LEI contribution to:

Nuclear analysis of high power molten target LIEBE at MEDICIS for the production of radioisotopes

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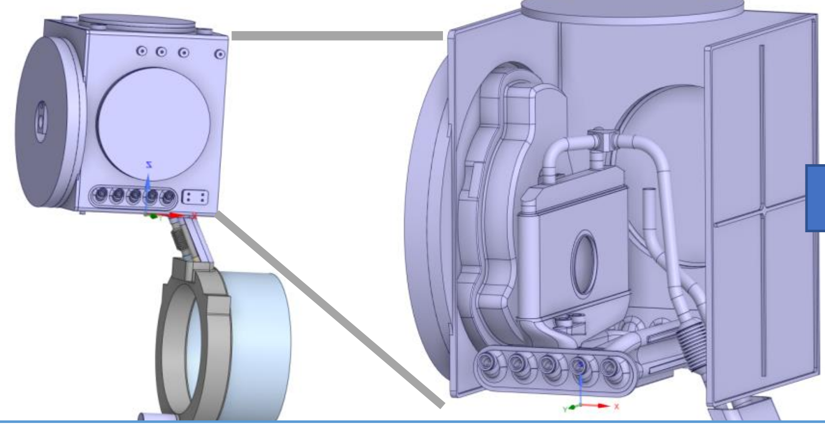
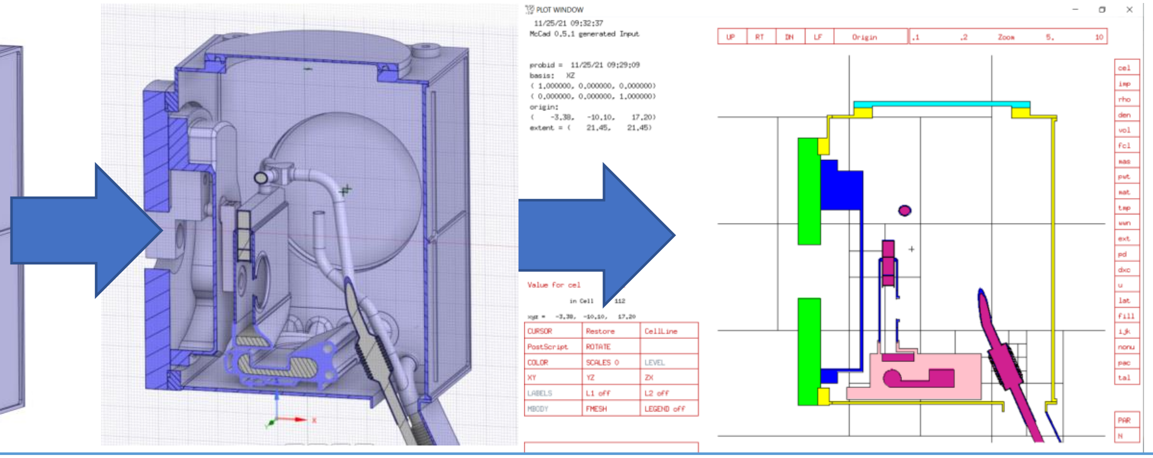
Nuclear analysis of high power molten targets at MEDICIS and ISOLDE for the production of radioisotopes

- CAD to MCNP conversion using McCAD code of LIEBE target.
- Nuclear analysis (proton/neutron/gama) flux, dose, activation etc.

CAD model



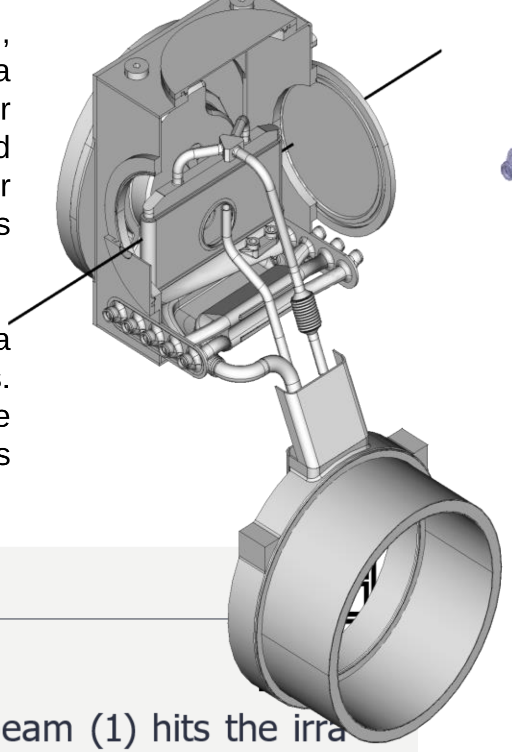
MCNP model



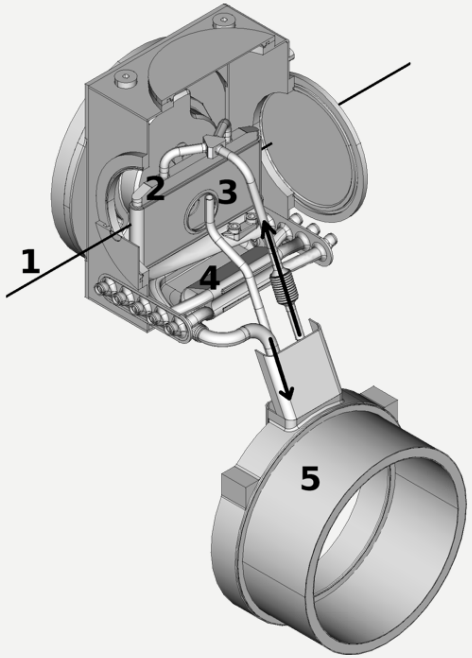
- **LIEBE (Liquid Eutectic Lead Bismuth Loop Target for Eurisol)** is a conceptual prototype liquid metal target for the radioactive ion beam facility EURISOL.
- LIEBE is being developed to create **a high-power beam target** that has a higher yield of **short-lived radioactive isotopes**. At the same time, such a liquid metal target would allow solving the problem of high thermal load because the liquid target could give off excess heat more efficiently with the help of a heat exchanger.
- The prototype **LIEBE is composed of a liquid metal circuit** in which the metal flows through various components of the device and radioactive isotopes are generated in it. LIEBE will use a circuit in which the lead-bismuth eutectic will circulate.
- Circulation will be provided by an external electromagnetic pump. From the pump, the eutectic will flow to another component - an irradiation chamber installed in the circuit, where **the liquid metal will be irradiated with a proton beam**.

- In the irradiated LIEBE target with a proton beam, part of the energy goes to the neutrons and gamma rays generated during the reactions, which transfer it to radiation-sensitive components. The detailed determination of neutron/gamma effects and their impact on the properties of the structural materials of the devices in needed.

- The **CAD** model was successfully converted into a high-detail **MCNP** model to solve these problems. The analysis of particle transport processes in the liquid lead target LIEBE were performed using this MCNP model.



The LIEBE target



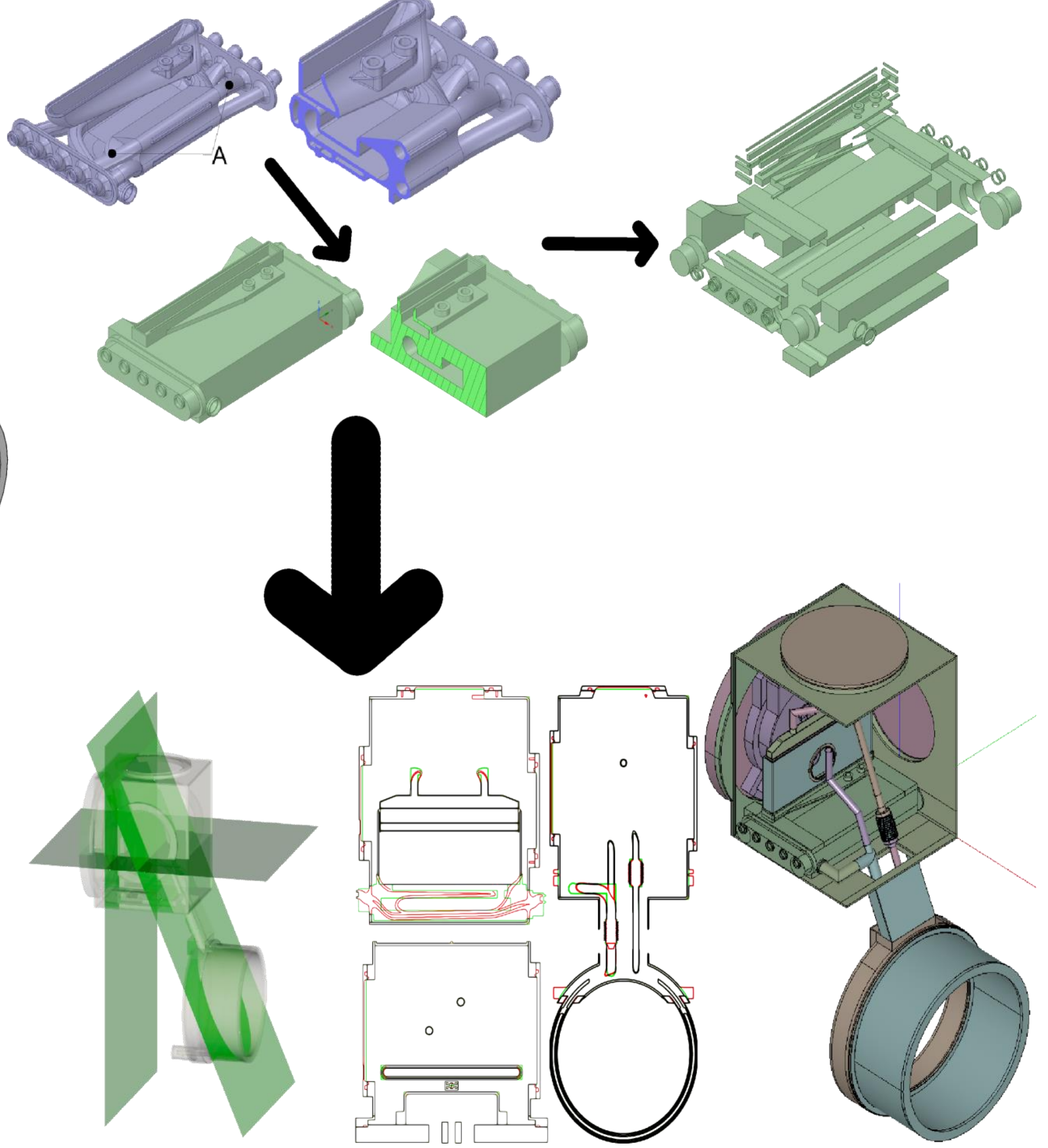
LIEBE - LIquid Eutectic lead Bismuth for Eurisol

1 – Proton beam (1) hits the irradiation chamber (2).

2 – Irradiated liquid lead-bismuth eutectic (LBE) falls through a grid fragmenting it into 0.4 mm diameter droplets, which fall along the height of diffusion chamber (3).

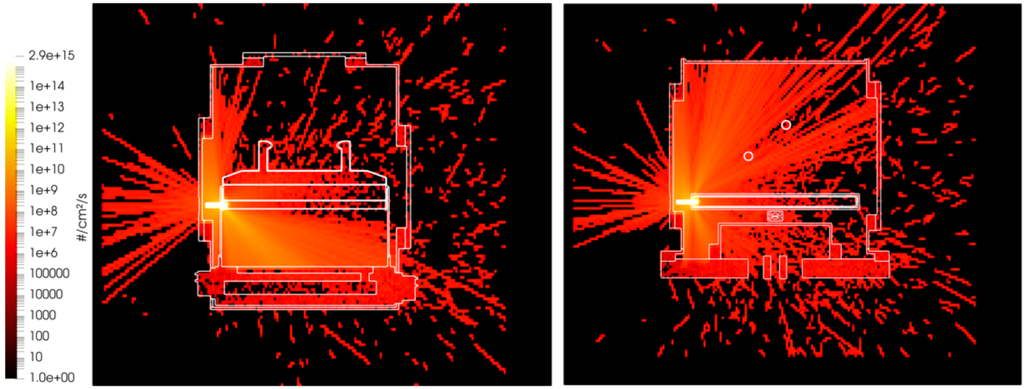
3 – Heat, deposited to the LBE by the proton beam, is removed in the water-cooled heat-exchanger (4).

4 – LBE goes through the EM pump channel (5) back to the irradiation chamber (2).

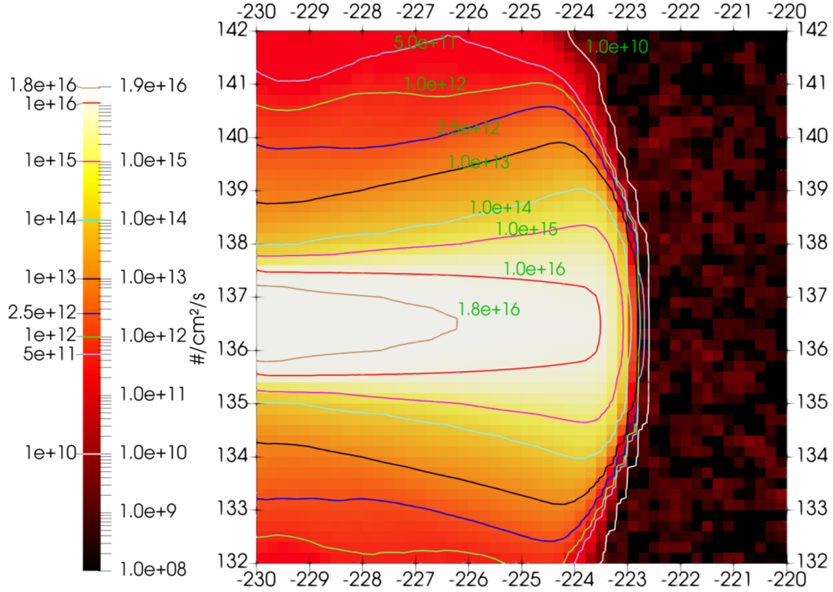


Proton flux in the target

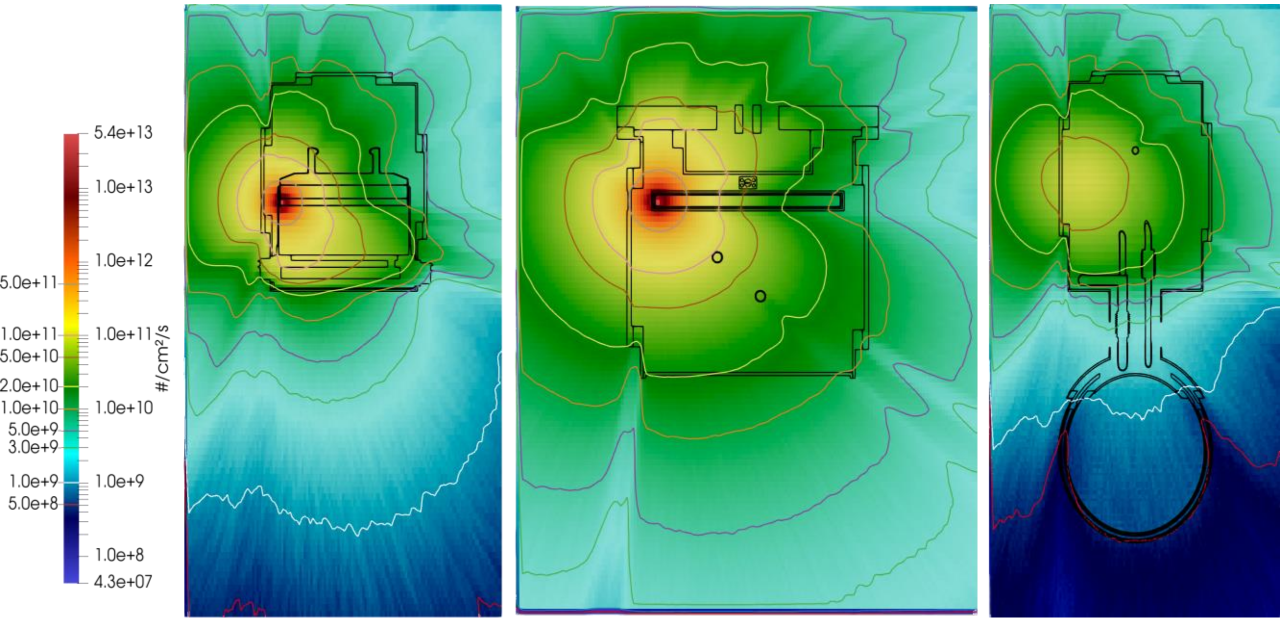
- MCNP Monte Carlo code, FENDL-3.1 cross-section data library, 10^9 number of histories
- 1 mm radii 70 MeV – 100 μA proton beam.



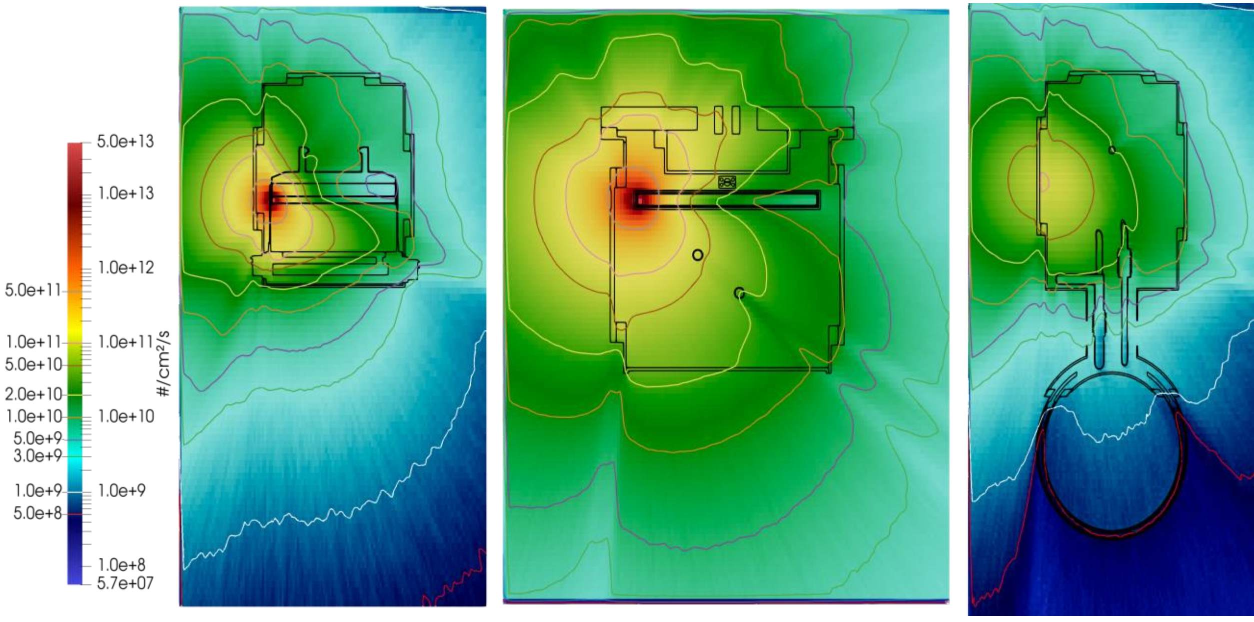
Proton flux in the target



Neutron flux

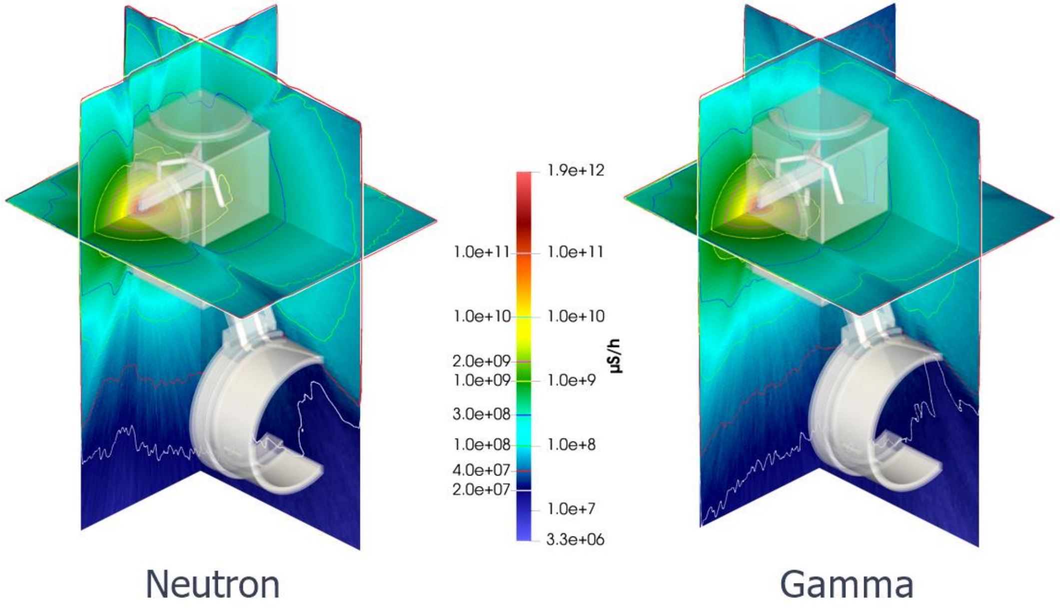


Gamma flux



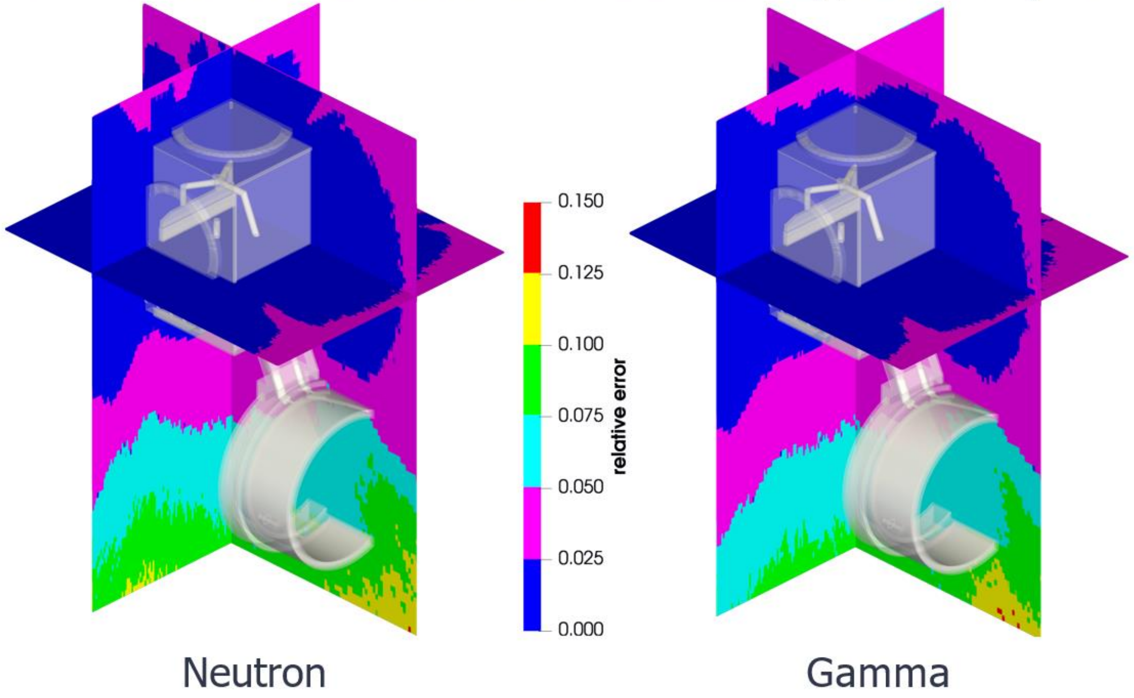
Neutron and gamma induced dose rate distribution

Gamma and neutron dose rates there reach almost 2 MSv/h each. However, around the target dose rates are much lower, around 361 Sv/h for gamma rays and 214 Sv/h for neutrons.



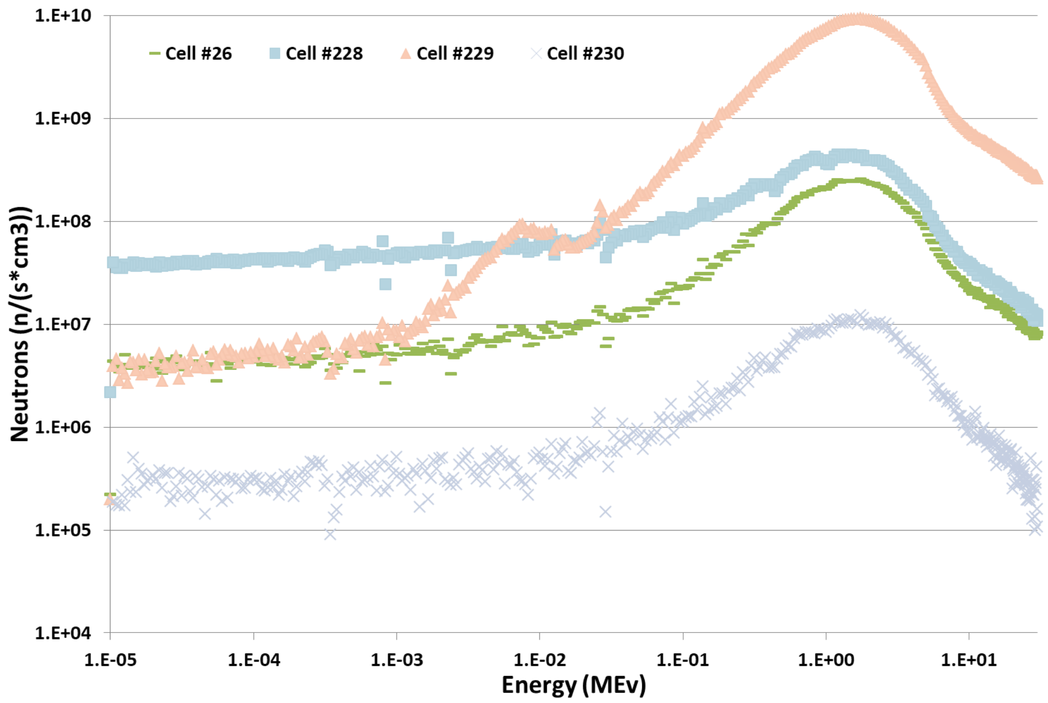
Neutron and gamma induced dose rate relative error

The maximum error for the dose rates reaches approximately 22 %.



- The successful conversion of the LIEBE target to an accurate MCNP model.
- Successful MCNP simulations of the proton induced neutron and gamma flux around the target.
- From the distributions the maximum dose around the target is roughly 361 Sv/h for gamma rays and 214 Sv/h for neutrons.
- The monoenergetic 70 MeV – 100 μA proton beam penetrates roughly 7 mm deep in to the liquid eutectic lead bismuth.
- Obtained neutron distributions allow us to obtain the induced activities in the LIEBE target.
- Based on the obtained fluxes and dose rate maps further changes to the LIEBE target can be evaluated.

Lead Bismuth FISPACT II simulations

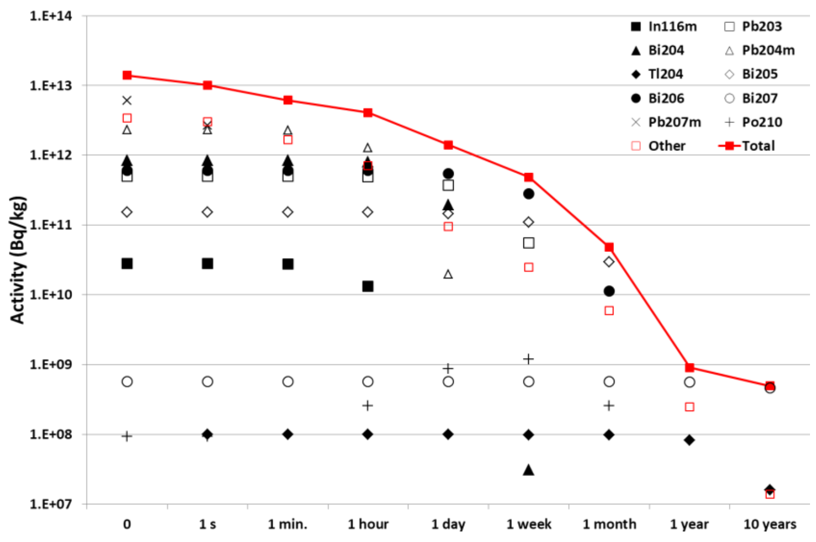


	Cell 26	Cell 228	Cell 229	Cell 230
Volume (cc)	130.13	264.54	117.07	344.12
Density (g/cc)	10.3	10.3	10.3	10.3
Mass (g)	1340.38	2724.74	1205.84	3544.42
Total flux (n/(s*cc))	1.64E+10	4.51E+10	5.15E+11	7.46E+08

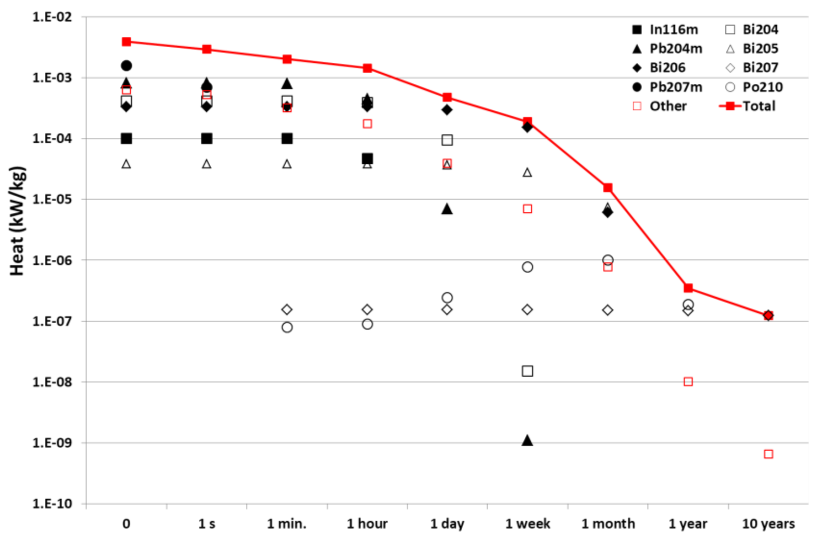
Nuclide	Weight	Atoms (1g)
B10	6.51E-06	3.92E+17
B11	2.62E-05	1.43E+18
Mg24	1.35E-06	3.40E+16
Mg25	1.71E-07	4.13E+15
Mg26	1.71E-07	3.97E+15
Ca40	1.96E-06	2.96E+16
Ca42	2.03E-08	2.91E+14
Ca44	4.05E-08	5.55E+14
Cr50	6.96E-08	8.39E+14
Cr52	1.34E-06	1.56E+16
Cr53	1.52E-07	1.70E+15
Cr54	3.79E-08	4.23E+14
Fe54	4.32E-08	4.83E+14
Fe56	6.84E-07	7.36E+15
Fe57	1.64E-08	1.73E+14
Fe58	2.09E-09	2.17E+13
Ni58	5.79E-06	6.02E+16
Ni60	2.23E-06	2.24E+16
Ni61	9.70E-08	9.59E+14
Ni62	3.09E-07	3.01E+15
Ni64	7.88E-08	7.42E+14
Cu63	4.76E-06	4.55E+16
Cu65	2.12E-06	1.97E+16
Ag107	6.60E-06	3.72E+16
Ag109	6.13E-06	3.39E+16
Cd106	1.39E-08	7.90E+13
Cd108	9.89E-09	5.52E+13
Cd110	1.39E-07	7.60E+14
Cd111	1.42E-07	7.72E+14
Cd112	2.68E-07	1.44E+15
Cd113	1.36E-07	7.24E+14
Cd114	3.19E-07	1.69E+15
Cd116	8.32E-08	4.32E+14
In113	2.03E-06	1.08E+16
In115	4.87E-05	2.55E+17
Sn112	1.98E-06	1.06E+16
Sn114	1.30E-06	6.90E+15
Sn115	6.72E-07	3.52E+15
Sn116	2.83E-05	1.47E+17
Sn117	1.52E-05	7.84E+16
Sn118	4.78E-05	2.44E+17
Sn119	1.70E-05	8.61E+16
Sn120	6.44E-05	3.24E+17
Sn122	9.09E-06	4.57E+16
Sn124	1.15E-05	5.57E+16
W182	8.04E-07	2.66E+15
W183	4.37E-07	1.44E+15
W184	9.41E-07	3.08E+15
W186	8.74E-07	2.83E+15
Pb206	0.10772	3.15E+20
Pb207	0.09878054	2.87E+20
Pb208	2.40E-01	6.96E+20
Bi209	0.5527098	1.59E+21

- LIEBE target material was inputted in atomic mass units
- TEDNL2021 nuclear data database with the 1102 energy groups structure was used for the analysis
- The continuous 1-day irradiation using the MCNP-produced neutron fluxes was considered for the analysis
- Considered time slots for cooldown simulations: 1 s, 1 min., 1 hour, 1 week, 1 month, 1 year, 10 years

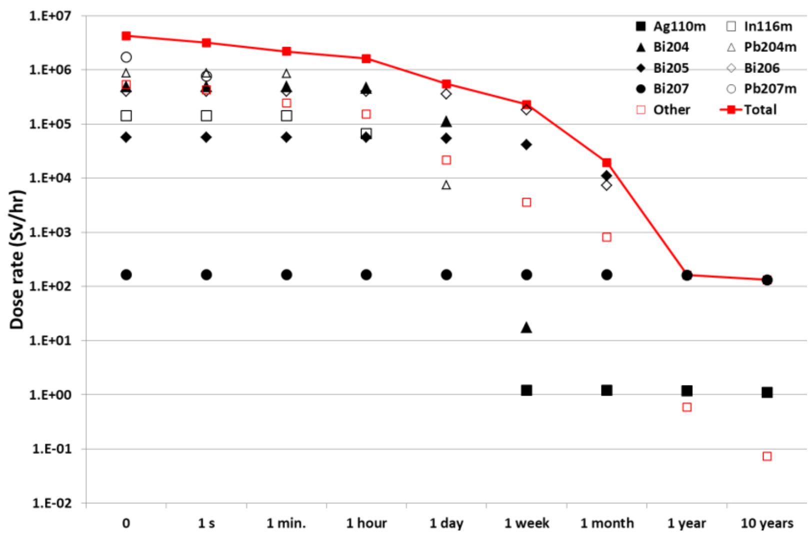
Inventory calculations



- Activities are estimated considering only 1 g of the LIEBE target material.
- Only nuclides that contribute more than 10% of total activity are included in the plots.
- Activities from different cells were weighted according to their mass.
- **Pb204m** and **Pb207m** dominate in the first hour after the irradiation, **Bi206** - in the first week, **Bi205** - in the first month, and **Bi207** - after the year and longer time period.



- Heat is estimated considering only 1 g of the LIEBE target material.
- Only nuclides that contribute more than 10% of total heat are included in the plots.
- Heat from different cells were weighted according to their mass.
- **Pb204m** and **Pb207m** dominate in the first hour after the irradiation, **Bi206** - in the first week, **Bi205** - in the first month, and **Bi207** - after the year and longer time period.



- A dose rate is a contact dose from a semi-infinite slab of the material. Only nuclides that contribute more than 10% of total heat are included in the plots. Heat from different cells were weighted according to their mass.
- **Pb204m** and **Pb207m** dominate in the first hour after the irradiation, **Bi206** - in the first week, **Bi205** - in the first month, and **Bi207** - after the year and longer time period.

Pathways analysis

- Pb207m, half-life – 0.806 s:
  - 36.74% Pb207 99.36% (n,n), 0.64% (n,O) -> Pb207m 100% (IT) -> Pb207
  - 53.72% Pb208 6.2% (n,O), 93.8% (n,2n) -> Pb207m 100% (IT) -> Pb207
  - 1.43% Pb209 82.86% (n,O), 4.44% (n,nd), 4.66% (n,2np), 8.04% (n,t) -> Pb207m 100% (IT) -> Pb207
- Pb204m, half-life – 67.2 min.:
  - 48.52% Pb206 30.55% (n,O), 69.45% (n,3n) -> Pb204m 100% (IT) -> Pb204
  - 26.7% Pb207 89.08% (n,O), 10.92% (n,4n) -> Pb204m 100% (IT) -> Pb204
  - 22.39% Pb208 100% (n,O) -> Pb204m 100% (IT) -> Pb204
  - 1.34% Bi209 100% (n,O) -> Bi204 100% (b+) -> Pb204m 100% (IT) -> Pb204
  - 0.94% Bi209 100% (n,O) -> Pb204m 100% (IT) -> Pb204

NOTE 1: (n,O) - spallation-evaporation reaction. When the incident neutron energies climb above the thresholds of 30 MeV range, a surprising number of multi-particle and spallation reactions become available. These reactions suffer from rarely possessing any experimental measurement and near total absence from the major nuclear data libraries. The total reaction is processed as (n,O) in the FISPACT II.

NOTE 2: Weights are averaged according the cell masses.

- Bi206, half life – 6.2143 days:
  - 99.69% Bi209 18.56% (n,4n), 81.44% (n,O) -> Bi206 100% (b+) -> Pb206
- Bi205, half life – 15.3125 days:
  - 99.98% Bi209 100% (n,O) -> Bi205 100% (b+) -> Pb205m
- Bi207, half life – 32.978 years:
  - 99.98% Bi209 86.13% (n,3n), 13.87% (n,O) -> Bi207

Future works

- Corrections to the MCNP input.

- -- it is necessary to round the corners at the irradiation chamber
- -- inside the irradiation chamber, we assume that the places where the grid is located can be changed to lower density steel
- -- at present, where we have a diffusion chamber, there is simply argon, but theoretically there must also be drops of lead, so we suggest to make a certain mixture of lead and argon inside the diffusion chamber.

- Activity, dose rate, decay heat and energy distributions at different proton beam energies and different target materials.

- Changing of BiPb to La (Lanthanum) eutectics (i.e. AgLa, AuLa, NiLa) determination, isotope production, neutron-gamma shielding/activation calculations under 70 MeV proton beam operation in ISOLDE/MEDICIS

Publications

- Dose rate maps of LIEBE target employing Monte Carlo code MCNP B. Togobickij, M. Povilaitis, A. Slavickas, G. Stankunas, T. Stora, V. Barozier, International Conference on Individual Monitoring of Ionising Radiation (IM2022) and Neutron and Ion Dosimetry Symposium (NEUDOS-14), 25-29.04.2022 Kraków, Poland
- CYSENI @ LEI (1 contribution)
- 2nd CERN Baltic Conference (CBC 2022) (2 contributions)
- Togobickij B., M. Povilaitis, A. Slavickas, Th. Stora, V. Barozier, G. Stankunas, Nuclear analysis of high-power LIEBE molten target at CERN for the production of radioisotopes, **Applied Science**, 2022, **accepted**

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