Numerical optimization of radiation shielding of target used for production of ^{18}F

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NICA accelerating complex: problems and solutions - 2018

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БЪЛГАРСКА АКАДЕМИЯ на НАУКИТЕ 1869

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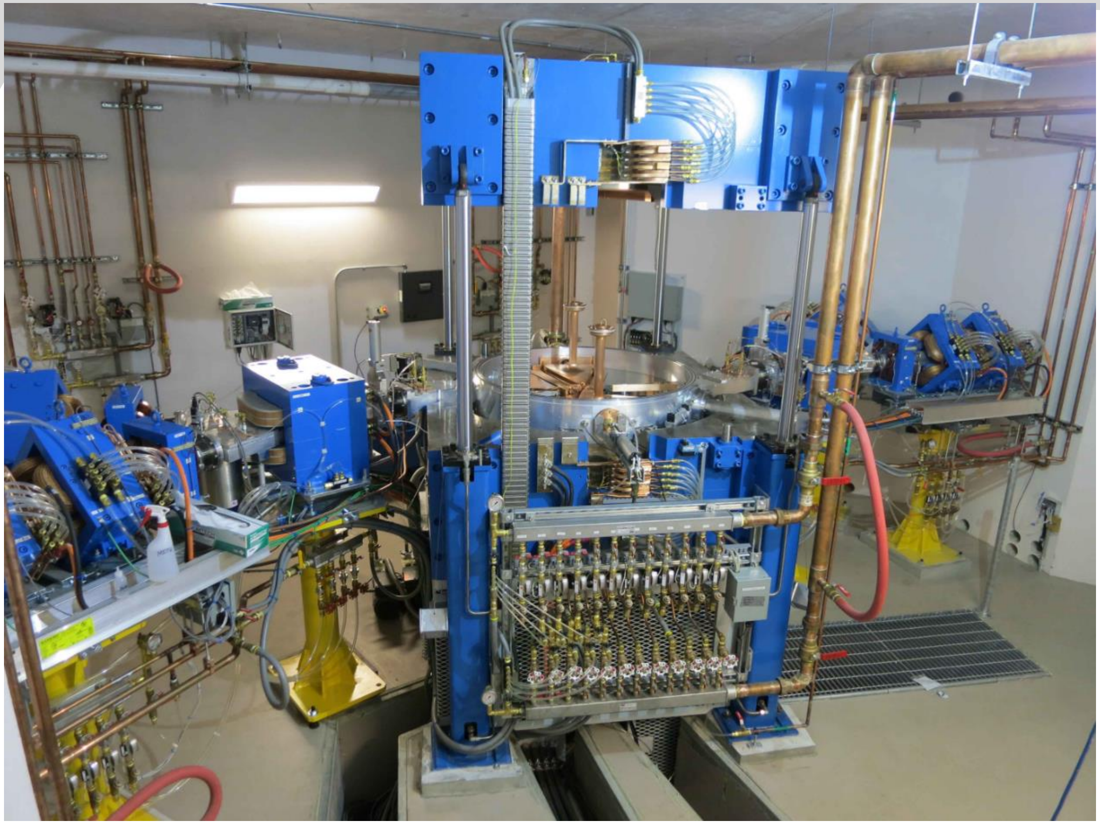


TR24 Cyclotron parameters:

- ACSI, Vancouver, Canada
- Beam Energy: 15 – 24 MeV
- Beam Current: 400 μA
- Upgradeable to 1 mA

PET: ^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{124}I, ^{64}Cu, ^{68}Ge

SPECT: ^{123}I, ^{111}In, ^{67}Ga, ^{57}Co, ^{99m}Tc

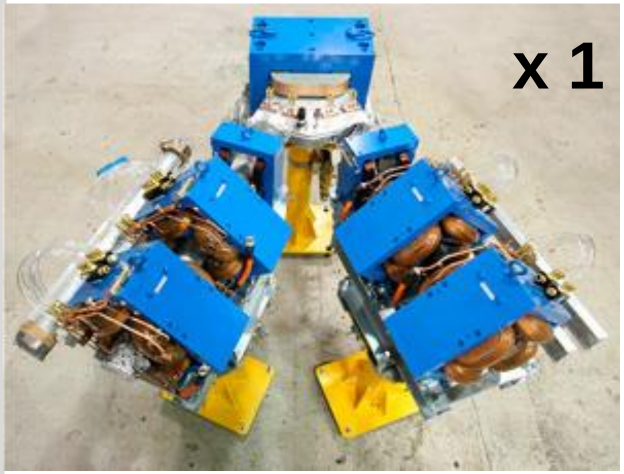
Cyclotron Physics laboratory current status:

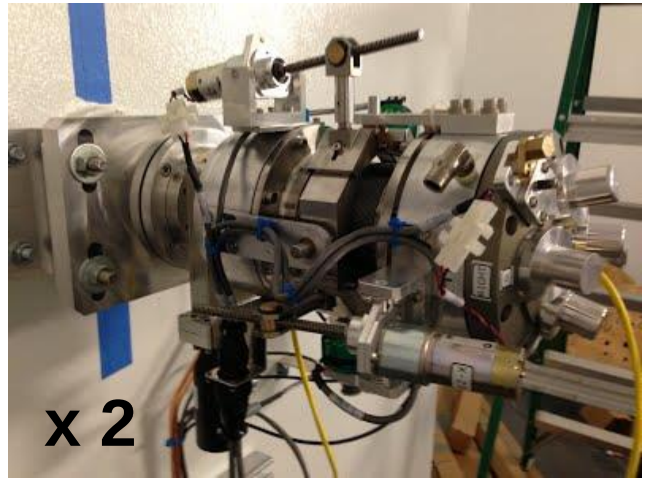
» cyclotron successfully delivered - 12.01.2016

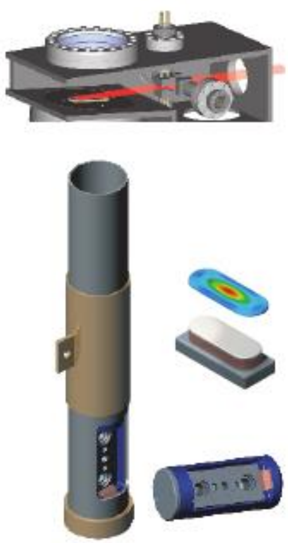
» cyclotron center building has to be build

» current research activity - numerical studies on the possibilities to produce various medical isotopes; radiological characterization of the setup.

Beamlines, targets and target stations for PET&SPECT radioisotopes







Radiological characterization

Evaluate internal hazards:

- Nuclides in target body
- Define nuclides expected to be produced over the operation time of the machine and the vault
- Check vault radiation specs w.r.t. neutrons and gamma rays
- Define cooling time - short lived nuclides (airborn ^{41}Ar?)
- Check operators dose rate

Monte-Carlo approach

FLUKA used for simulations

Radiological characterization

- Emission and transport of secondary particles due to primary nuclear reaction
  - low energy neutron transport
  - takes into account the geometry of the impinging beam (e.g. point source)
- Assessment of the produced residual nuclei
- Possibility to score the same physics process at different irradiation & cooling times
  - buildup and decay of waste

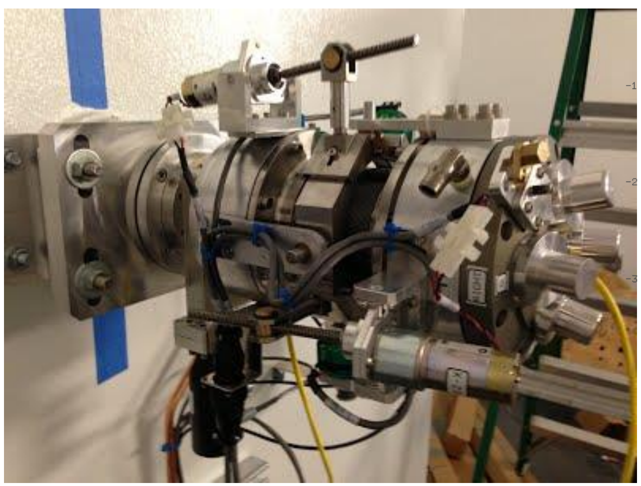
- Not possible to include missing X-section libraries

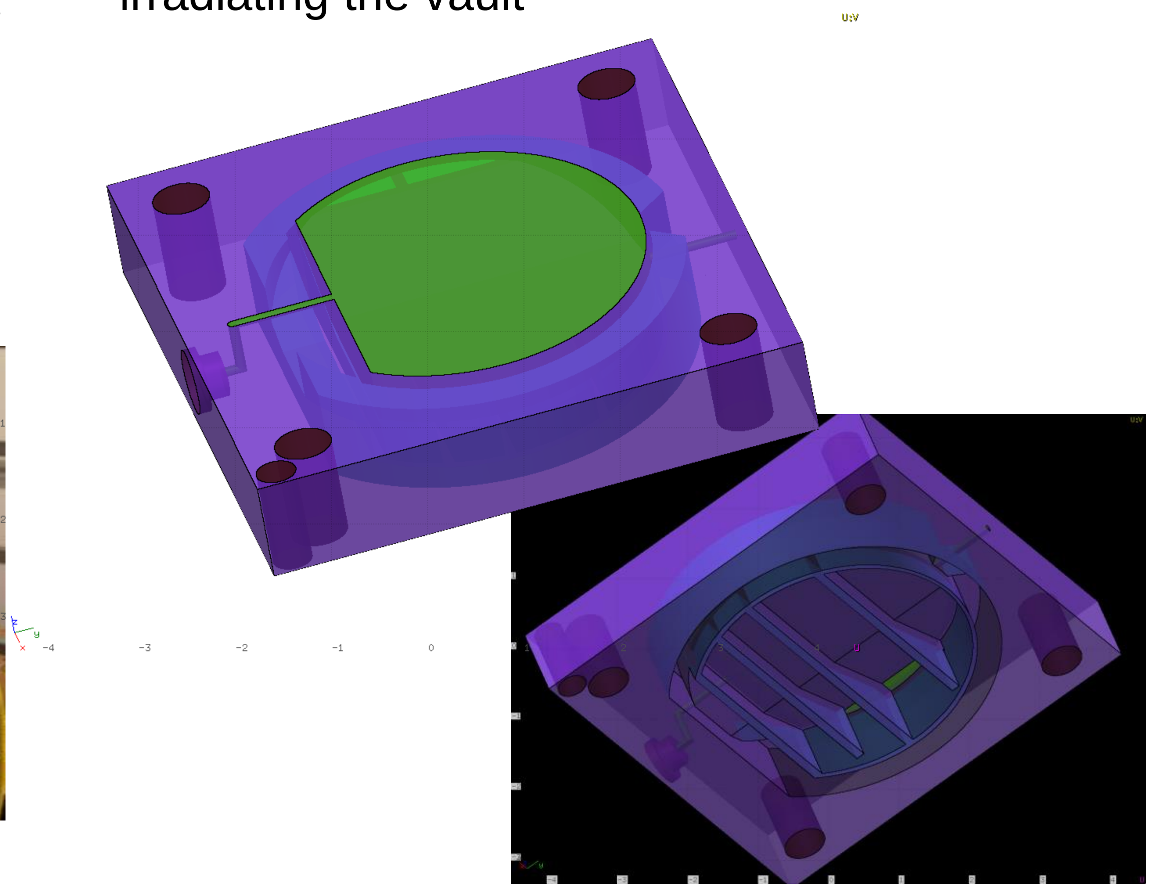
Two-step approach to estimate fluence/waste within the vault

- Simulate target irradiation, assess secondary particles
  - (p, n), (p, γ)
- Use secondary particles as source irradiating vault components

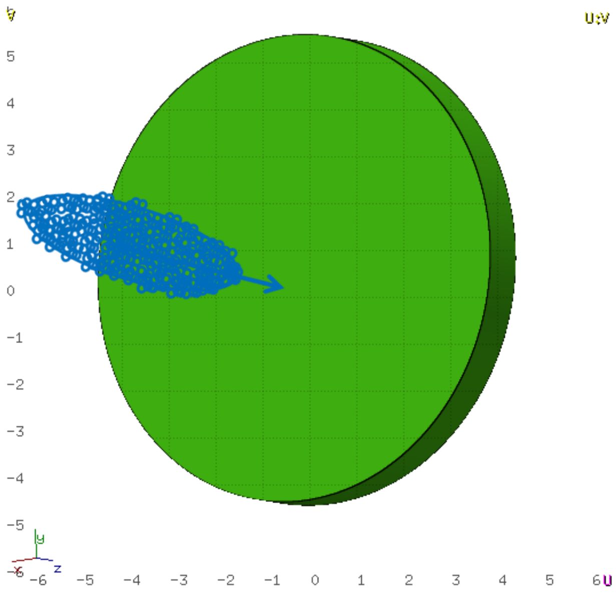
^{18}F high-current liquid target

- Delivered 3.8 mL targets
- Check thick target yield in $^{18}O(p, n)^{18}F$
- Pipe secondary particles to be used as source irradiating the vault

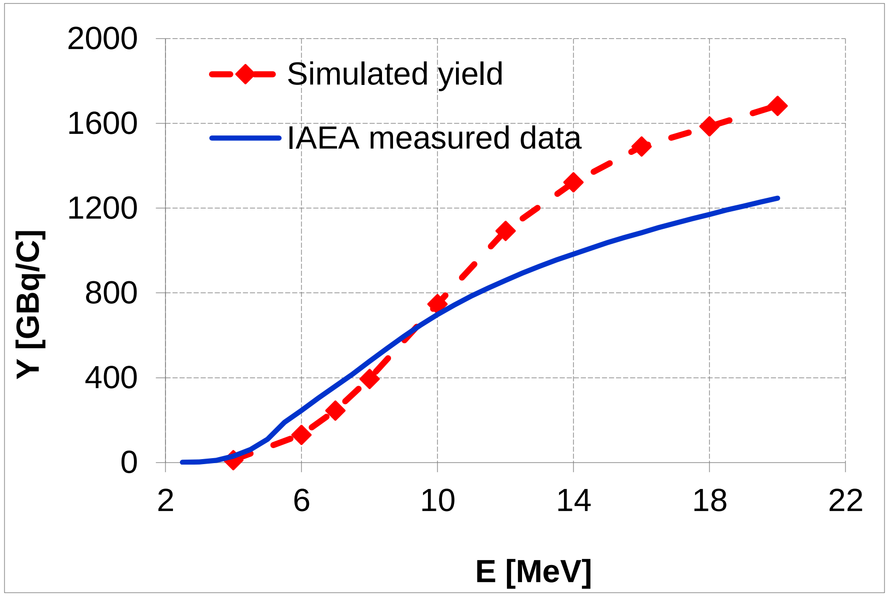




Check the FLUKA Monte-Carlo methodics



A proton beam (various E, fixed I) impinges on a simple target



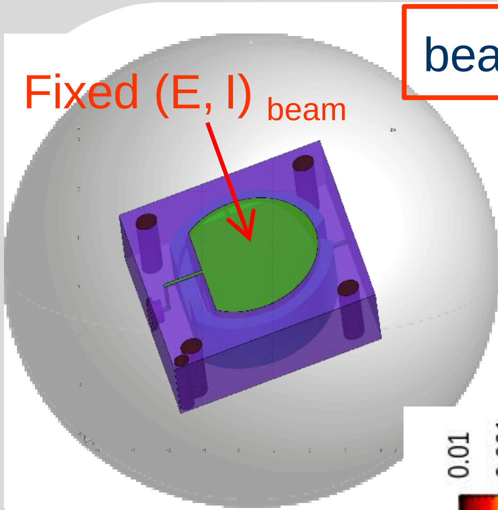
Thick target – the reaction takes place with the volume of enriched water.

The lower the beam energy, the better the agreement:

» Real beam not gaussian in any plane, not point-like, no experimental data on phase space

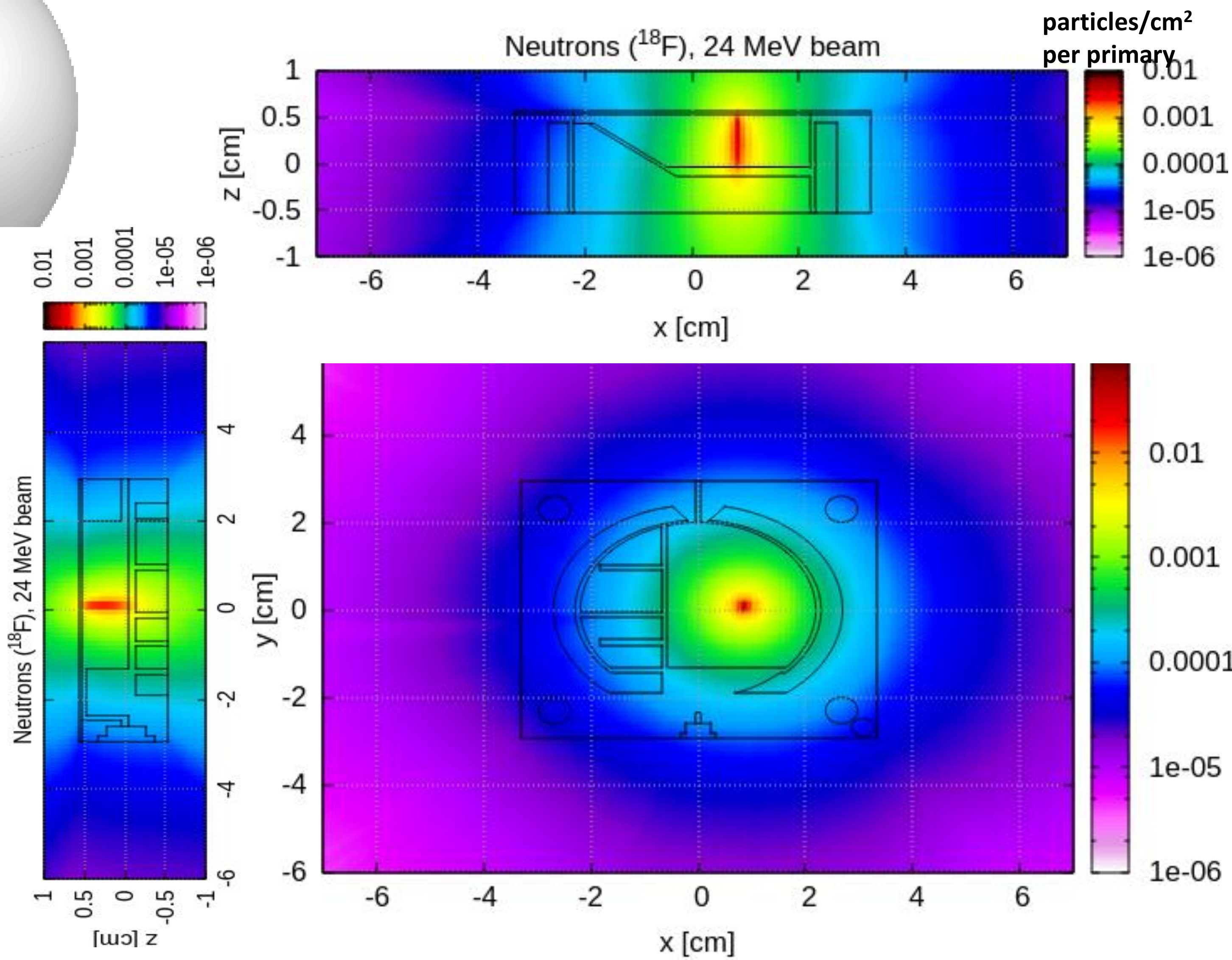
» The FLUKA model is limited in terms of energy

Secondary particles – real target: density distribution

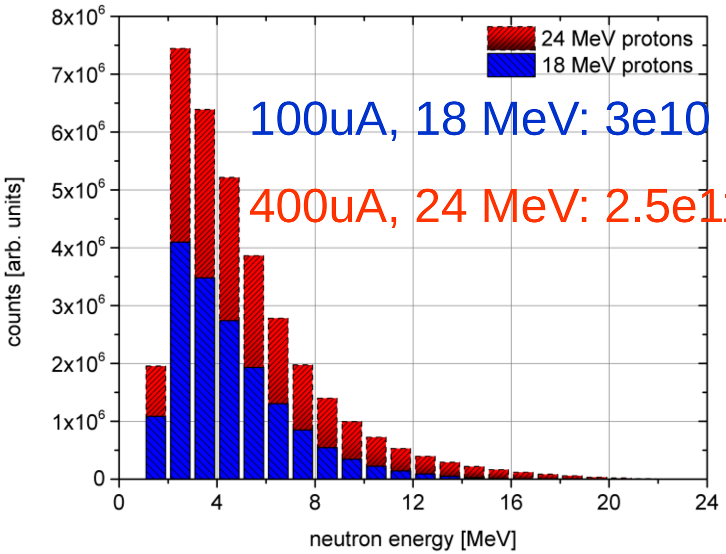


beam orientation w.r.t. target

rate of emission of secondaries

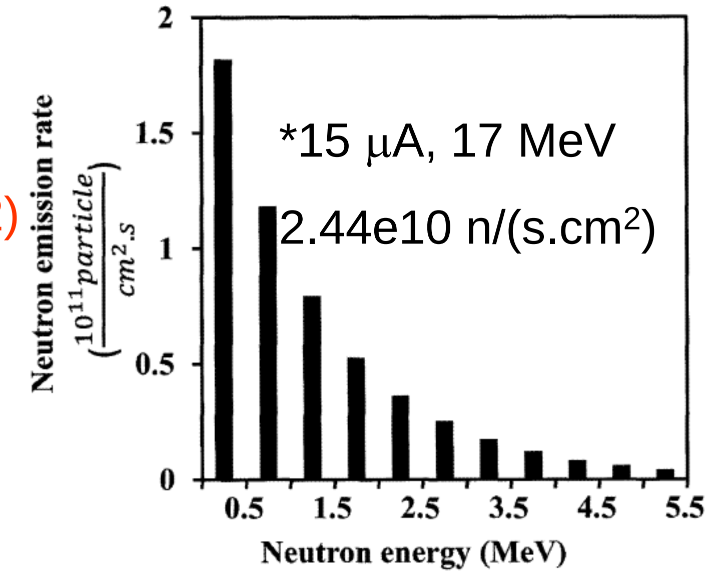


Secondary particles – real target: energy spectrum



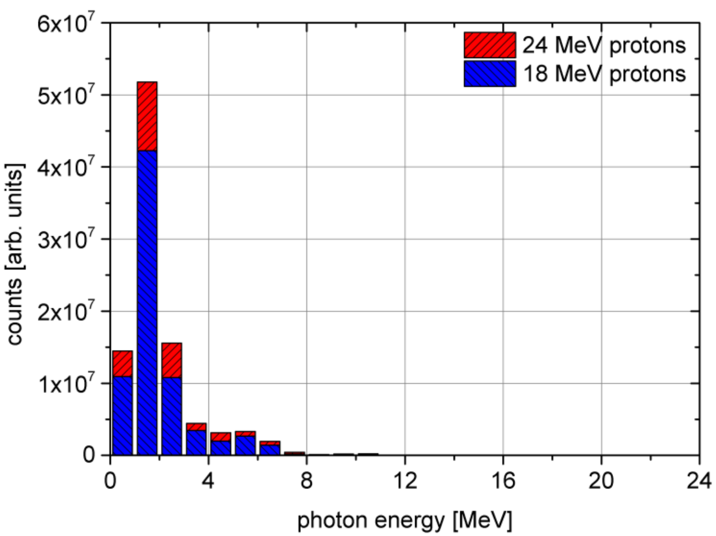
100uA, 18 MeV: 3e10 n/(s.cm^2)

400uA, 24 MeV: 2.5e11 n/(s.cm2)



*15 μA, 17 MeV

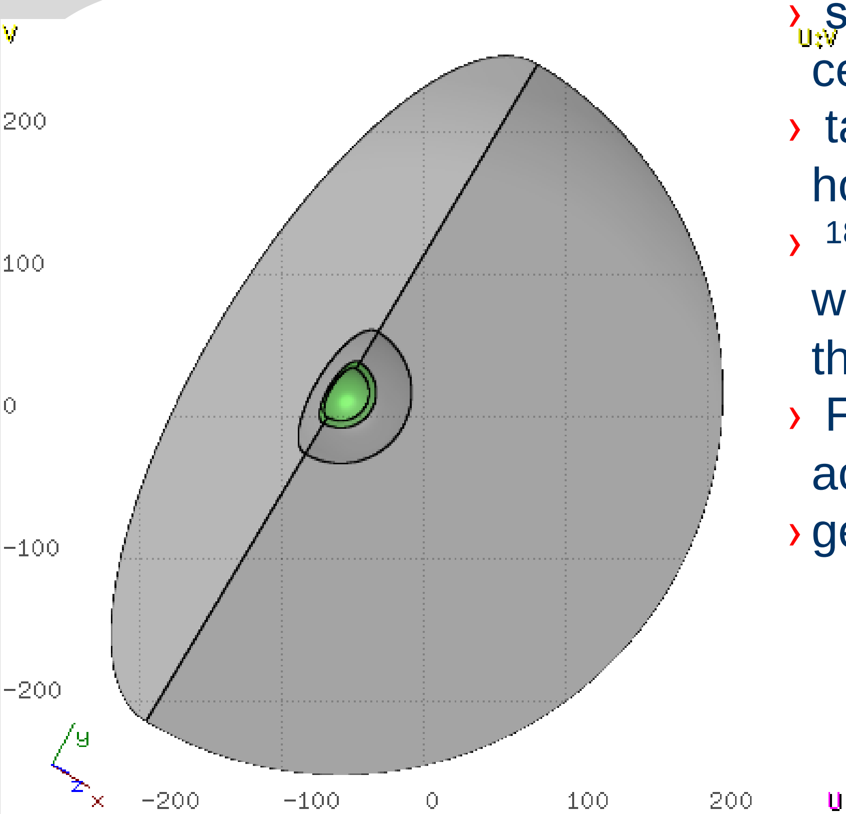
2.44e10 n/(s.cm^2)



*Sadat-Eshkevar et al, Assessment of the staff absorbed dose related to cyclotron operation and service in the production of ^{18}F radiopharmaceuticals, *Nukleonika 2012; 57 (3):407-410*

Neutron and gamma spectra for two different proton beam energies. The secondary particle count is scored in a 4-π volume surrounding the target.

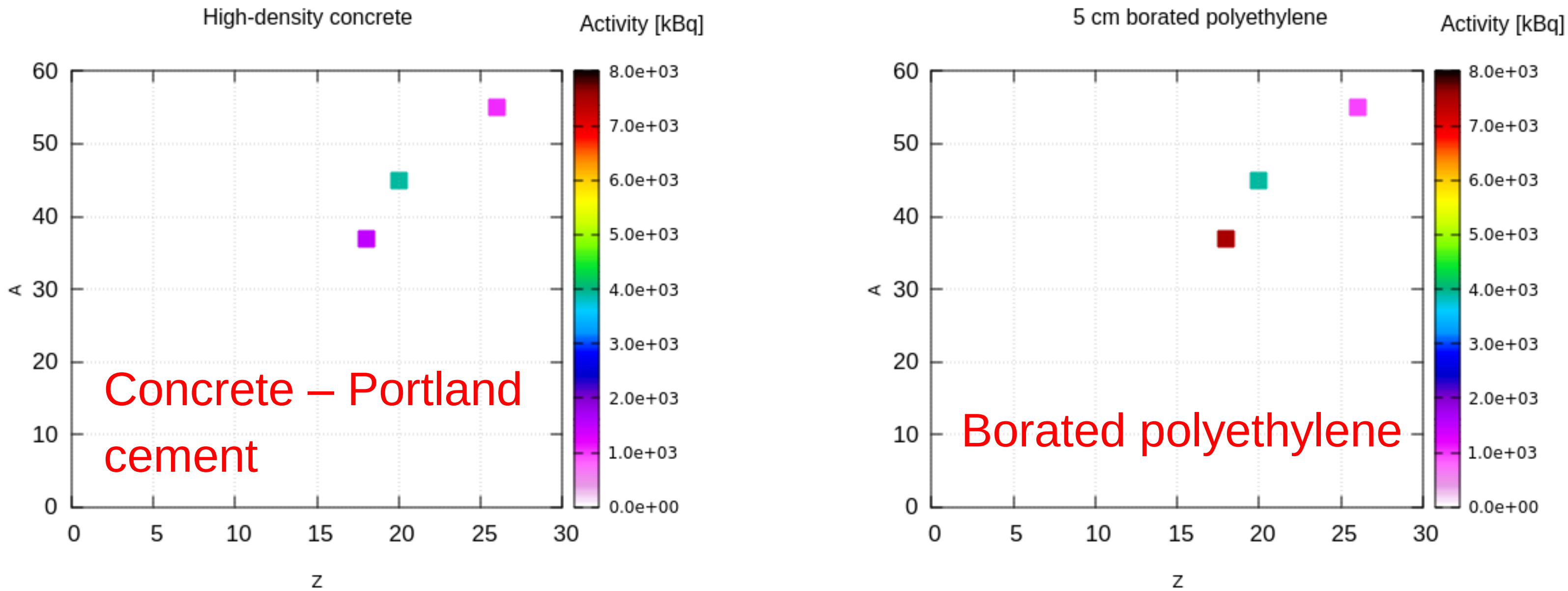
Description of the volume



- source of secondary particles → geometrical center
- target material irradiation → one month, six hours daily, five days per week
- ^{18}F-target, neutrons emitted → scored and written in files → neutron source irradiating the vault
- FLUKA → particle transport; nuclides' activities
- geometry:
  - at the center → sphere R = 20 cm (air)
  - spherical shell with thickness of 250 cm:
    - innermost layer 5 cm;
    - second layer 25 cm;
    - second and third shells → concrete with Portland cement

- Two cases of chemical composition of the innermost layer: concrete with Portland cement, borated polyethylene.
- preliminary results
- worst case scenario: target and local shielding close to the vault walls

After a month of cooling



›Nuclides in the first concrete layer for the two cases without (left) and with borated polyethylene local target shielding.

Results and discussion: Nuclides in concrete layer behind shielding

Activities in [Bq] of some of the nuclides generated in the first 25 cm thick layer behind the shielding. The borated polyethylene layer here has thickness of 5 cm.

Isotope	High-density concrete	Borated polyethylene	Parent nucleus
^{55}Fe	1.0×10^{6}	9.4×10^{5}	^{55}Mn
^{45}Ca	3.9×10^{6}	3.9×10^{6}	^{44}Ca
^{41}Ca	472	491	^{40}Ca
^{39}Ar	3264	2164	^{39}K
^{37}Ar	1.5×10^{6}	7.5×10^{6}	^{40}Ca

Independently from the chemical composition of the innermost shielding, all three cases show similar levels of activities for the nuclides seen.

Summary

- The distribution of radionuclides outside of a local target shielding within a vault of a low-energy high-intensity cyclotron with application in the field of nuclear medicine was evaluated using Monte-Carlo simulations.
- Preliminary results showing that taking into account the activity of long-living nuclides a layer of 5 cm is preferable over no shielded high-density concrete but it is not sufficient.
- Possible next steps are: changing the concrete recipe with one containing marble (e.g. reduced content of Si); studying the effect of changing the position of the borated polyethylene layer within the vault wall; and optimizing the thickness of the local shielding.

Thank you for the attention!

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