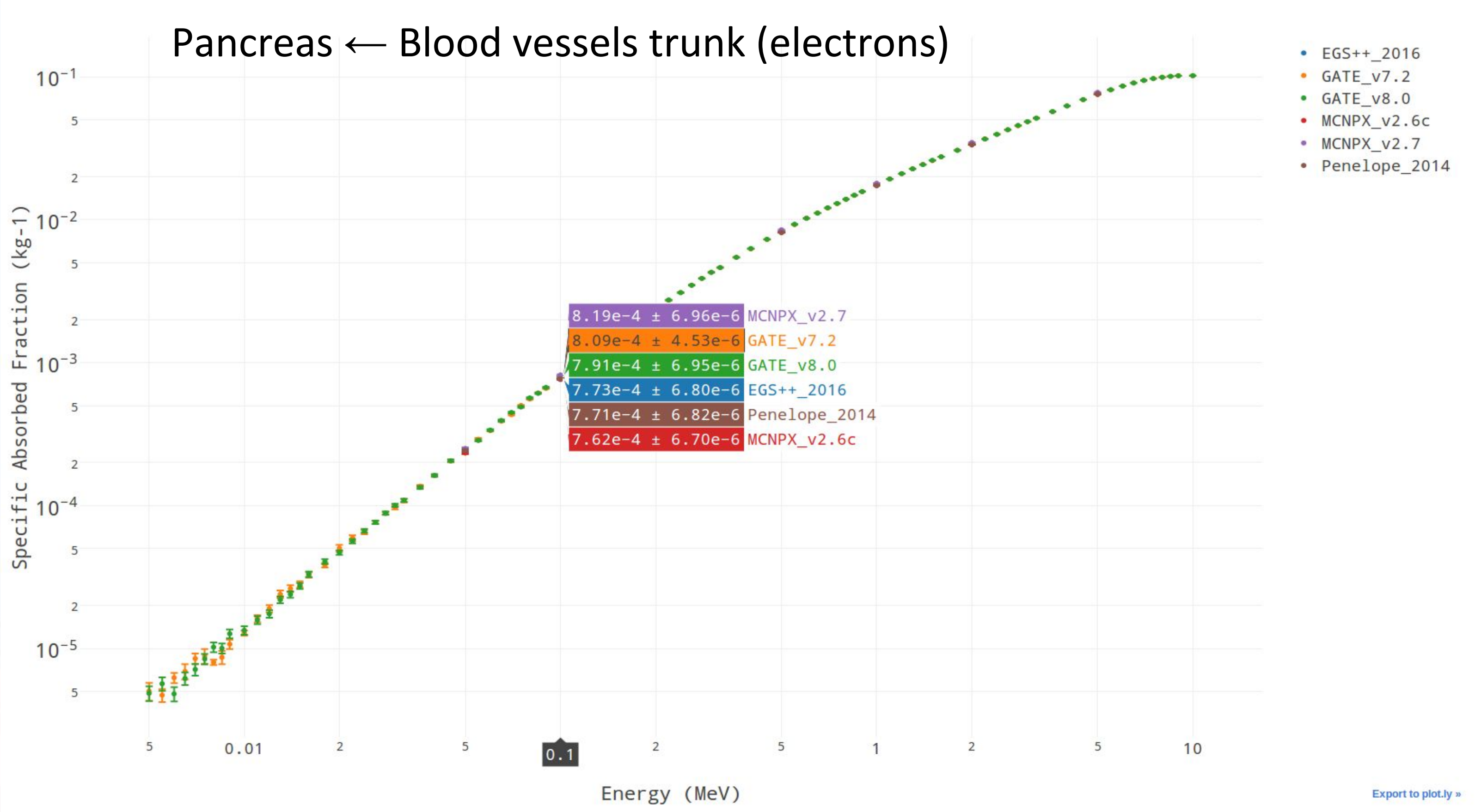
	Tissue to be used in the Monte Carlo simulation	Density	H	C	N	O	Na	Mg	P	S	Cl	K	Ca	Fe	I
No.	(% by mass)														
1	Teeth	2.75	2.2	9.5	2.9	42.1	0	0.7	13.7	0	0	0	28.9	0	0
2	Mineral bone	1.92	3.6	15.9	4.2	44.8	0.3	0.2	9.4	0.3	0	0	21.3	0	0
3	Humeri,upper half, spongiosa	1.185	8.7	36.6	2.5	42.2	0.2	0.1	3	0.3	0.1	0.1	6.2	0	0
4	Humeri, lower half, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
5	Lower arm, bones, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
6	Hand, bones, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
7	Clavicles, spongiosa	1.191	8.7	36.1	2.5	42.4	0.2	0.1	3.1	0.3	0.1	0.1	6.4	0	0
8	Cranium, spongiosa	1.245	8.1	31.7	2.8	45.1	0.2	0.1	3.7	0.3	0.1	0.1	7.8	0	0
9	Femora, upper half, spongiosa	1.046	10.4	49.6	1.8	34.9	0.1	0	0.9	0.2	0.1	0.1	1.9	0	0
10	Femora, lower half, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
11	Lower leg, bones, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
12	Foot, bones, spongiosa	1.117	9.6	47.3	1.7	34.1	0.2	0	2.2	0.2	0.1	0	4.6	0	0
13	Mandible,spongiosa	1.189	8.7	35.7	2.6	42.9	0.2	0.1	3	0.3	0.1	0.1	6.3	0	0
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…



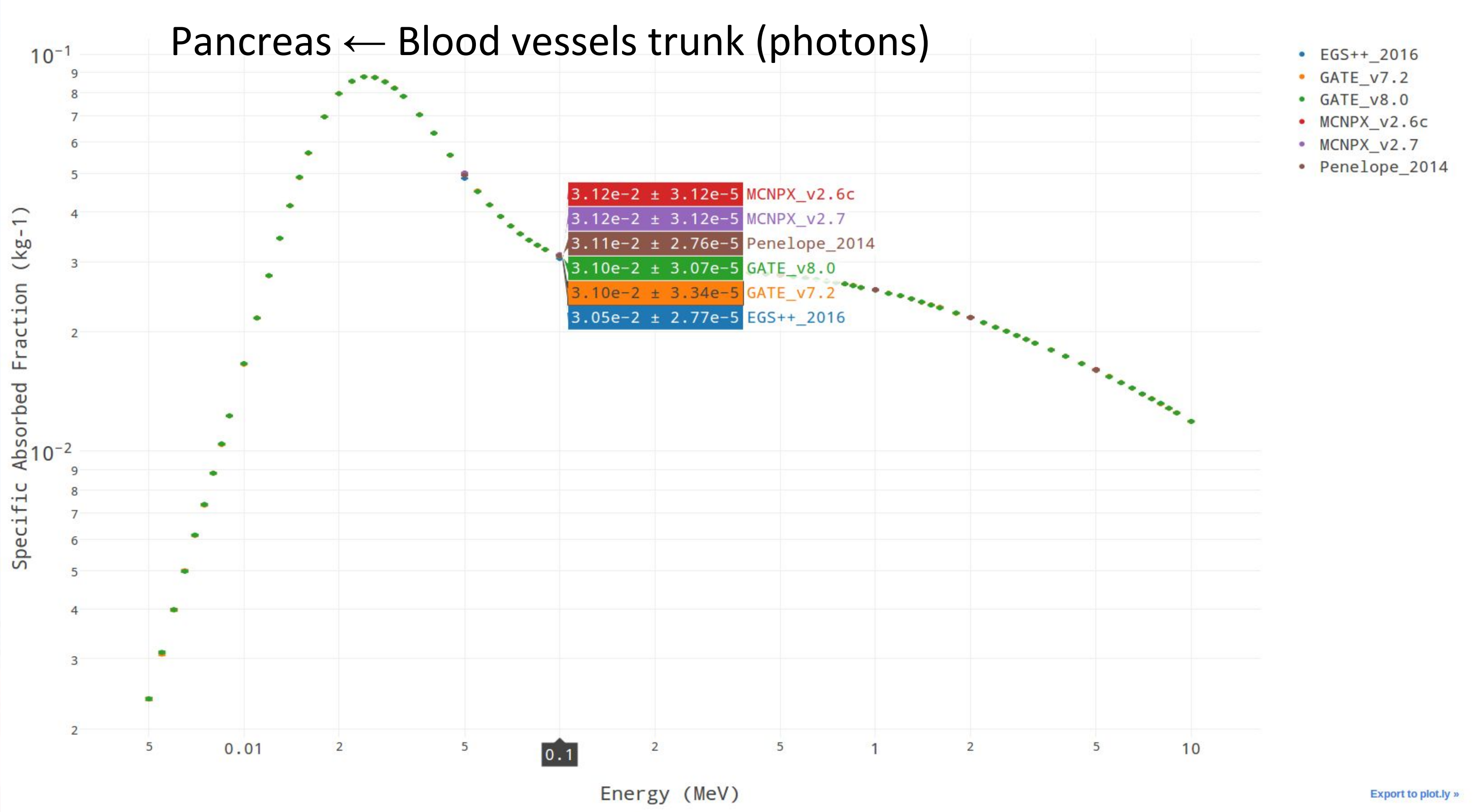
Initial comparisons results

- First results from 7 teams – presented at EANM and MCMA 2017:
  - CRCT with GATEv8.0
  - CRUK with PENELOPE_2014
  - IEO-CNAO with Fluka_2011 (was missing uncertainties)
  - IRSN with MCNPXv2.6c
  - NPL with EGSnrc/EGS++ 2016
  - SCK.CEN with MCNPXv2.7
  - SGH and UOW with GATEv7.2
- Output format:
  - 2 × csv files with computed SAFs and uncertainties
  - (+ absorbed dose voxel maps and uncertainties)

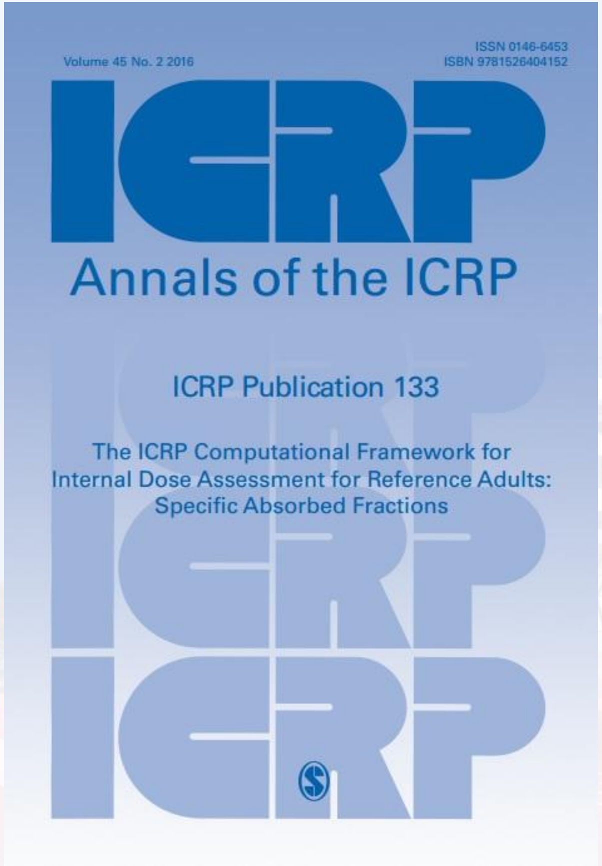
Initial comparisons results



Initial comparisons results



ICRP 133



It provides SAFs based on ICRP 110 (2009) phantoms

- 79 source organs
- 43 target organs
- Energies: 1 keV – 10 MeV

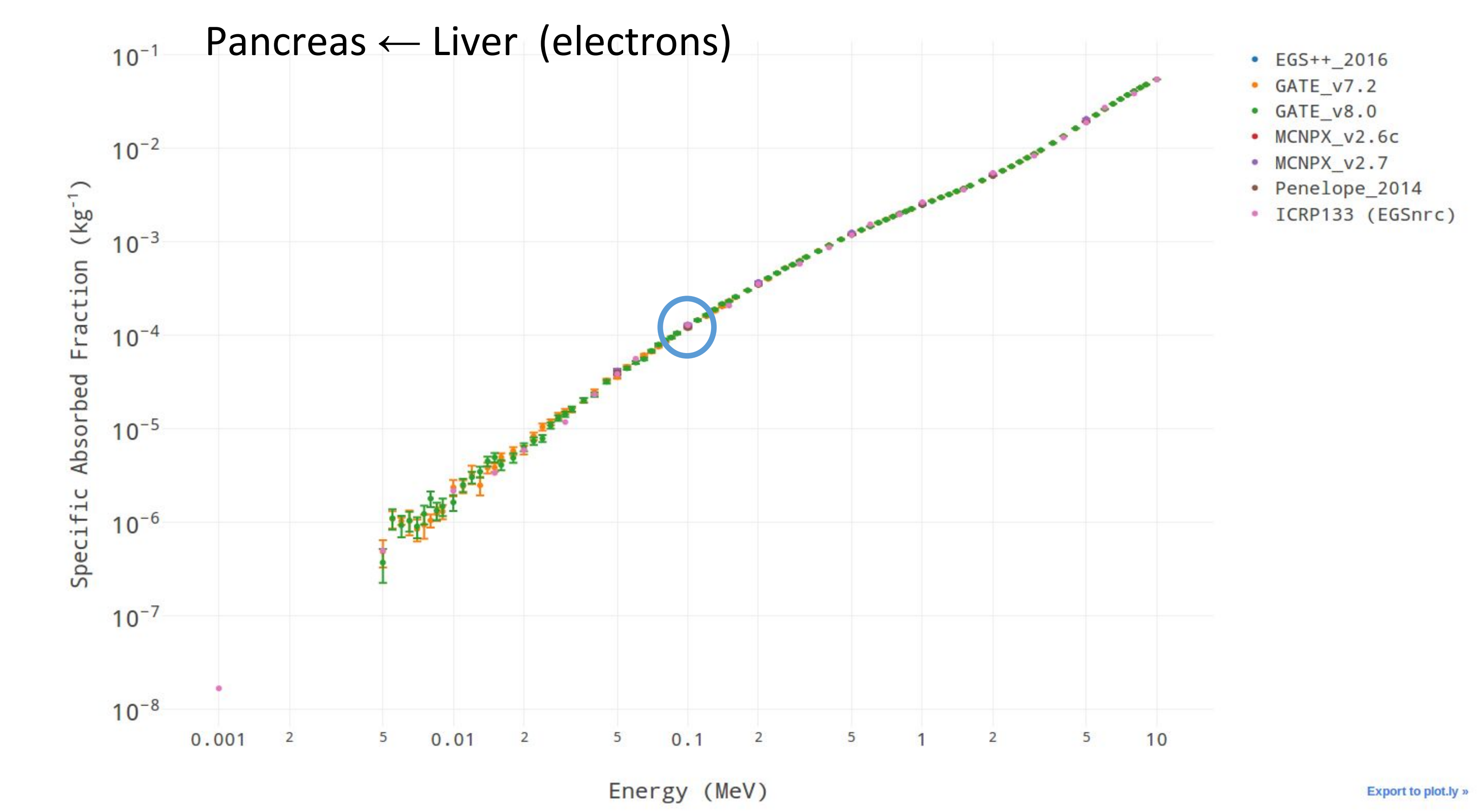
IDAC-Dose 2.1 (2017) dosimetry software by QDOSE*

- Free and endorsed by ICRP
- 83 source and 47 target organs
- 1252 radionuclides published in ICRP107
- It will be CE certified in early 2018

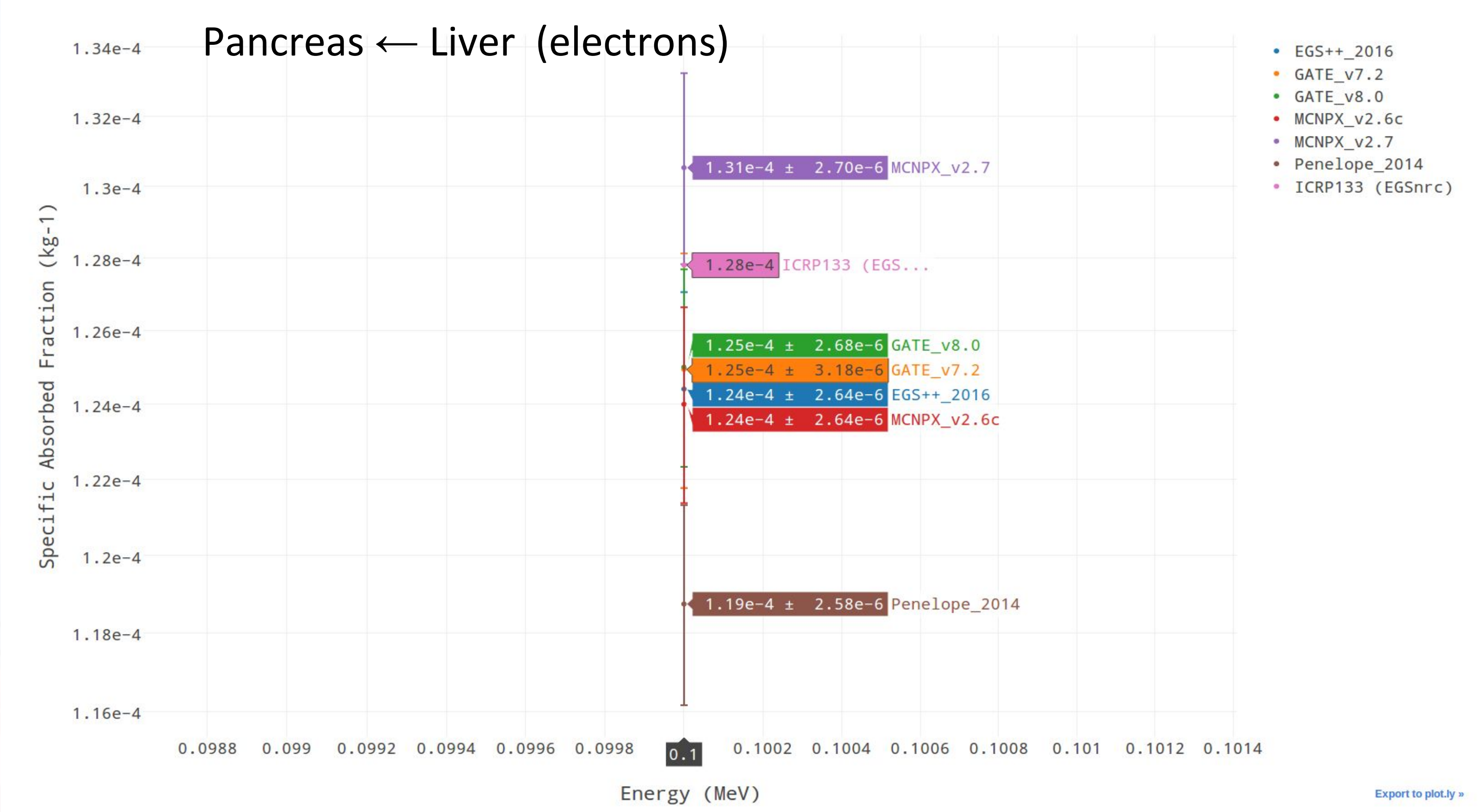
- ❑ data production delay ?
- ❑ traceable data ?
- ❑ uncertainties ?

*Anderson et al. EJNM Research 2017

Initial comparisons results



Initial comparisons results



Data production status

Data to produce for the digital models of ICRP 110:

- 2 (female/male models) × 140 (sources) × 2 (particles) × 91 (energies) = 50960 simulations

Production status:

- CRCT (local cluster + EGI + GateLab):
  - **GATE 8.1**: 2 models, all sources from 5 keV to 60 keV (75% total)
  - **Geant4 10.5**: 2 models, all sources, all energies (100% total)
- CRUK (local cluster) with **PENELOPE_2014**: 1 model, 2 sources, 7 energies
- IEO-CNAO (local cluster) with **Fluka_2011**: 1 model, 2 sources, 7 energies
- IRSN (local cluster) with **MCNPXv2.6c**: 1 model, 3 sources, 7 energies
- NPL (local cluster) with **EGSnrc/EGS++ 2016**: 1 model, 2 sources, 7 energies
- SCK.CEN (local cluster) with **MCNPXv2.7**: 1 model, 2 sources, 7 energies
- SGH and UOW (local cluster) with **GATEv7.2**: 2 models, 80 sources, all energies (30% total)

Traceability and storage: database

- PostgreSQL for efficiency and stability
- 5 tables to hold the data:

```
opendose=# \dt
             List of relations
 Schema |      Name      | Type  |  Owner
--------+----------------+-------+----------
 public | t_particles    | table | postgres
 public | t_phantoms     | table | postgres
 public | t_provenances  | table | postgres
 public | t_regions      | table | postgres
 public | t_safs         | table | postgres
(5 rows)
```

- The provenances table (team + code + date):

```
opendose=# SELECT * FROM t_provenances LIMIT 10;
 provenance_id | provider | code  | version |      contact       |            email             |    date
---------------+----------+-------+---------+--------------------+------------------------------+------------
             1 | NPL      | EGS++ | 2016    | Ana Denis-Bacelar | ana.denisbacelar@npl.co.uk | 2017-09-26
             2 | SCK.CEN  | MCNPX | 2.7     | Jérémie Dabin    | jeremie.dabin@sckcen.be     | 2017-10-12
             3 | IRSN     | MCNPX | 2.6c    | Aurélie Desbrée | aurelie.desbree@irsn.fr     | 2017-09-28
             4 | IRSN     | MCNPX | 2.6c    | Aurélie Desbrée | aurelie.desbree@irsn.fr     | 2018-07-25
             5 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-06-06
             6 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-10-30
             7 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-11-02
             8 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-06-08
             9 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-12-03
            10 | SGH      | GATE  | 7.2     | Erin McKay         | erin@computerhead.com.au     | 2018-07-02
(10 rows)
```

Traceability and storage: database

- The model regions table:

opendose=# SELECT * FROM t_regions LIMIT 10;

region_id	phantom_id	region	name	volume_cm3	mass_g
1	1	0	Air outside body	158092.65029085	158.09265029085
2	1	1	Adrenal, left	5.565894125	5.73287094875
3	1	2	Adrenal, right	7.060298575	7.27210753225
4	1	3	Anterior nasal passage (ET1)	4.193481875	4.31928633125
5	1	4	Posterior nasal passage down to larynx (ET2)	13.87661275	14.2929111325
6	1	5	Oral mucosa, tongue	17.5668768	18.44522064
7	1	6	Oral mucosa, lips and cheeks	3.81225625	4.0028690625
8	1	7	Trachea	7.761753725	7.99460633675
9	1	8	Bronchi	8.432710825	8.68569214975
10	1	9	Blood vessels, head	5.718384375	6.0614874375

(10 rows)

- The SAF table:

opendose=# SELECT * FROM t_safs LIMIT 10;

provenance_id	source_id	target_id	particle_id	energy_MeV	saf	saf_std	nb_primaries
3	11	2	2	0.05	0.0002913584	1.899657e-05	100000000
3	11	3	2	0.05	6.852924e-19	6.852924e-19	100000000
3	11	4	2	0.05	0	0	100000000
3	11	5	2	0.05	4.551655e-07	3.805184e-07	100000000
3	11	6	2	0.05	3.23879e-07	2.993938e-07	100000000
3	11	7	2	0.05	1.272372e-18	1.272372e-18	100000000
3	11	8	2	0.05	3.465562e-05	4.325021e-06	100000000
3	11	9	2	0.05	0.0001484566	1.082248e-05	100000000
3	11	10	2	0.05	2.183266e-08	2.183266e-08	100000000
3	11	11	2	0.05	4.110873	0	100000000

(10 rows)

S-value calculation from SAFs

```python
if (particle_id == 4) or (particle_id == 5) or (particle_id == 10):
    # ======================== #
    # ======== photons ======== #
    # ======================== #
    #safs_p = dict(sorted(safs[target_id][1].items()))
    safs_p = safs[target_id][1]
    energies = list(safs_p)
    e_min = min(energies)
    e_max = max(energies)
    saf_values = [x['saf'] for x in safs_p.values()]
    std_values = [x['saf_std'] for x in safs_p.values()]
    f_saf = interp1d(energies, saf_values, kind='linear', assume_sorted=False)
    f_std = interp1d(energies, std_values, kind='linear', assume_sorted=False)
    if 'photons' not in sv:
        sv['photons'] = {'svalue': 0, 'svalue_std^2': 0}
    for row in isotope[particle_id]:
        # get E/nt for this row
        ene_yield = row['energy_MeV']*MeV * row['yield'] * 1e9
        if (row['energy_MeV'] < 0.005):
            if (target_id == source_id):
                # consider local energy deposit
                sv['photons']['svalue'] += ene_yield / target['mass_kg']
                #sv['photons']['svalue_std^2'] += 0
        elif (row['energy_MeV'] < e_min):
            valid = False
        elif (row['energy_MeV'] > e_max):
            valid = False
        else:
            # s-value calculation using interpolated SAFs
            sv['photons']['svalue'] += f_saf(row['energy_MeV']) * ene_yield
            sv['photons']['svalue_std^2'] += pow(f_std(row['energy_MeV']) * ene_yiel

if (particle_id == 1) or (particle_id == 9):
    # ======================== #
    # ======== alphas ======== #
    # ======================== #
    # -> alpha particles and alpha recoil nuclei
    if 'alphas' not in sv:
        sv['alphas'] = {'svalue': 0, 'svalue_std^2': 0}
    if (target_id == source_id):
        # consider local energy deposit
        for row in isotope[particle_id]:
            # get E/nt for this row
            ene_yield = row['energy_MeV']*MeV * row['yield'] * 1e9
```

A python program has been developed to calculate S-values from the SAFs:

- Read isotope data from ICRP 107 (ICRP, 2008. Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107. Ann. ICRP 38).
- Read SAFs from all codes and calculate the average for each of the 91 energies
- For each emission lines (gammas, Augers, etc…), interpolate the SAF from the OpenDose average.
- For the beta spectrum, interpolate the SAFs from the OpenDose average and integrate between Emin and Emax.

$$S(r_t \leftarrow r_s) = \sum_i \frac{\Delta_i \Phi_i (r_t \leftarrow r_s)}{m_t}$$

The website

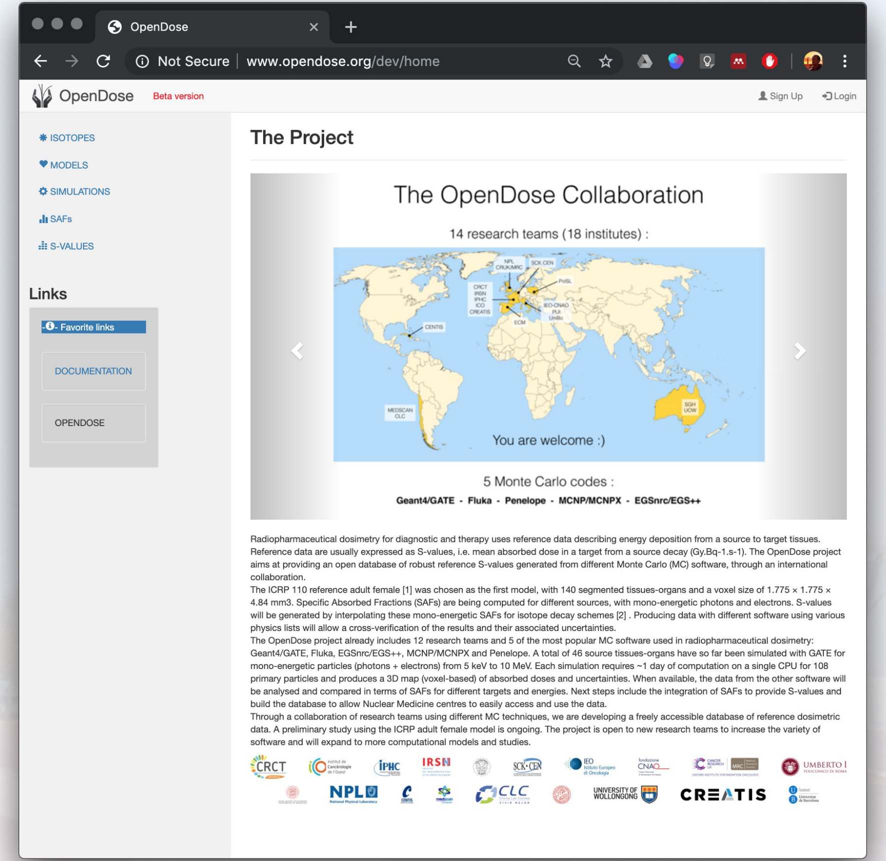
What we would like to provide:

- One homepage to display general information
- One section to show radioisotope emissions
- One section to show the digital phantoms
- SAFs display and download
- S-values calculation, display and download
- Absorbed dose calculation for patient

The website

- The website is online ! http://www.opendose.org
- It is developed in HTML5 + CSS, PHP and JavaScript
- The source code is versioned with Git in a private repository on GitLab
- The website is deployed in a Virtual Machine hosted at creatis.insa-lyon.fr :
  - Fedora 28, 4 virtual CPUs, 8 GB RAM, 250 GB disk size.

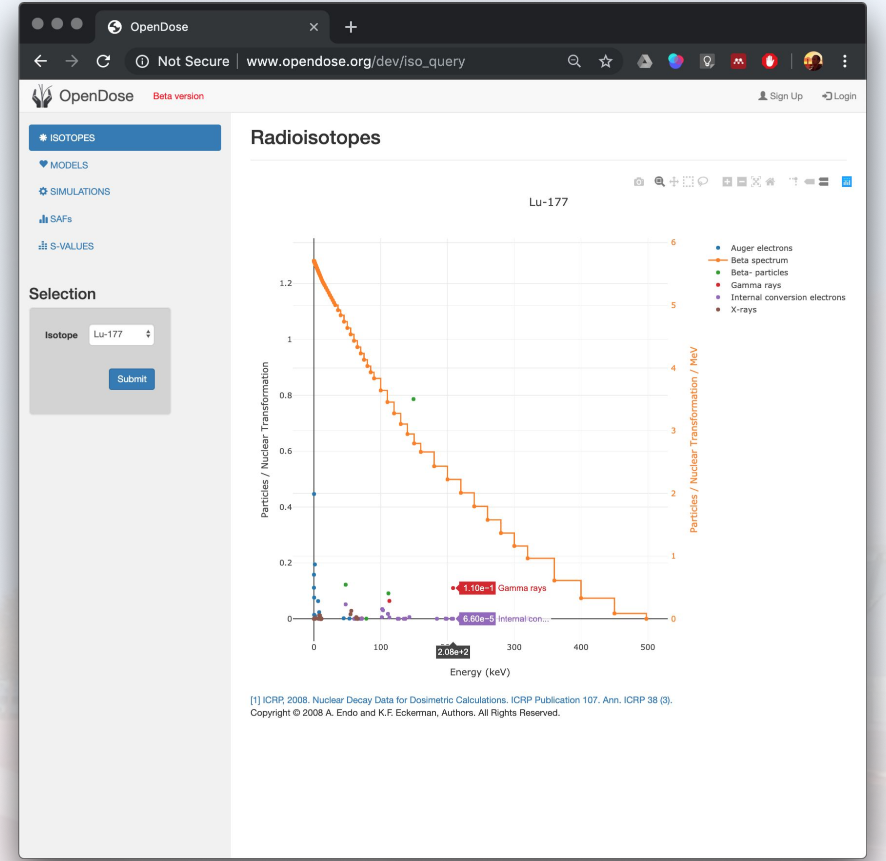
The website



The homepage display general information:

- illustrative images of the project and/or results
- a description of the project
- the institutes and members of the collaboration
- links to other websites (like team institutes)
- a link to subscribe to a newsletter
- publications
- funding
- contacts

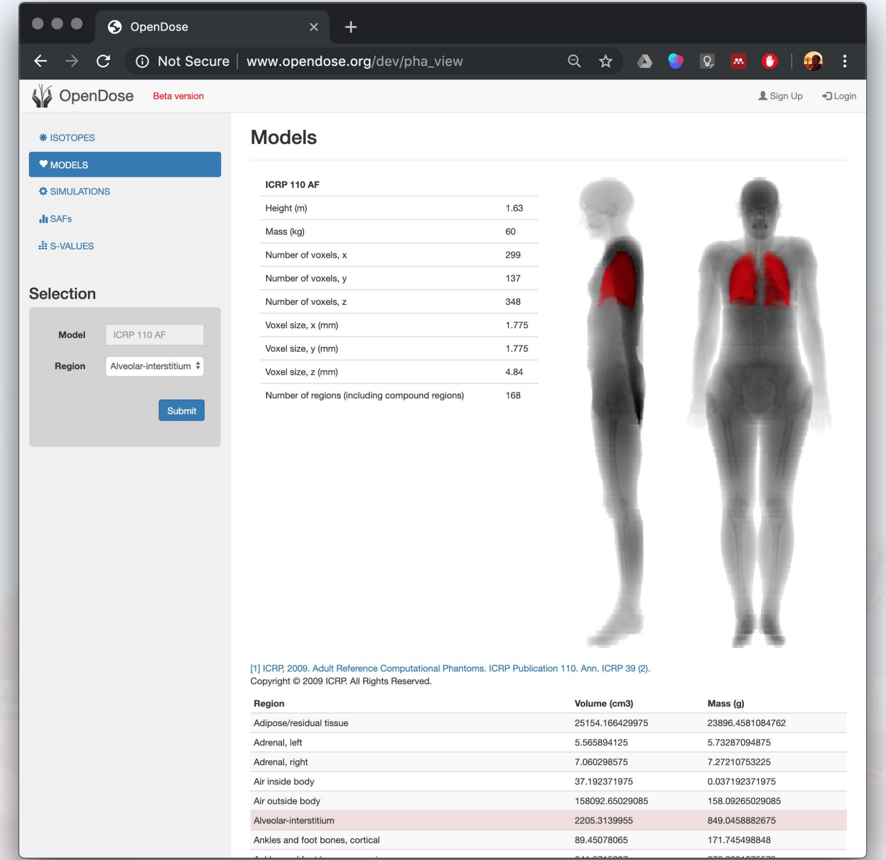
The website



The isotope section:

- a menu allows selecting one radioisotope from the 1252 of the ICRP 107 database
- an interactive graph displays the isotope emission lines and beta spectrum

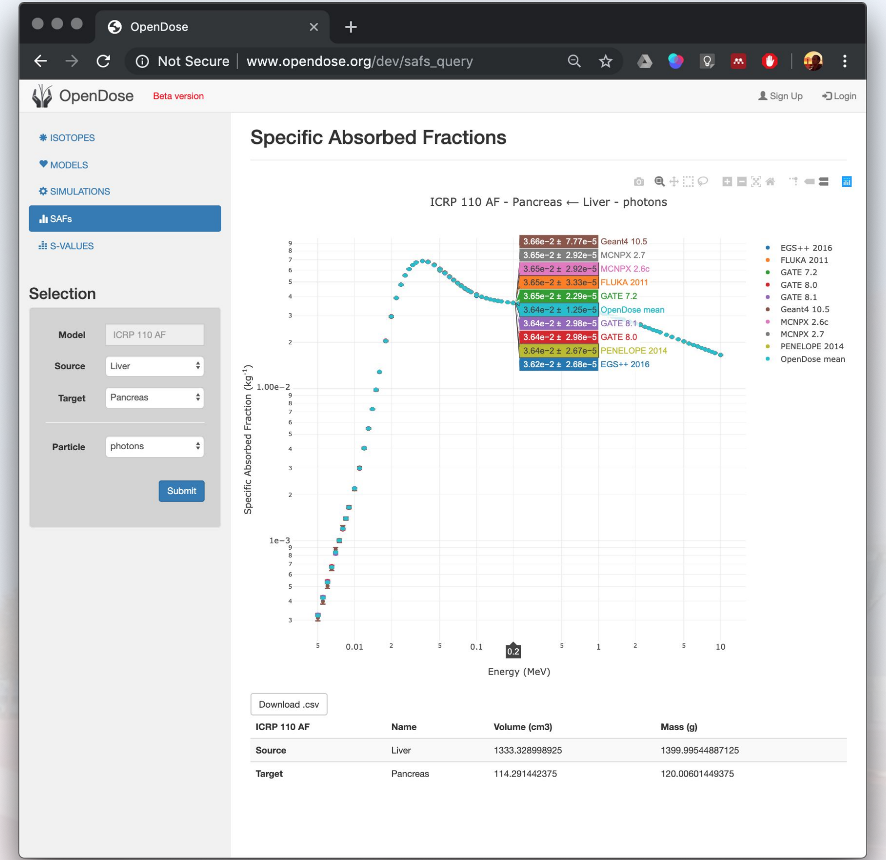
The website



The models section:

- a menu allows selecting a model and one organ
- a table shows the characteristics of the model
- an image shows the selected model (densities) and organ highlighted in red
- a table displays the model organs and tissues with volume and mass

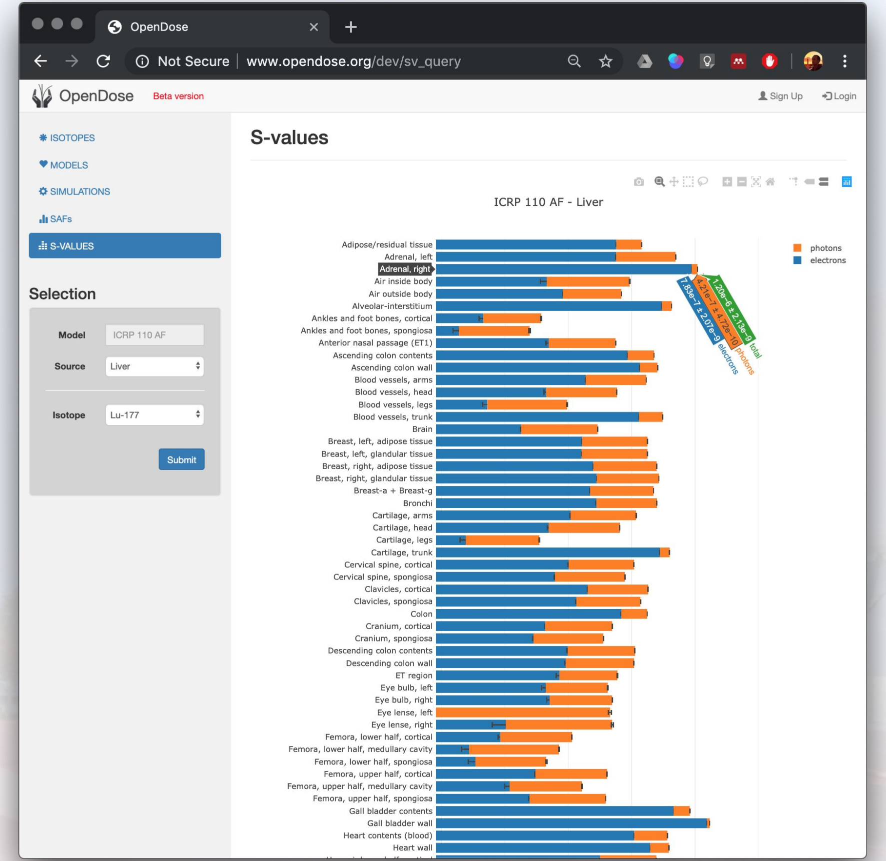
The website



The SAFs section:

- a menu allows selecting the model, source, target and the particle type
- an interactive graph displays the corresponding SAFs (and uncertainties) for all energies and Monte Carlo codes + an average 'OpenDose' SAF (and uncertainty).
- a table shows the volume and mass of the source and target
- a button allows to download a .csv file with all the SAF values (and uncertainties) from the Monte Carlo codes for all energies

The website



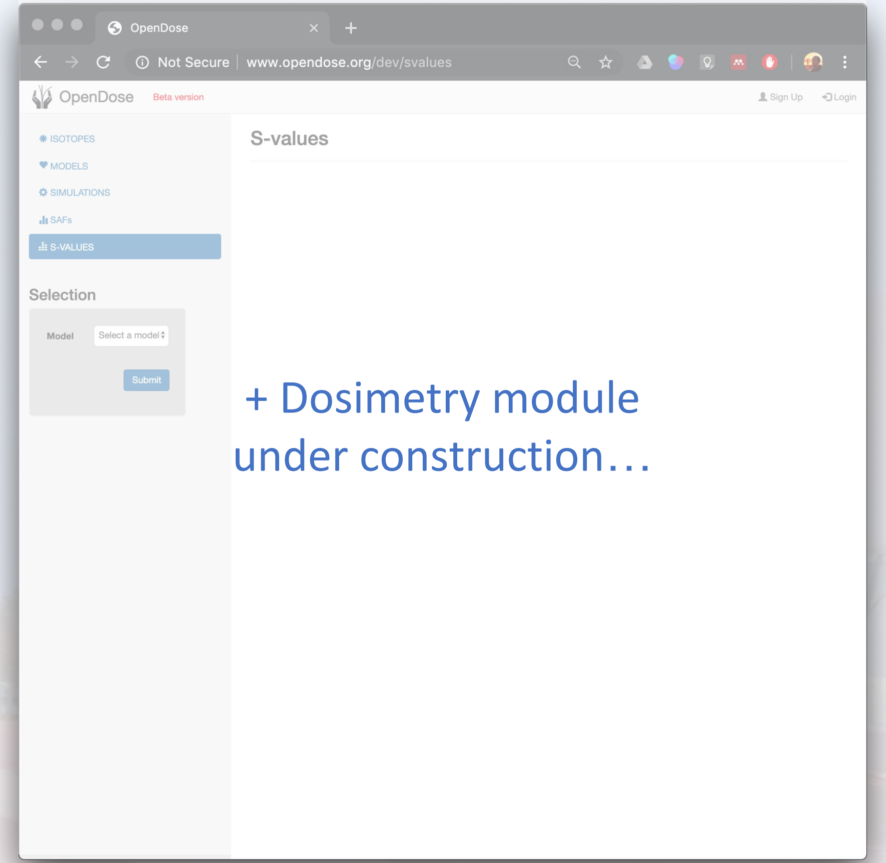
The S-values section:

- a menu allows selecting the model, source and isotope
- the website calculate the S-values in real-time with the current SAFs present in the database

$$S(r_t \leftarrow r_s) = \sum_i \frac{\Delta_i \Phi_i (r_t \leftarrow r_s)}{m_t}$$

- an interactive graph displays the corresponding S-values (and uncertainties) per particle type for all targets
- a table shows the S-values (and uncertainties) per target and the mass of the target
- a button allows to download a .csv file with all the S-values (and uncertainties) per target

The website



+ Dosimetry module under construction…

This section will allow the user to perform absorbed dose calculations. It will include:

- a menu to select the model, the source organ and the isotope
- a menu to select the activity (cumulated or TAC points)
- a possibility to make organ mass adjustments
- a plot to display the corresponding absorbed dose (and uncertainties) per target
- a table to show the data
- a button to download the data in .csv format

Next steps

- Complete data production for the 2 ICRP 110 models
- Assess SAFs differences between codes
    - Radiation transport parameters (cross sections…)
- Develop the dosimetry section of the website
- Use the absorbed dose voxel maps produced by the simulations to study absorbed dose variability within organs
- Generate data for other models: pediatrics, mesh-based phantoms, etc...

In summary

- The collaboration already includes 14 teams over 9 countries, with 5 different Monte Carlo codes: Geant4/GATE, FLUKA, PENELOPE, MCNP/MCNPX and EGSnrc/EGS++
- A first case demonstrated the feasibility and relevance of the concept
- Production of the data for the 2 adult models is on going
- The SQL database is built and scripts developed to automatically populate the tables
- The website is online ! and offers functionalities to display isotope, model, SAF and S-value data
- The collaboration is open to new research teams (and new codes) and will expand to more computational models (pediatric and next generation mesh-based phantoms)

Join the collaboration !

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