OpenDose3D: a free/open clinical dosimetry software for nuclear medicine

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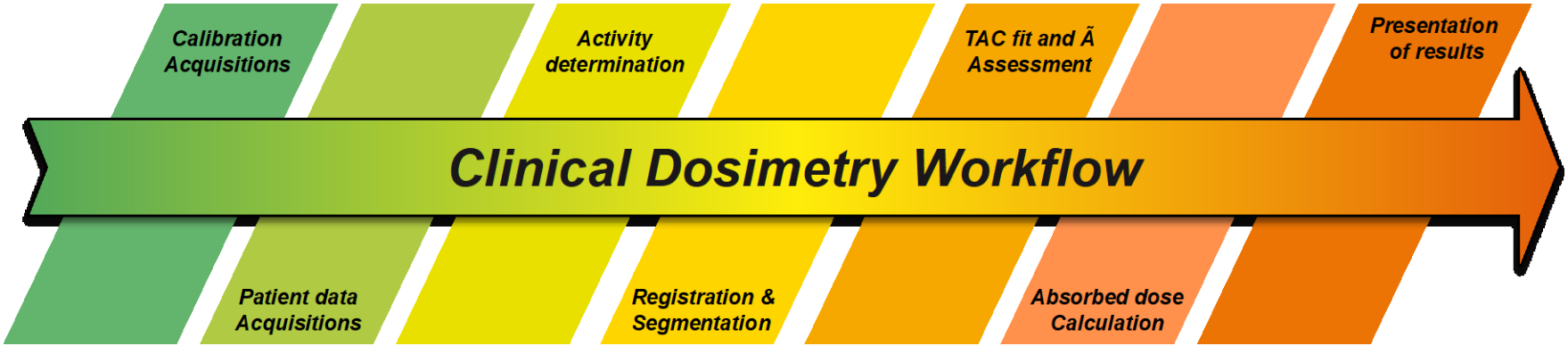
Declaration of interest

- Manuel Bardiès supervises a PhD project sponsored by DOSIsoft
- José Fragoso (PhD student) is sponsored by DOSIsoft
- Development of OpenDose3D was made within the MEDIRAD project

MEDIRAD

http://www.medirad-project.eu

Clinical dosimetry workflow (CDW)



Bardiès and Gear (2021) Scientific Developments in Imaging and Dosimetry for Molecular Radiotherapy. Clinical Oncology 33(2) 117-124

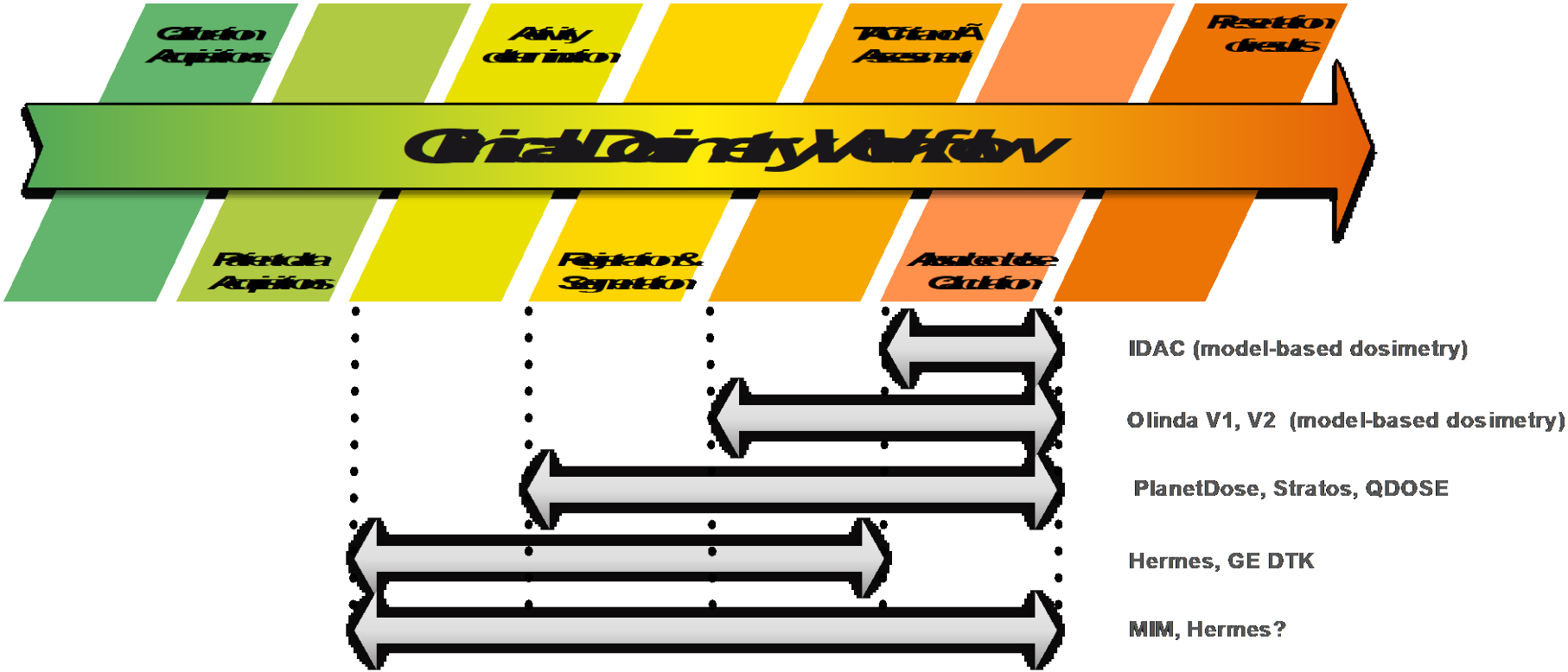
- Absorbed dose calculation is ONE part of the clinical dosimetry workflow
- All steps should be treated/addressed with the same care!
- Global uncertainty resulting from the whole CDW?

Clinical dosimetry software

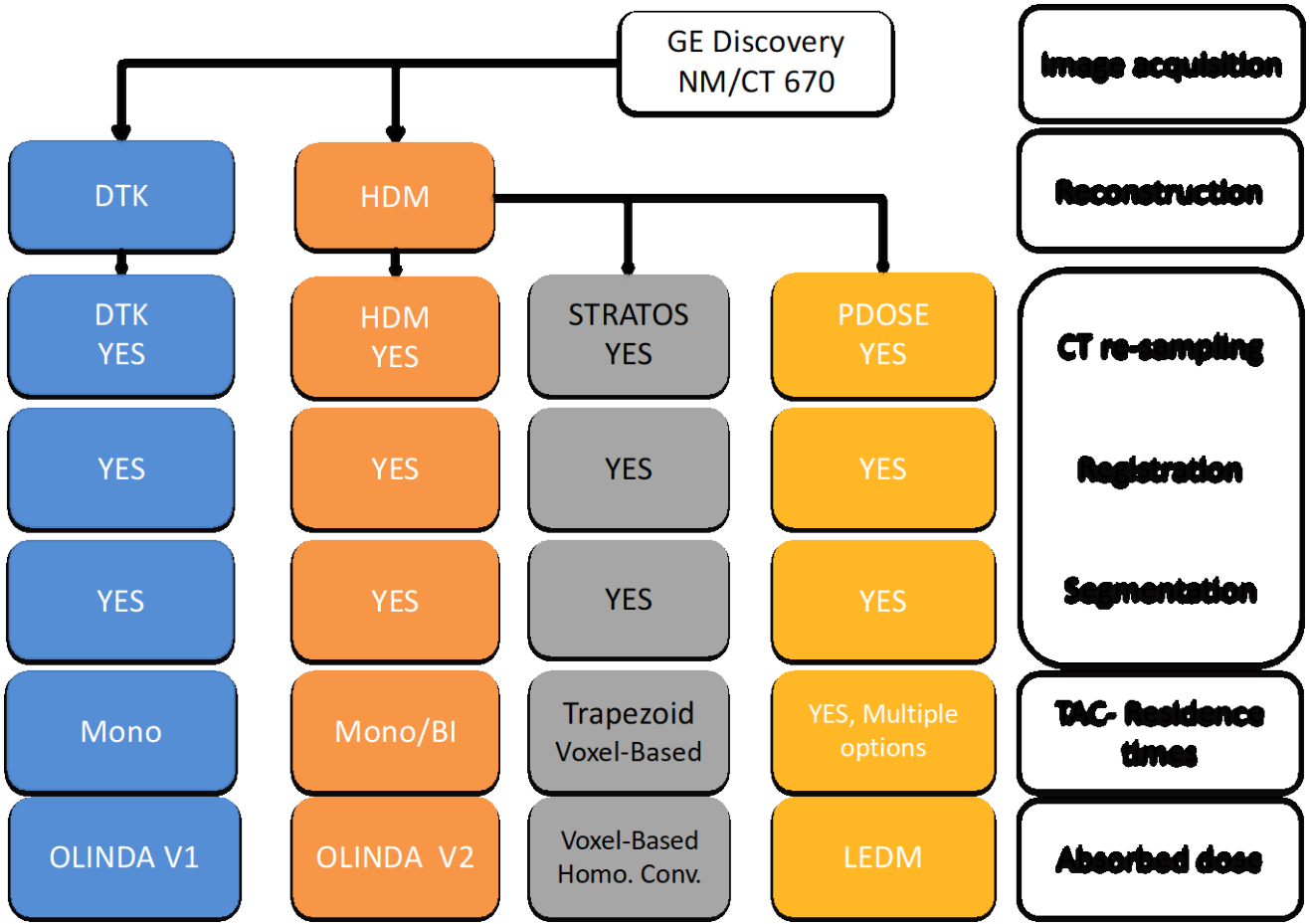
	Academic	Commercial
Available	?	✓
Free	✓	-
Maintained	-	✓
Documented	+/-	+/-
CE-marked/FDA approved	-	✓

- How to benchmark?

Comparing software?



Mora Ramirez et al. 2020 Medical Physics, Volume: 47, Issue: 9, Pages: 4602-4615



Mora Ramirez et al. 2020 Medical Physics, Volume: 47, Issue: 9, Pages: 4602-4615

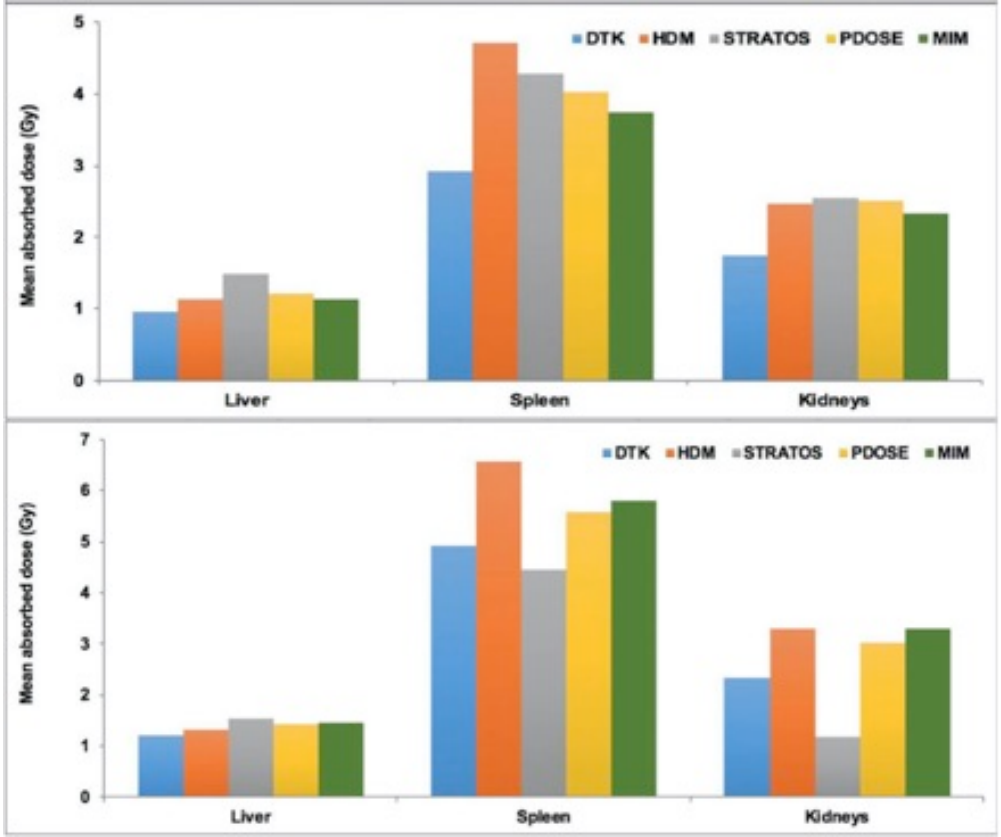
MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

Research Article | Open Access

Comparison of commercial dosimetric software platforms in patients treated with ^{177}Lu-DOTATATE for peptide receptor radionuclide therapy

Erick Mora-Ramirez, Lore Santoro, Emmanuelle Cassol, Juan C. Ocampo-Ramos, Naomi Clayton, Gunjan Kayal, Soufiane Chouaf, Dorian Trauchessec, Jean-Pierre Pouget, Pierre-Olivier Kotzki, Emmanuel Deshayes, Manuel Bardiès ... See fewer authors

First published: 06 July 2020 | https://doi.org/10.1002/mp.14375 | Citations: 1



Still

- Comparison was done BUT
- Some choices were made to make the comparison possible
- Every manufacturer could object!
- No common reference, metrics…

Comparing software?

Fig. 1. Diagram of the proposed workflows in MRT and SRT TPSs. Workflow personalization is available for several TPSs.

Della Gala *et al*. Physica Medica 92 (2021) 52-61

Comparing software?

Table 6
Zero to first time
SurePlan-MRT, if
activity at inject
radionuclide. In t
administered acti
Intermediary valu
fraction of A_{Adm})
TAC integration,
decay of the radi

TPS
QDose
PlanetDose
HERMES Organ
HERMES Voxel
SurePlan-MRT

Table 9
Absorbed dose calculation methods implemented by the TPSs. DVK= Dose-voxel kernel; MC= Monte Carlo. *in Q-Suite, DVK is implemented only for post-treatment dosimetry, not for pre-treatment dose simulation.

TPS	Voxel S-value	Local deposition	Convolution DVK in homogenous media	Semi-MC
QDose	✓	×	×	×
PlanetDose, PlanetDose-SRT	✓	✓	✓	×
HERMES Voxel	×	×	×	✓
SurePlan-Liver	×	✓	×	×
SurePlan-MRT	✓	×	×	×
Simplicity	×	✓	×	×
Q-Suite	×	✓	✓*	×
RapidSphere	×	✓	×	×

Our wish list…

- Specific workflows (adapted to pathologies/isotopes/…)
- Import/export features …should include import/export DICOM RT-Struct and RT-Dose.
- Internal “sanity” checks should be performed automatically
- A modular approach … in order to allow step-by-step processing (providing checkpoints) or the possibility to perform a dosimetry study in different sessions
- The calibration process should be well described, or even better, a “calibration module” should be available
- Storing of intermediary results (segmentation, registration…) and a history of the processes performed should be available to allow traceability and a retrospective processing of dosimetric studies
- The output format should be standardized … at least well documented
- Uncertainty analysis should be implemented within the workflow.

Mora Ramirez et al. 2020 Medical Physics, Volume: 47, Issue: 9, Pages: 4602-4615

Comparing software?

Codes may address only some parts of the CDW.

Need for:

- Defining the *metrics* to benchmark clinical dosimetry
- Defining standards (DICOM updates*) to ensure traceability?
- Defining *check-points* in clinical dosimetry
- Designing virtual patients to test the CDW?
- Designing (digital?) *test objects* for addressing specific dosimetry steps
- Software for benchmarking/commissioning of codes?

Quality assurance in NM dosimetry

https://therapy.snmmi.org/SNMMI-THERAPY/Dosimetry_Challenge.aspx
www.dositest.org
www.opendose.org
*https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8075532/

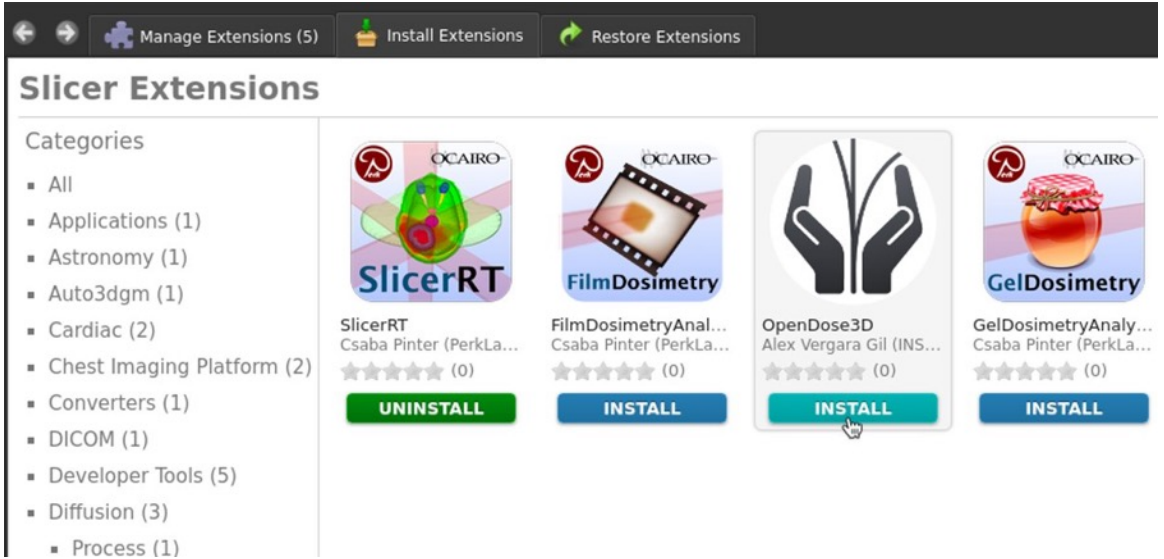
Why OpenDose3D?

Existing clinical dosimetry software
- Academic
- Commercial

Both have advantages/drawbacks

OpenDose3D:
- Open-source software
- Freely available

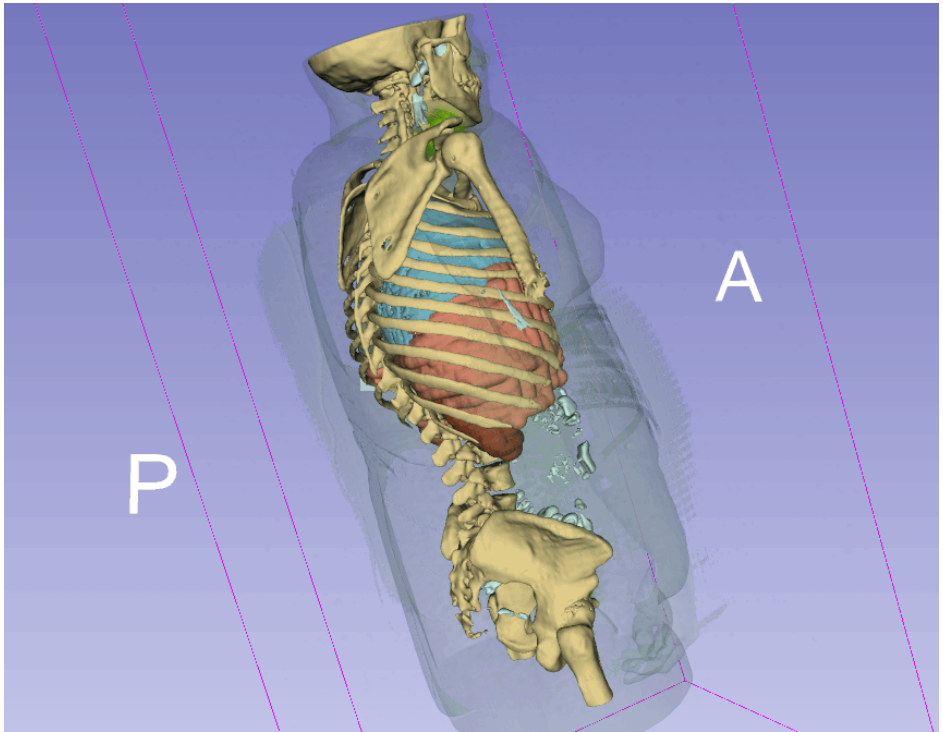
Based on 3D Slicer:
- Use cool features of 3D Slicer
- Develop missing features



OpenDose3D: Available as 3D Slicer plugin
- Designed for image based (patient specific) dosimetry
- Using different absorbed dose calculation algorithms

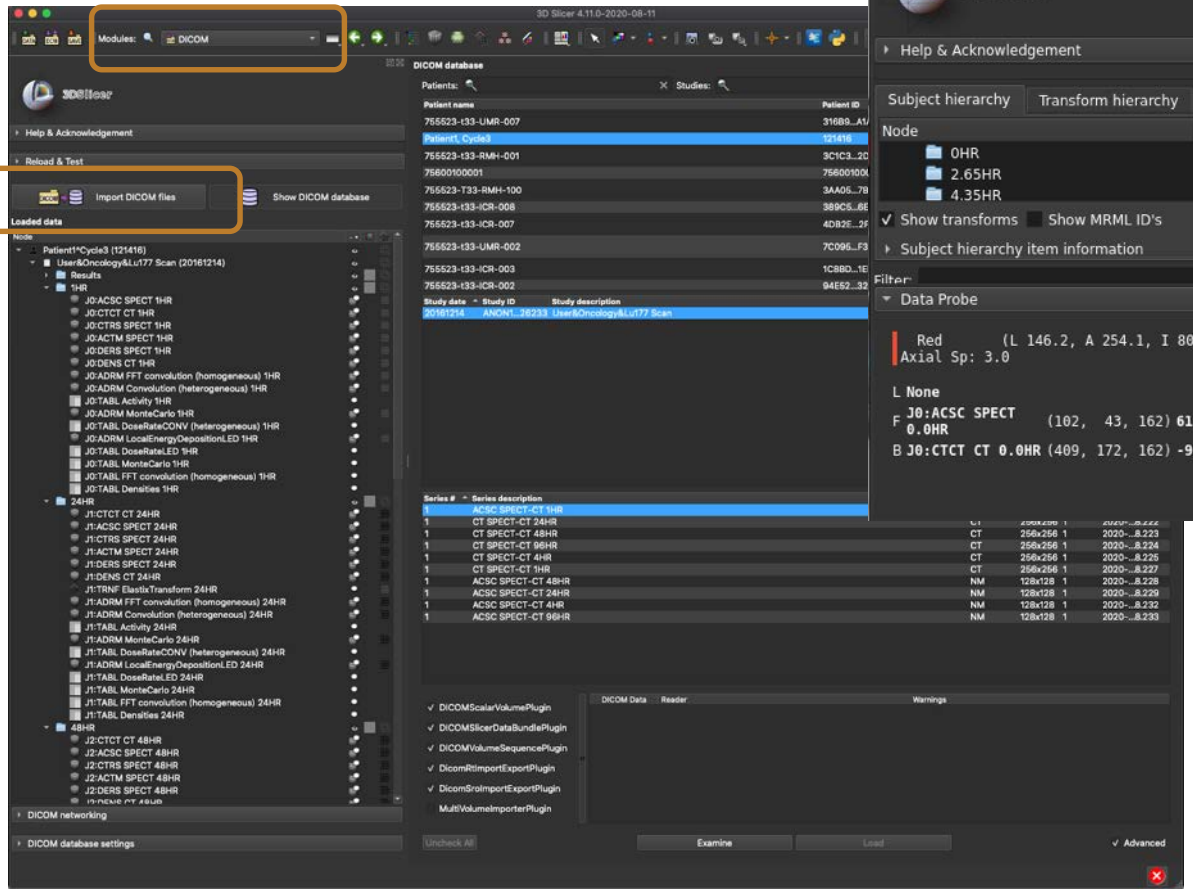
https://www.slicer.org/

- Analysis (registration / segmentation)
- Visualization (volume rendering)
- A free, open source software
- Available in multiple operating systems: Linux, Mac OSX and Windows.
- Extensible, with powerful plug-in capabilities for adding algorithms and applications.



There are no restrictions on use, but 3D Slicer is **not approved for clinical use** and is intended for **research**. Permissions and compliance with applicable rules are the responsibility of the user.

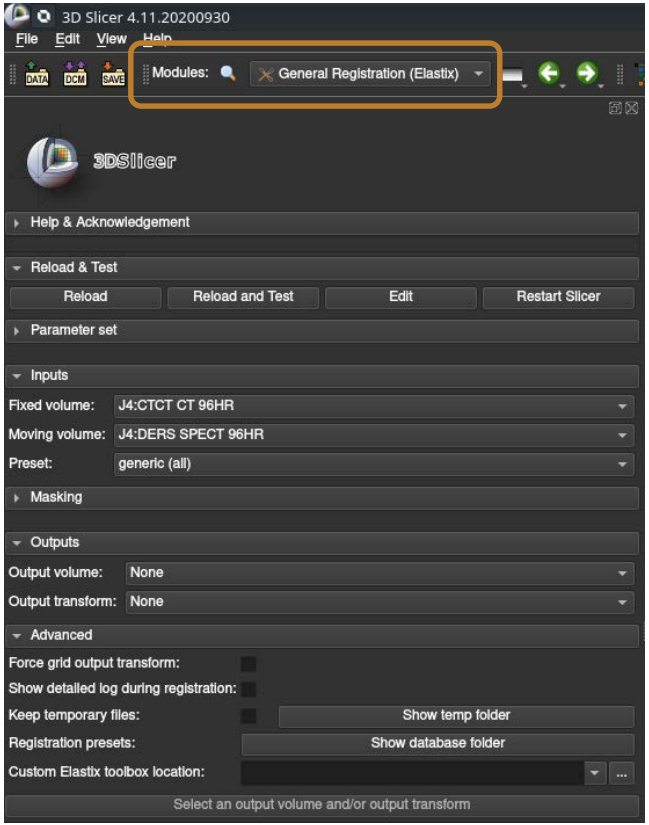
3D Slicer



Features of 3D Slicer:

- DICOM RT (I/O)
- Display
- Segmentation
- Registration

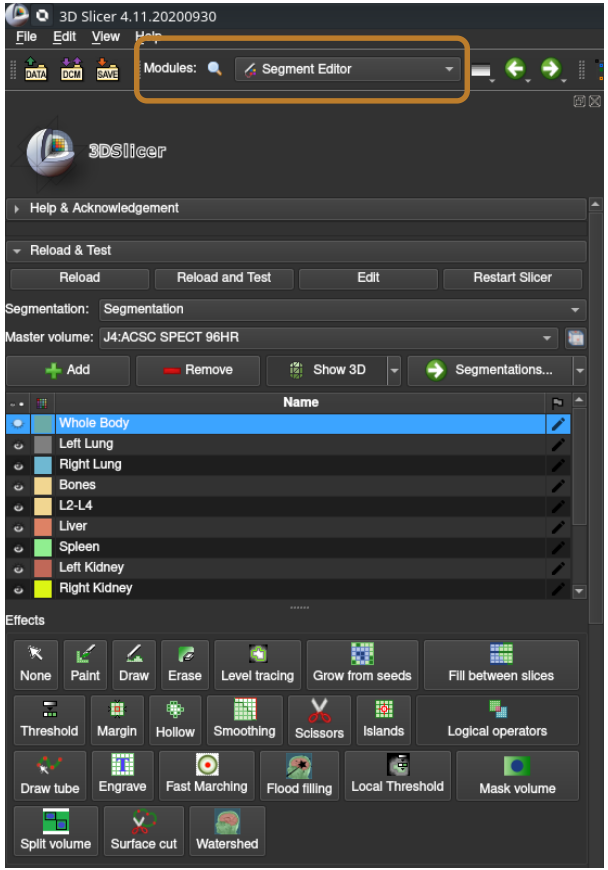
Slicer 3D features: Registration



Use of the Elastix module in Slicer for time point registration

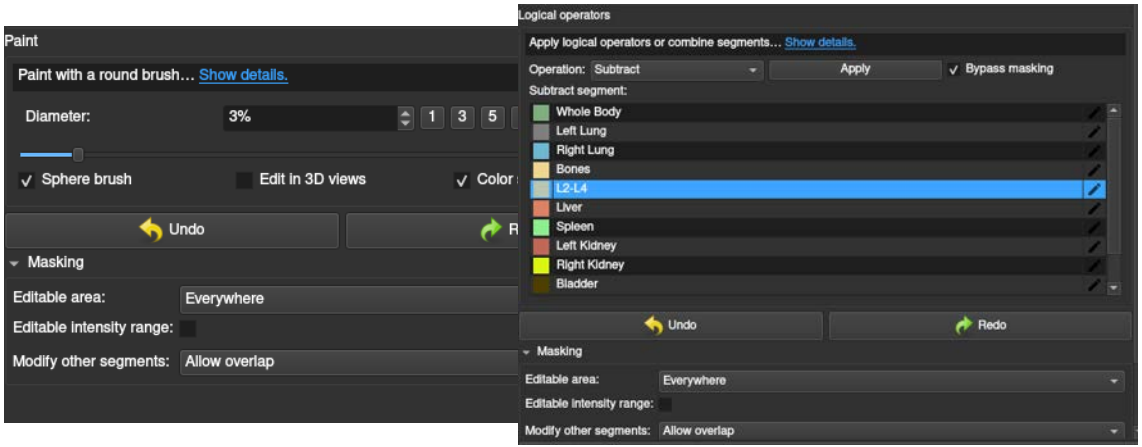
- Rigid and Elastic registrations
- The registrations are stored as Transformation fields, without modifying the original images
- Implicit inverse transformation while querying images for statistics
- Several objects (images, segmentations, even other transform fields) may share the same transformation
- Visualization tools for assessing the registration.
- Possibility to implement extra linear transformations (semi-automatic) before the elastic step to improve results

Slicer 3D features: Segmentation



Use of Slicer full toolset for Segmentation

- Various options to define structures
- Each tool contains full customizations
- One segmentation per time point if necessary
- Some AI tools are available for segmentation



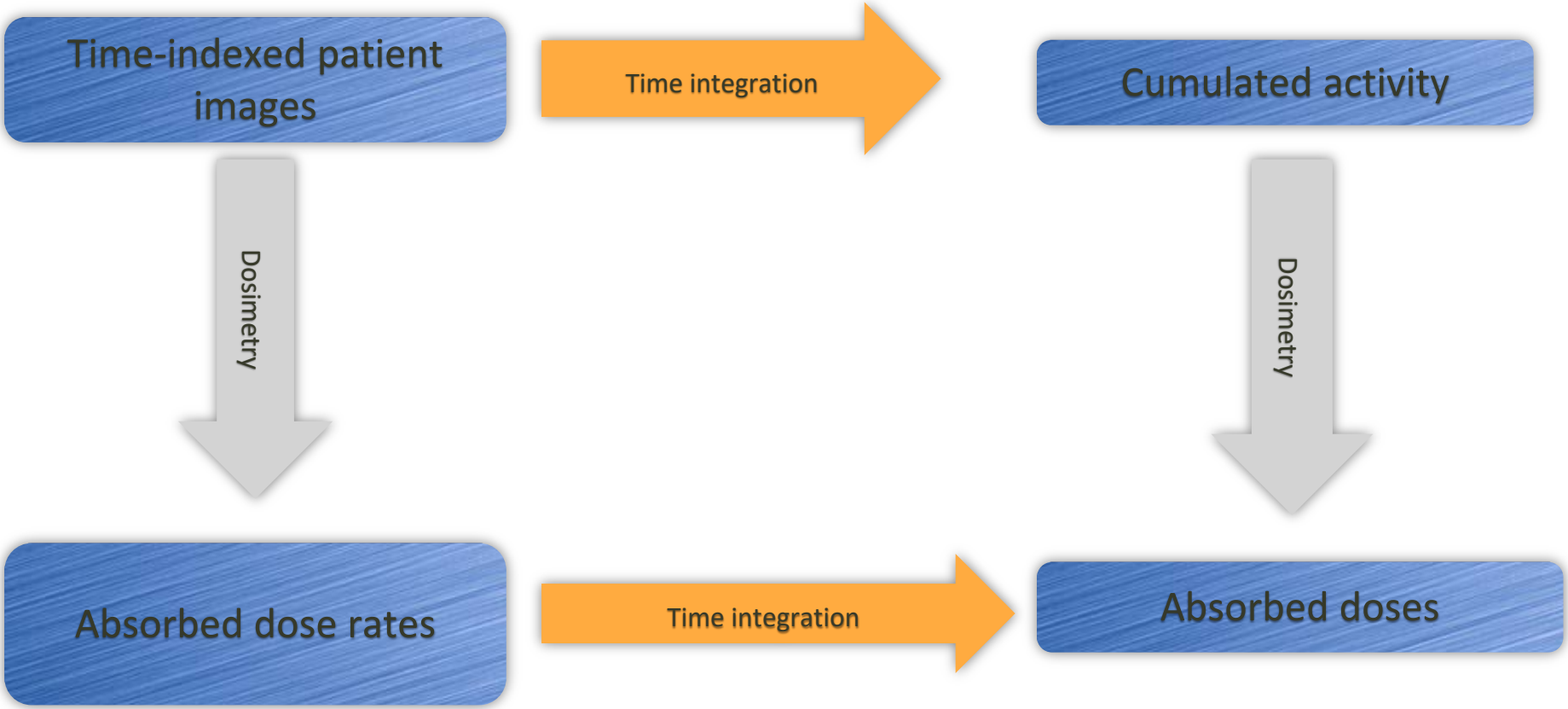
OpenDose3D data workflow

- **Data workflows defined in the Medirad project**
- **Modular design (each step has data input and data output that is preserved on saving)**
- **Possibility to import/export intermediary results at every stage**
- **Integration of the calibration module**
- **Different time-dependent variable integration**
- **Different absorbed dose calculation algorithms**

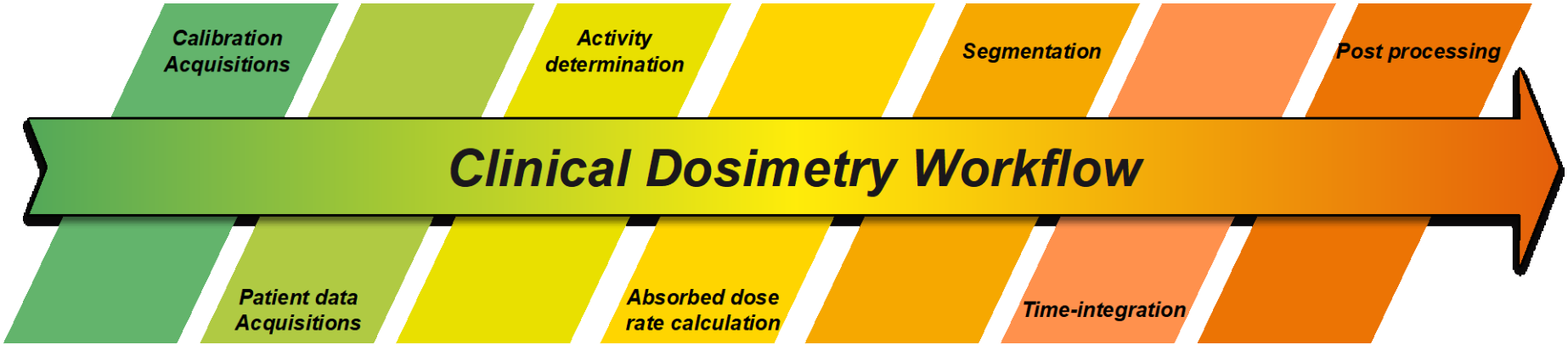
MEDIRAD

[1] http://www.medirad-project.eu/

Data processing workflow?

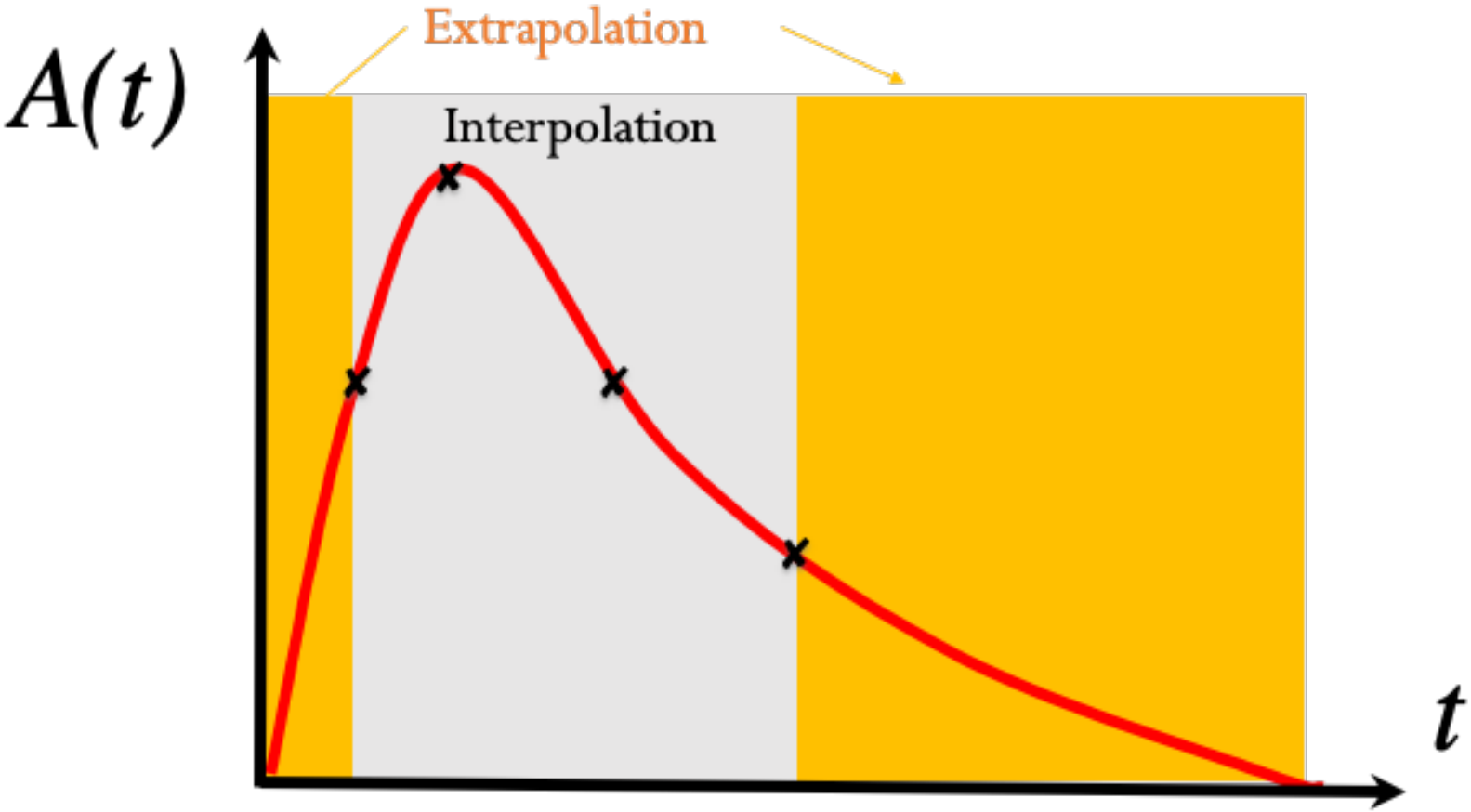


Alternate Clinical Dosimetry Workflow?

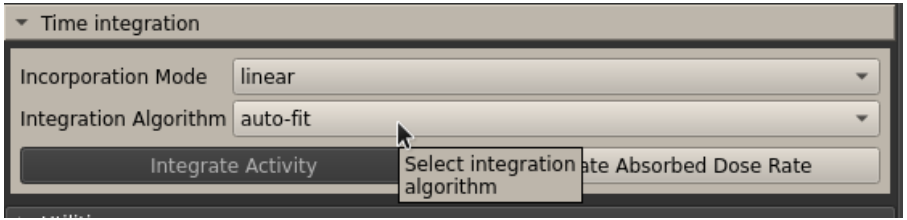


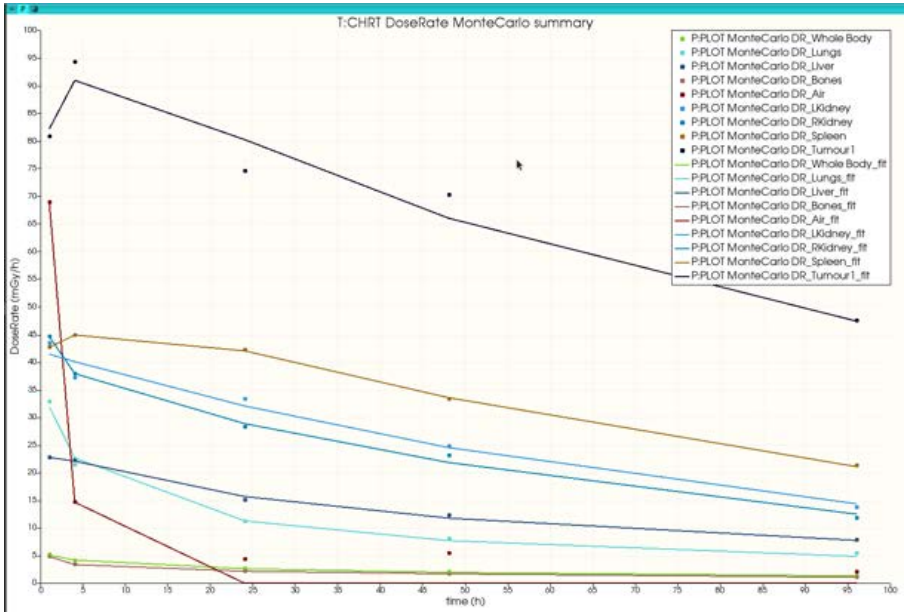
- Already implemented in some codes
- Various implications…
- Previous CDW also possible

TAC fitting



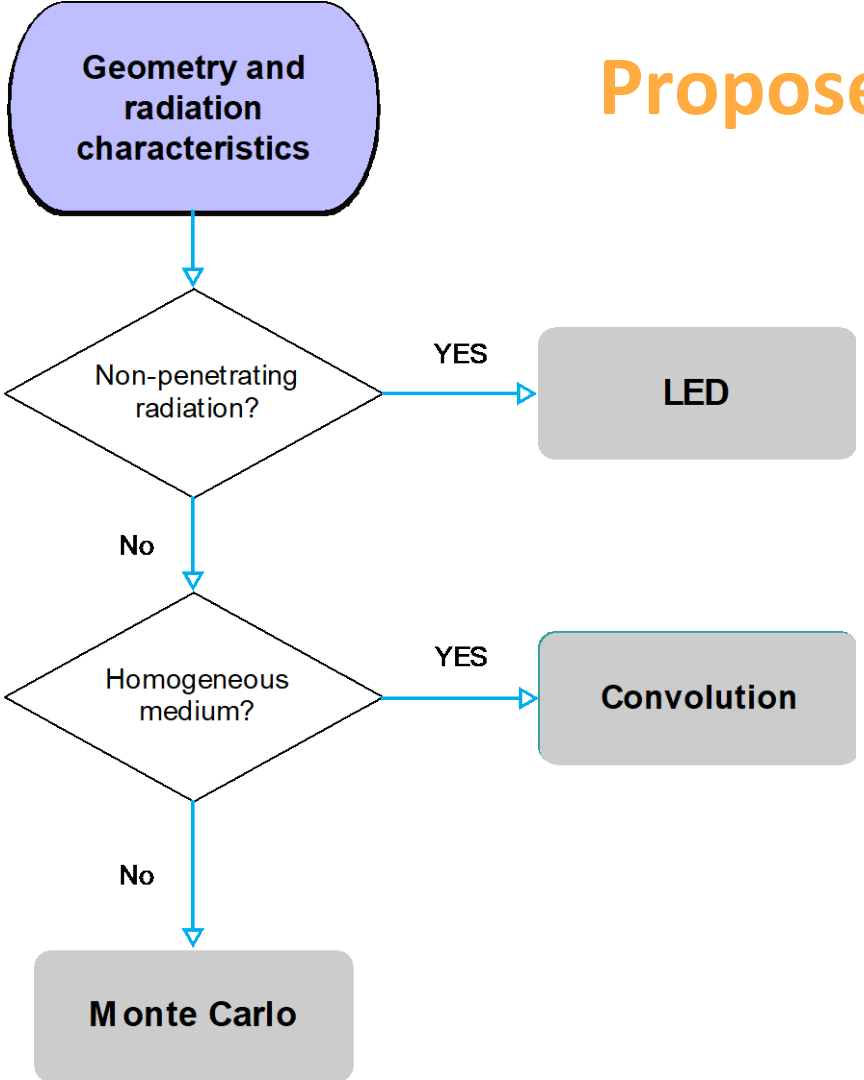
Time integration





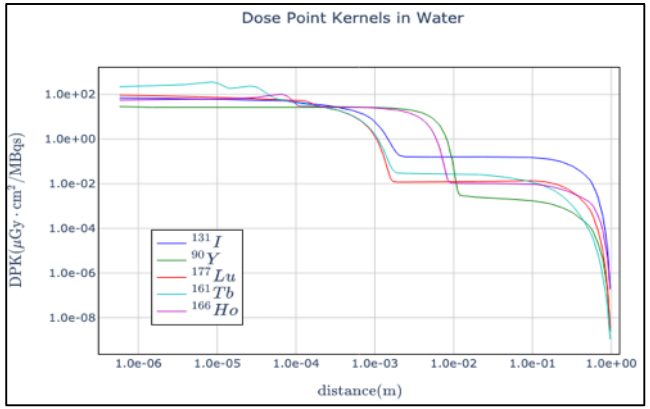
- Time integration:
  - ADR integration
  - Activity integration
- Several fit function implemented
  - Mono-Bi-Tri-X-Exponential
  - Auto selection of best fit using bayesian stats
- Handling of extrapolations:
  - 0 to first time-point
  - Last time-point to infinity

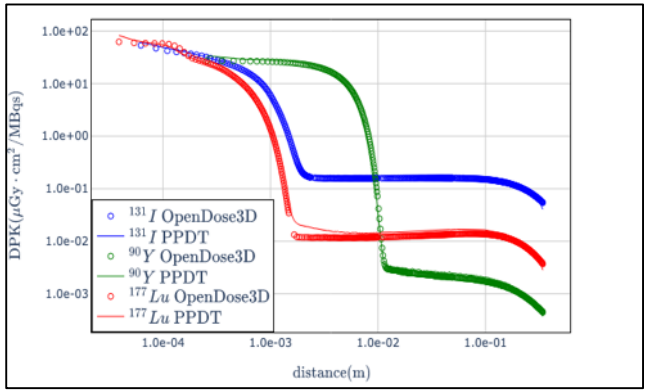
Proposed selection algorithm



M Bardiès & A Gil Vergara, Absorbed dose calculation, in
Dosimetry for Radiopharmaceutical Therapy
IAEA Tech Series, in Press

Absorbed dose calculation algorithms





Local Energy Deposition (LED) w/o Density correction

- Use of ICRP 107 radionuclide emission database (electrons/beta only)

Convolution (VSV)

- Use of GATE 8.2 (all emissions - ion source) to generate DPK in spherical shells with effective radius correction*
- Home-made python script to generate VDK by Monte Carlo integration in selected voxel sizes and material.
- Interpolation of precalculated VDK to real voxel size of NM images
- Possibility to implement density correction

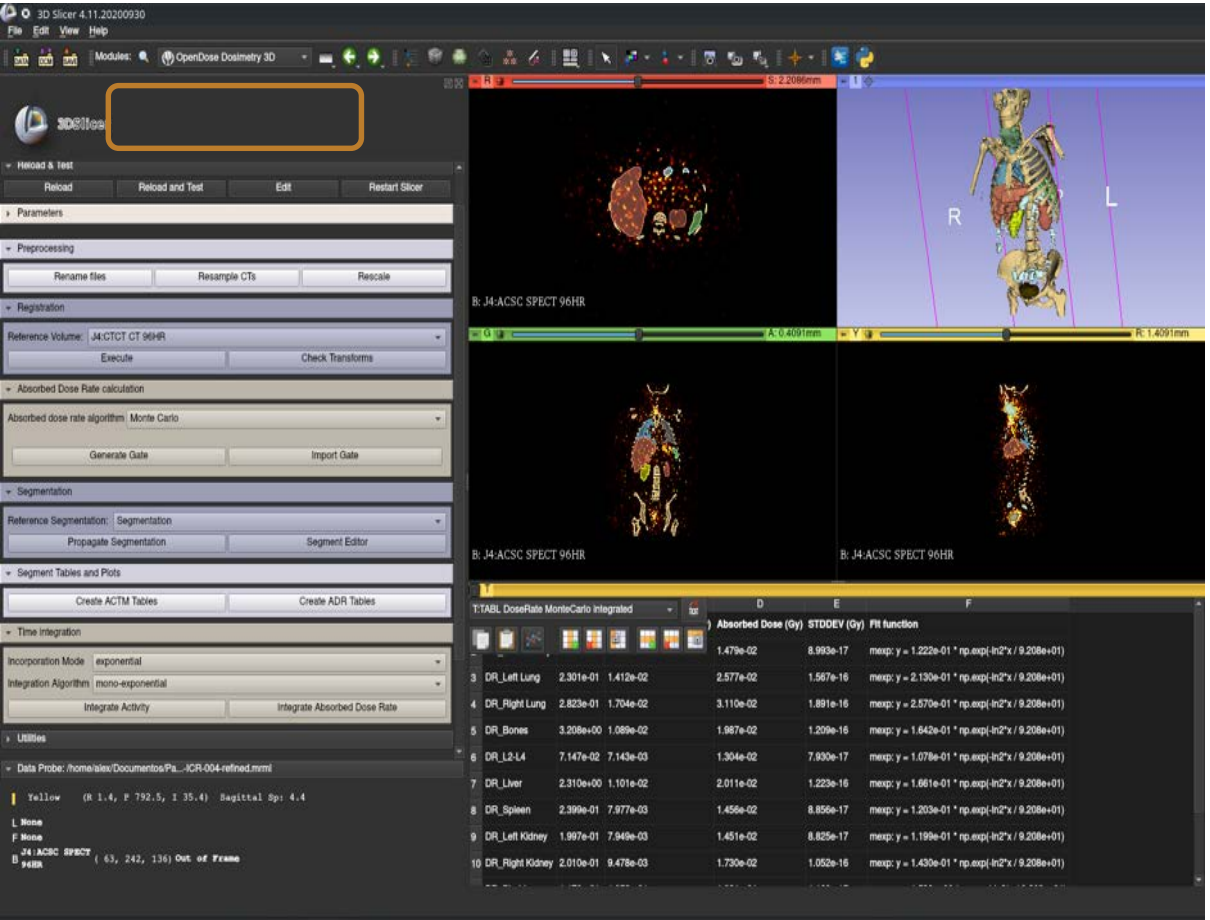
Monte Carlo (MC)

- Generation of GATE macros for simulations (all emissions - ion source)
- Automatic loading of GATE results (with correct path)

Comparison vs data from Papadimitroulas, Med. Phys. 39(8), 2012

*Janicki, Med. Phys. 31(4), 2004

OpenDose3D



Specific developments:

- Data workflow
  - ➔ Saved I/O
- Time integration
  - ➔ ADR
  - ➔ TAC
- Dosimetry algorithms:
  - ➔ Local Energy Deposition (LED)
  - ➔ Convolution (VDK)
  - ➔ Monte Carlo (GATE)

Validation for ^{90}Y (SIRT)

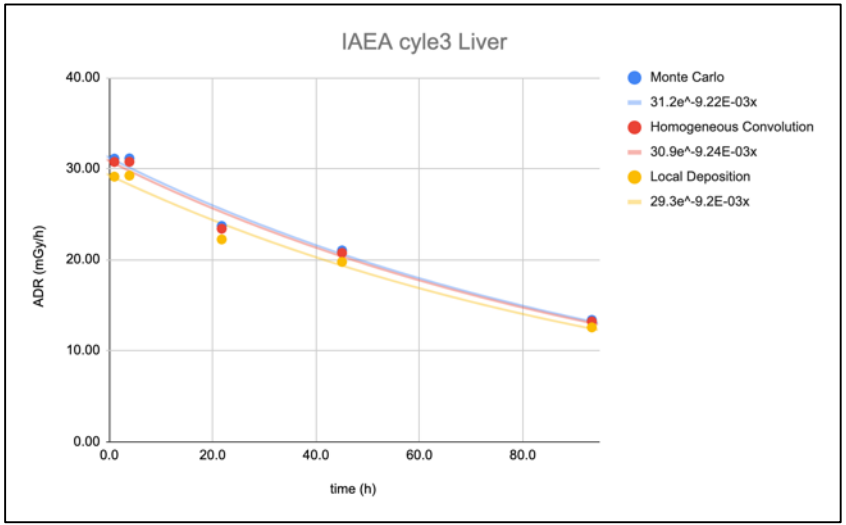
Comparison between OD3D algorithms for a sample clinical case

Absorbed doses (Gy)					
Algorithm	**Liver**	**Liver Perfused**	**Lesion**	**Healthy Liver**	**Healthy Liver Perfused**
LED	**28.90**	**137.70**	**153.60**	**7.22**	**78.60**
Homogeneous Convolution	**30.24**	**143.20**	**159.70**	**7.73**	**82.11**
Heterogeneous Convolution	**29.31**	**138.70**	**153.90**	**7.64**	**82.24**
Monte Carlo	**29.03**	**136.91**	**152.31**	**7.60**	**79.98**

Tested on 5 HCC patients treated by Trans-Arterial Radio-Embolization (Physica Medica 64:245-251, 2019).
Same segmentation applied for all methods. Differences in calculated absorbed doses between algorithms are small, therefore the fastest method (LED) is recommended for this application

Validation for ^{177}Lu (IAEA CRP)

Patient from IAEA CRP Project E2.30.05 on “Dosimetry in Radiopharmaceutical therapy for personalized patient treatment”. Comparison with Dosisoft PlanetDose®



Software	LL	RL	LK	RK	Spleen	Liver	RB
OpenDose 3D	2.64	2.34	36.2	38.1	41.8	29.9	3.51
PDOSE	2.52	2.45	35.2	36.9	40.8	28.8	3.28
Relative diff	-4.5%	4.7%	-2.8%	-3.1%	-2.4%	-3.7%	-6.6%

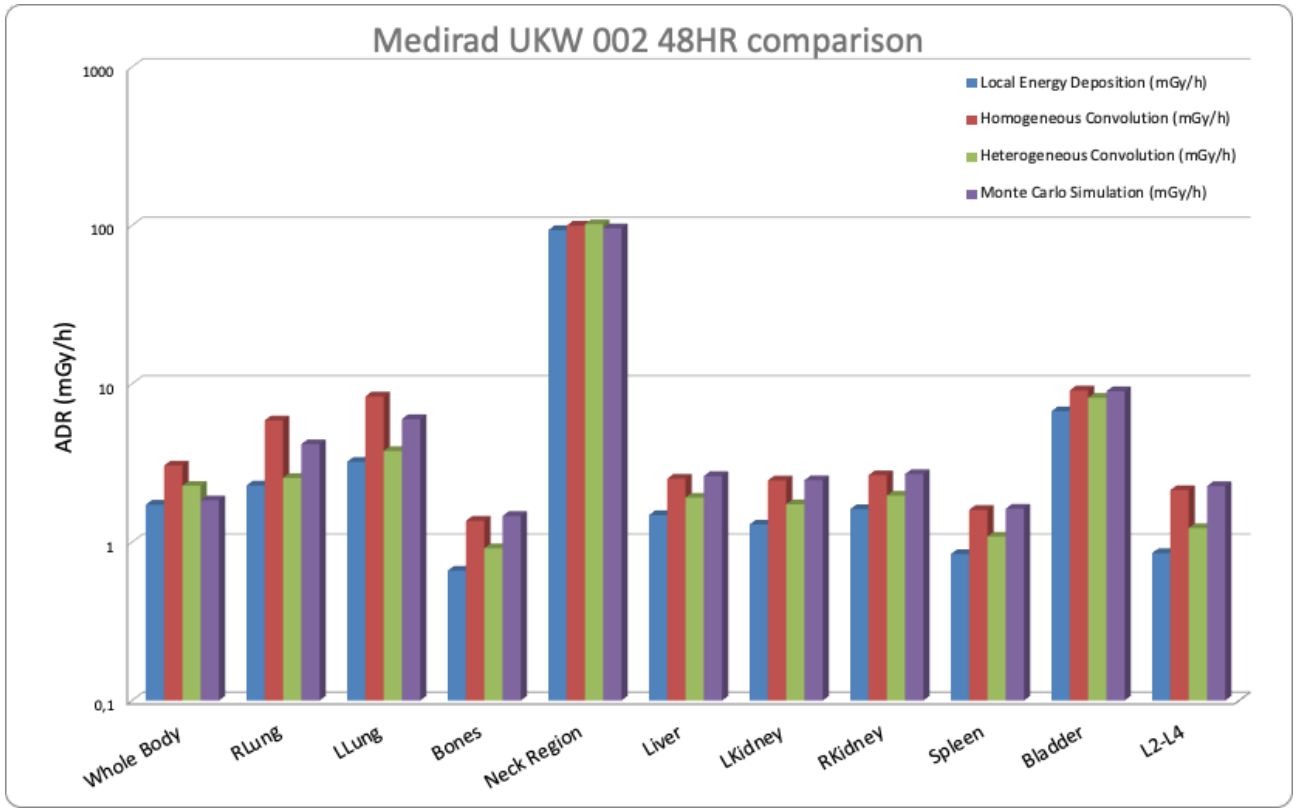
Absorbed dose rates after 1h using LED ***WITHOUT*** density correction (OpenDose 3D is taken as reference) (mGy/h)

Software	LL	RL	LK	RK	Spleen	Liver	RB
OpenDose 3D	7.77	8.66	35.9	37.6	40.8	29.2	3.64
PDOSE	5.08	5.00	35.5	36.9	40.6	28.2	3.42
Relative diff	-34.6%	-42.3%	-1.1%	-1.9%	-0.5%	-3.4%	-6.0%

Absorbed dose rates after 1h using LED ***WITH*** density correction (OpenDose 3D is taken as reference) (mGy/h).

Equivalent results obtained with MiM Sureplan®

Validation for ^{131}I (MEDIRAD)

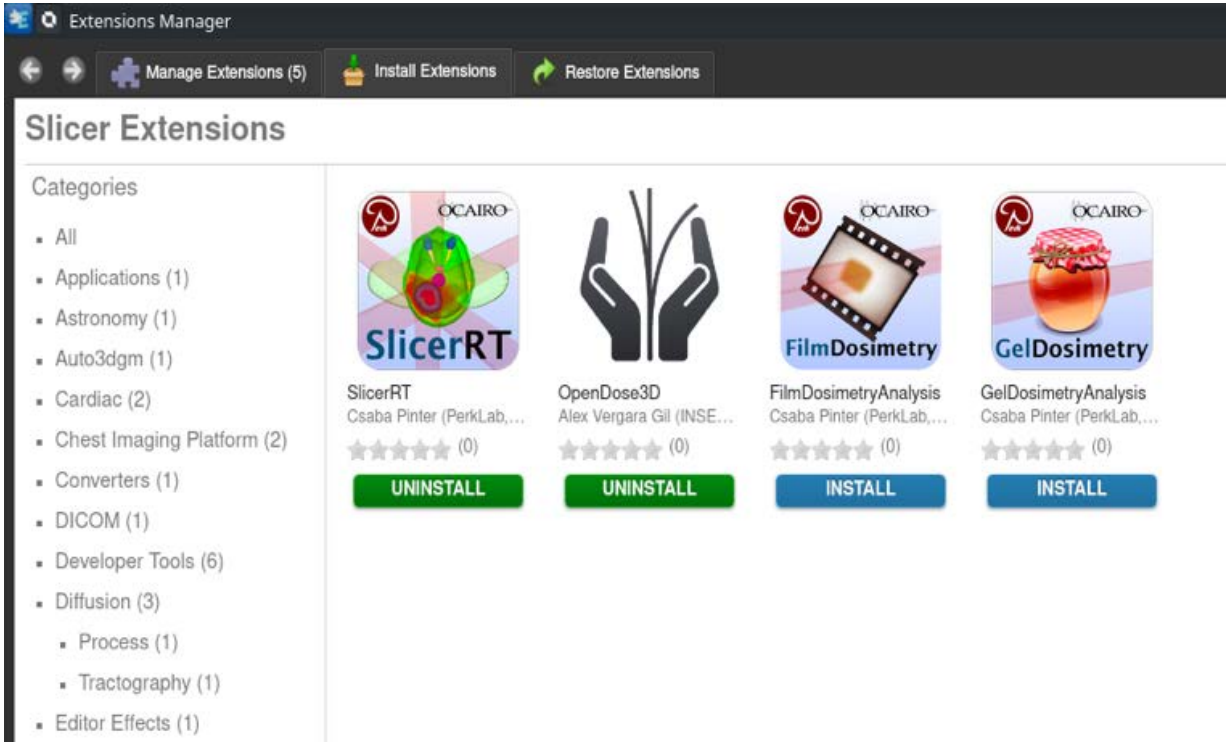


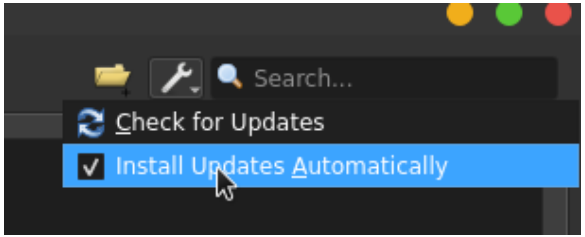
Comparison of ± ADR methods in a Thyroid cancer patient with thyroidectomy and post-therapy with ^{131}I.

Influence of the high gamma contribution.

MEDIRAD

The OpenDose3D Software

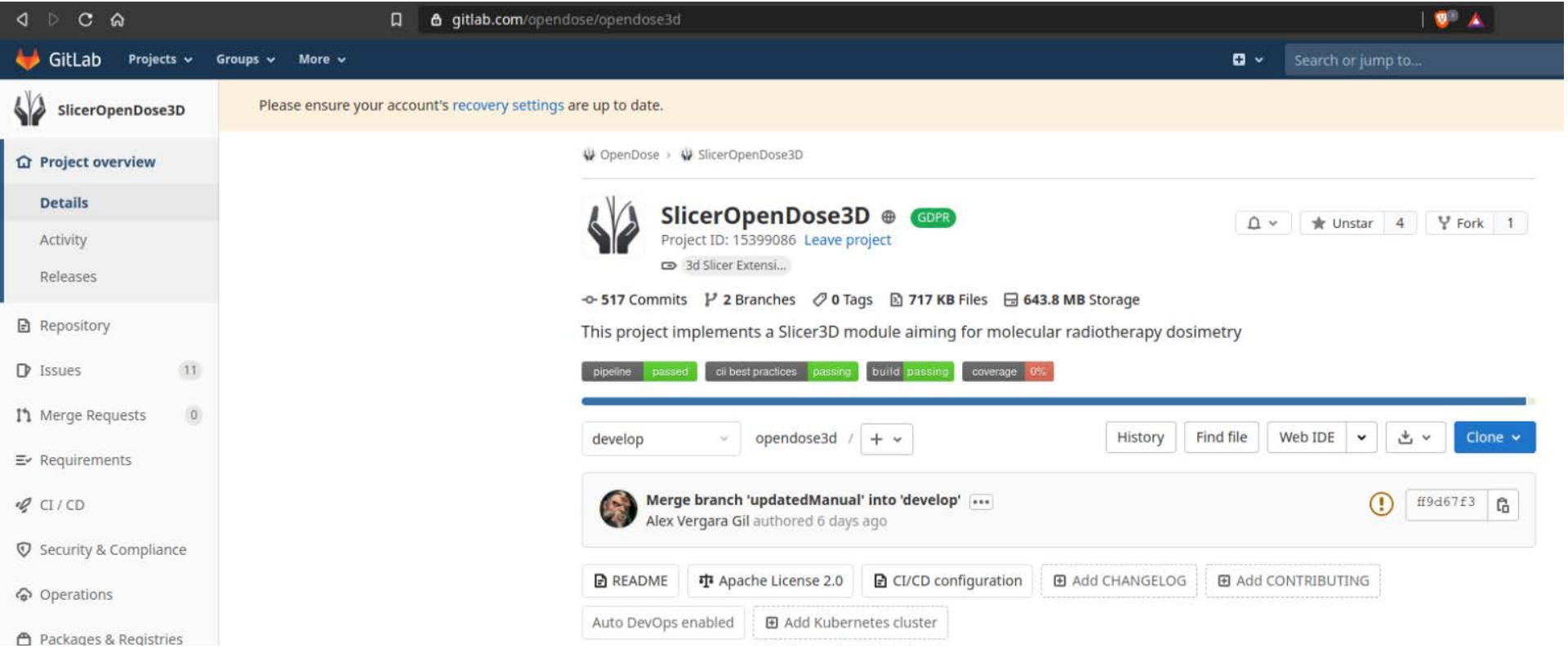




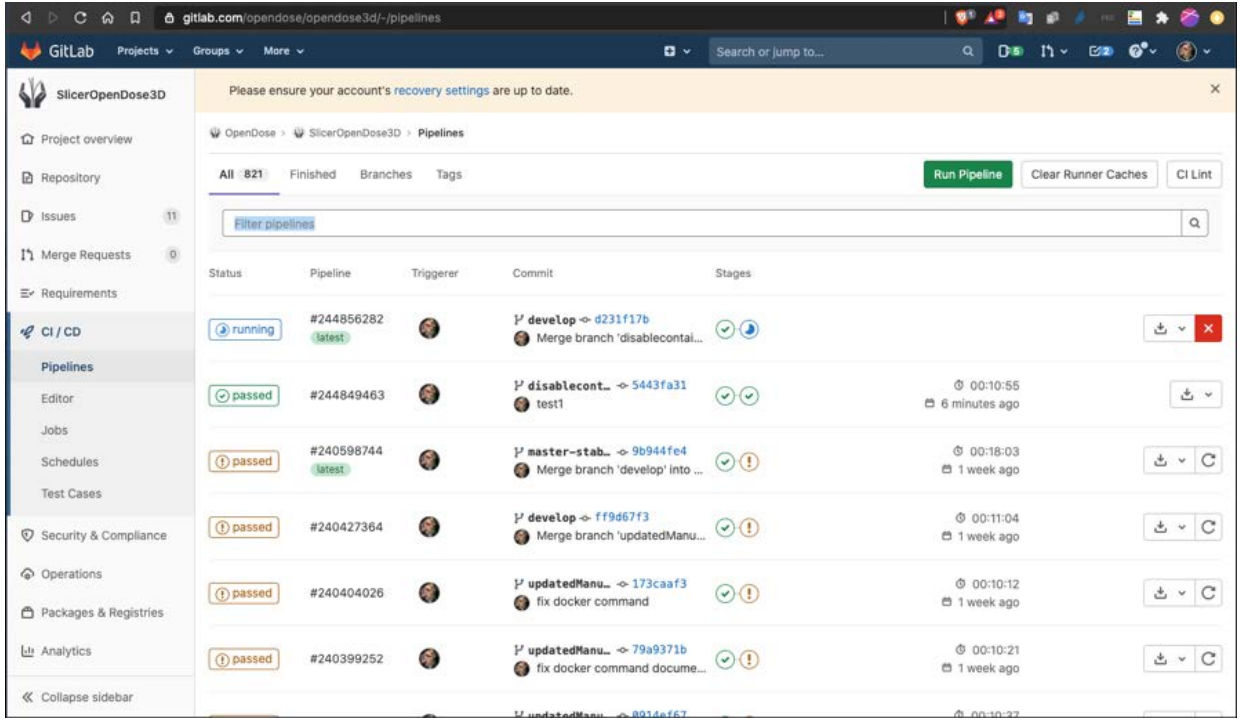
- Integrated into the Slicer official modules under the category of **Radiotherapy**
- Easy update inside the extension manager

The OpenDose3D Software

Fully open source, source available at https://gitlab.com/opendose/opendose3d



The OpenDose3D Software



Full Test suite created for this software covering 100% of the code, it contains data samples from a real patient [1].

Use of gitlab. Tests are automatically executed in every merge.

The tests check that the desired behaviour doesn't change after every modification.

[1] The sample patient data images used were shared as part of *IAEA Coordinated Research Project (CRP) on "Dosimetry in Radiopharmaceutical therapy for personalized patient treatment"(E2.30.05)*.

Conclusions

- OpenDose3D allows users to perform personalised internal dosimetry
- It is NOT and *WILL NOT be* FDA approved/CE-marked
- Designed to allow traceability of the clinical dosimetry workflow (CDW)
- Next steps:
  - Integrating calibration, more time-integration capability (NukFit?),
  - Reconstruction? Needed?
- Need to design (digital) test objects
  - For absorbed dose calculation (easy)
  - For all steps of the CDW (not so easy…)

For further questions please refer to the gitlab page

(https://gitlab.com/opendose/opendose3D) or contact jose.fragoso@inserm.fr

Thank you

EFOMP Special Interest Group on Radionuclide dosimetry

https://www.efomp.org/index.php?r=pages&id=sigs