SIMULATION OF THE LIQUID TARGETS FOR MOLYBDENUM-99 PRODUCTION

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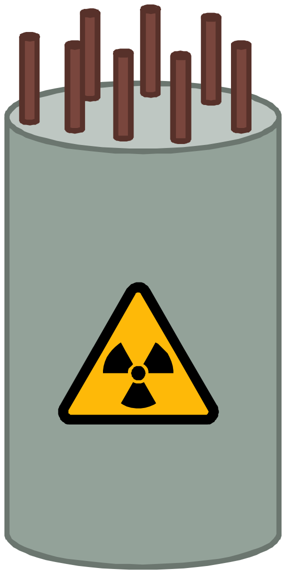
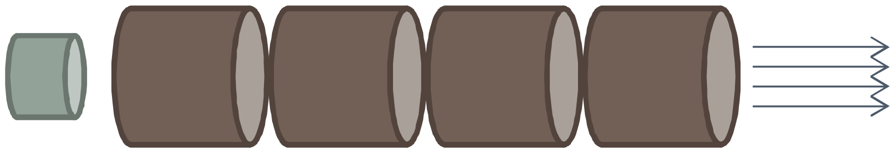
^{99}Mo/^{99}Tc Production Technologies





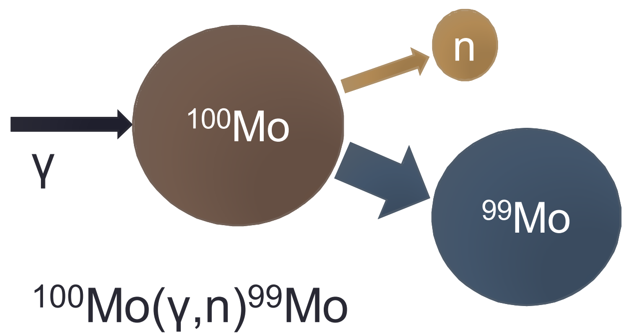
Research Reactor

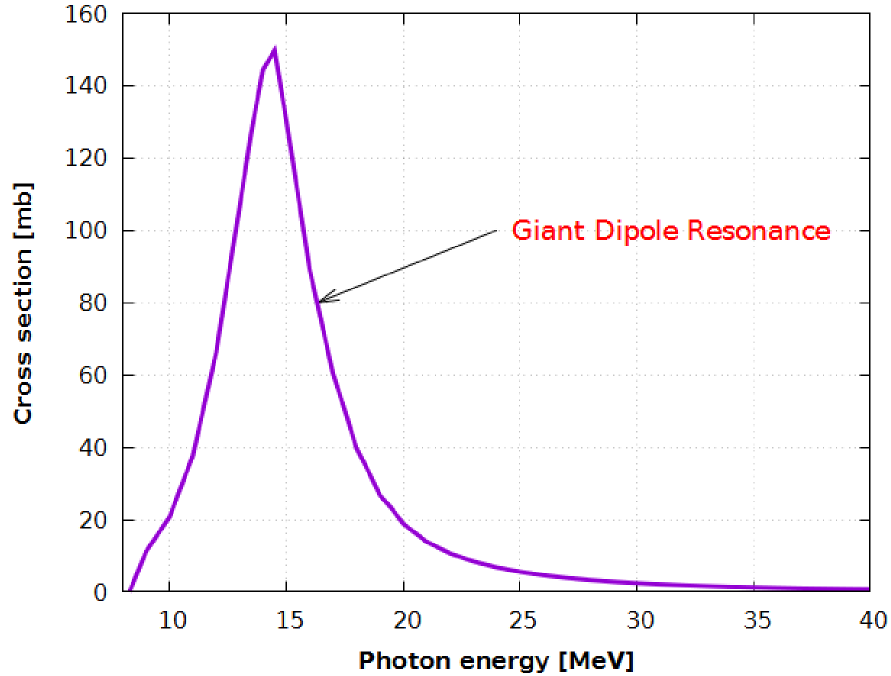
^{235}U(n,fission)^{99}Mo	35 b
^{98}Mo(n,γ)^{99}Mo (experimental)	0.14 b

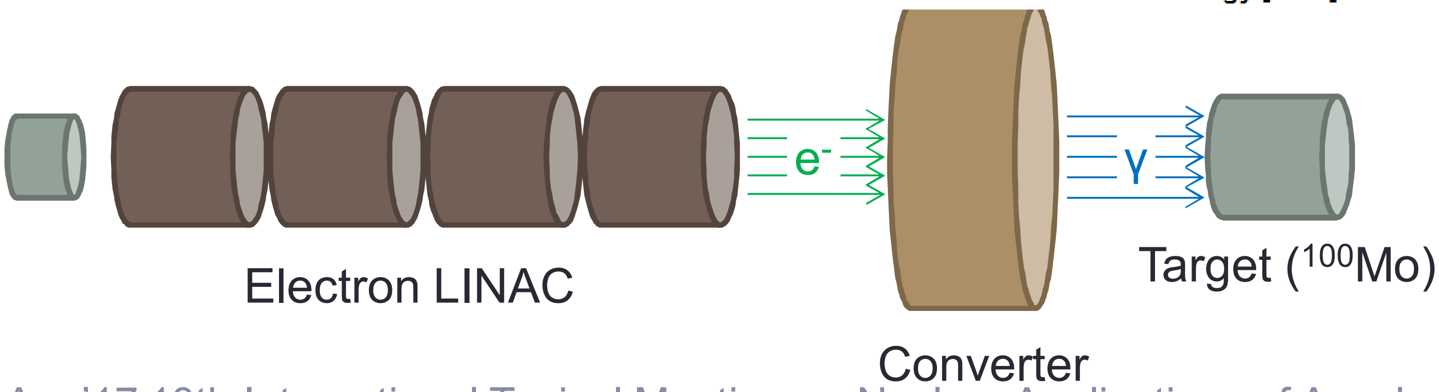
Accelerator

^{100}Mo(γ,n)^{99}Mo	0.16 b
^{100}Mo(p,pn)^{99}Mo	0.15 b
^{100}Mo(p,2n)^{99m}Tc	0.2 b

Photonuclear Production of ^{99}Mo





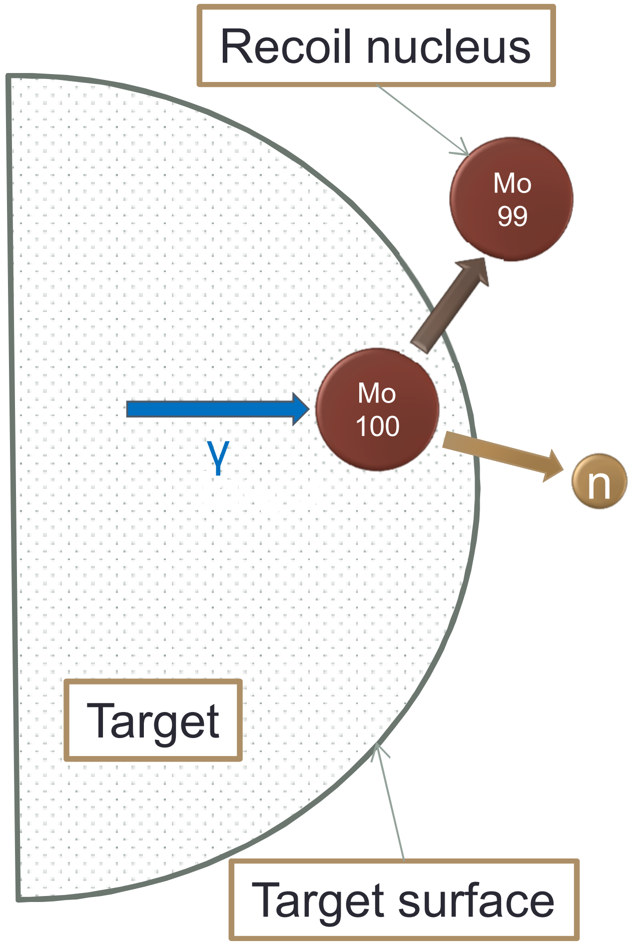


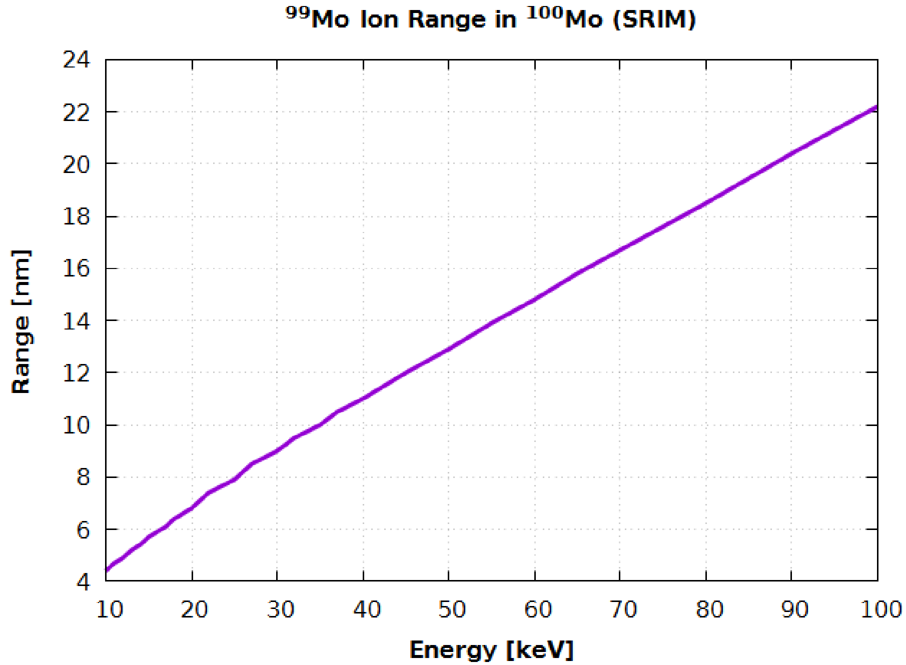
Photonuclear Production of ^{99}Mo

Problems

- High heat loads of converter and molybdenum target
- Low specific activity of the produced ^{99}Mo
- Complicated extraction process
- Target recycling is impossible

Recoil nuclei method



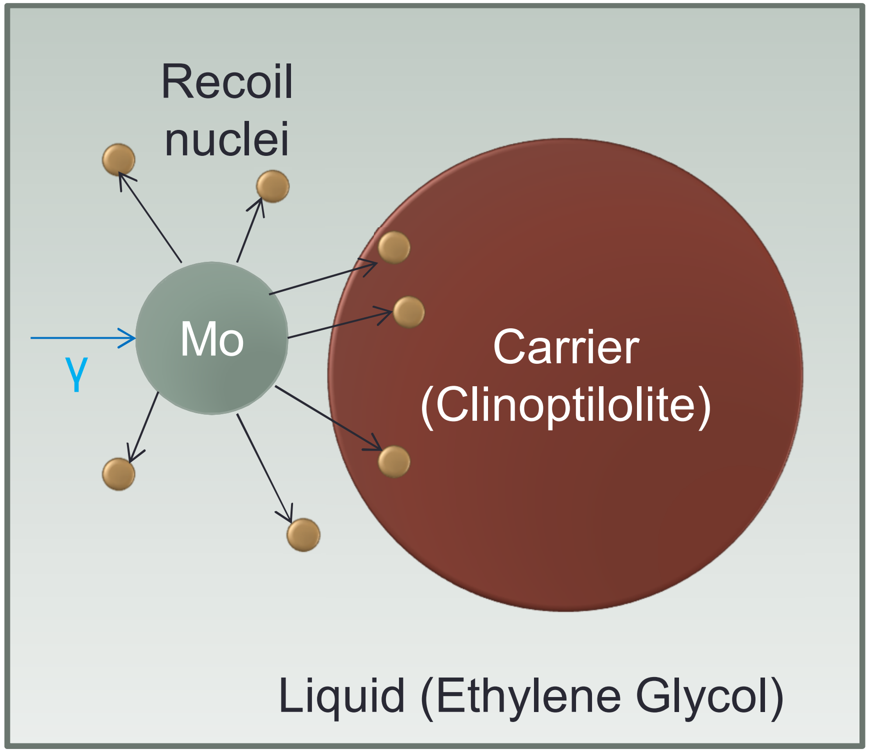


^{99}Mo recoil nucleus energy is 10-100 keV

Target should have size comparable to ^{99}Mo range

Targets: thin foils or nanoparticles

Liquid Target with Clinoptilolite Carriers



Target contains suspension of molybdenum nanoparticles and carrier particles

Molybdenum nanoparticle ≈ 40nm

Carrier particle ≈ 160 nm

Liquid – ethylene glycol

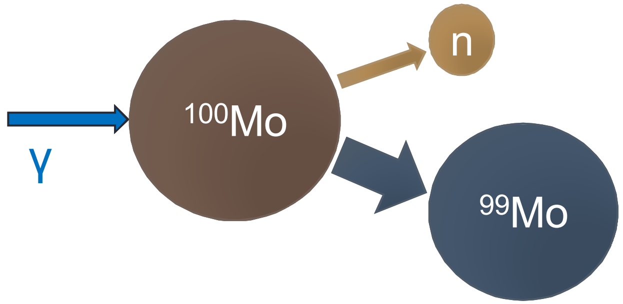
After irradiation carrier particles are filtered out for ^{99}Mo extraction

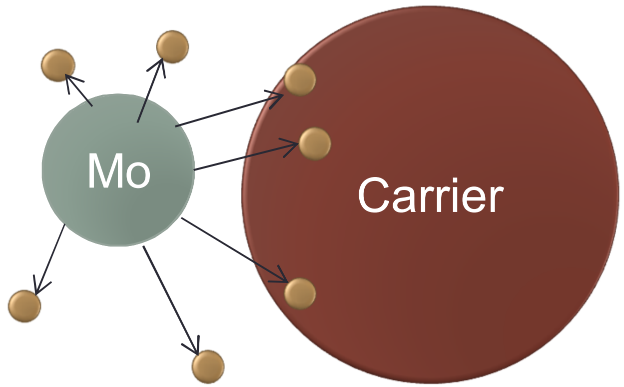
Suspension could be reused multiple times

Simulation sequence

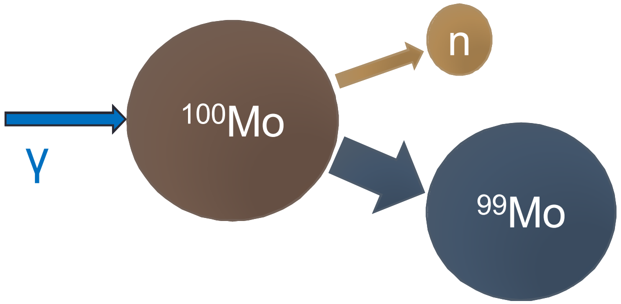
Simulation of the recoil nuclei spectra (TALYS)

Simulation of the recoil nuclei transport and capture (GEANT4)





Recoil nuclei spectrum

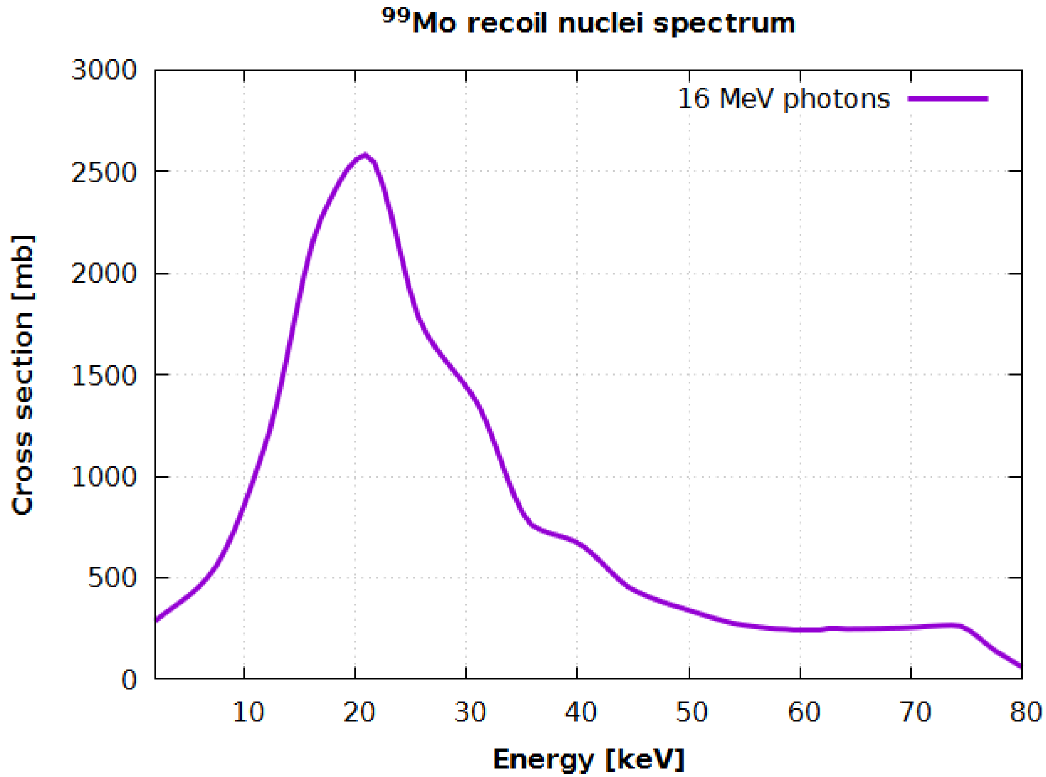


Cross section of the photonuclear reaction is 160 mb

Interaction probability for individual 40 nm nanoparticle is 4.5×10^{-8}

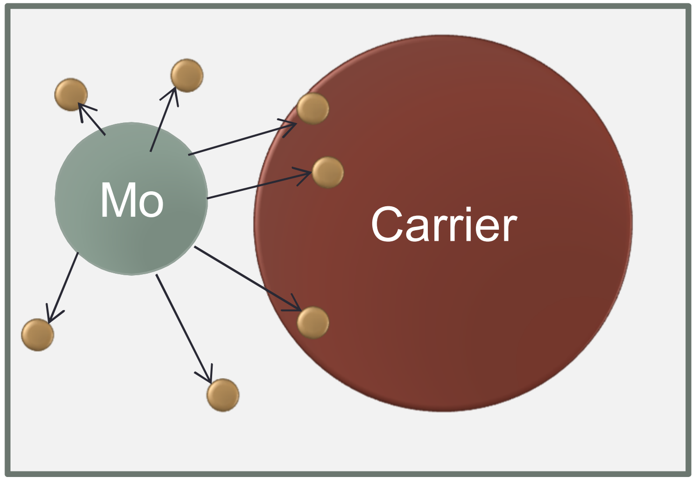
Direct Monte Carlo simulation is inefficient

Nuclear reaction code TALYS was used



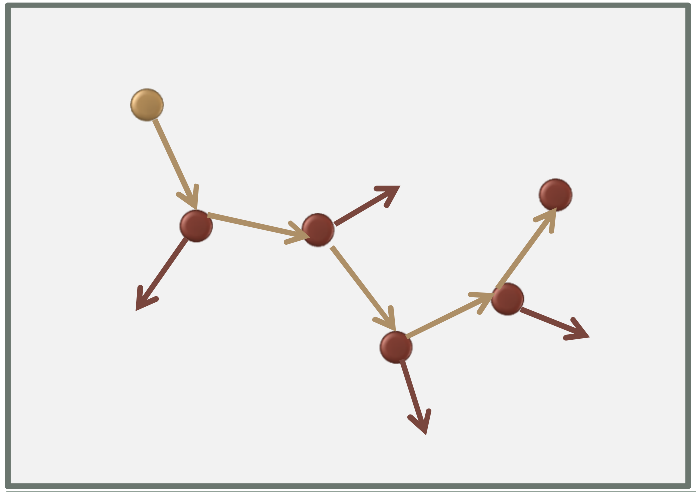
A.J. Koning, S. Hilaire and M.C. Duijvestijn, “TALYS-1.0”, *Proceedings of the International Conference on Nuclear Data for Science and Technology*, April 22-27, 2007, Nice, EDP Sciences, 2008, p. 211-214

Simulation of the recoil nuclei transport



Simulation software: GEANT4 release 10.3

Maintained by CERN collaboration	Open source	Numerous physical models	Open architecture



Simulation of the ion elastic scattering

Problems:

- Low ion energies (20-100 keV)
- Model size comparable to the ion mean free path
- Standard GEANT4 model are not valid

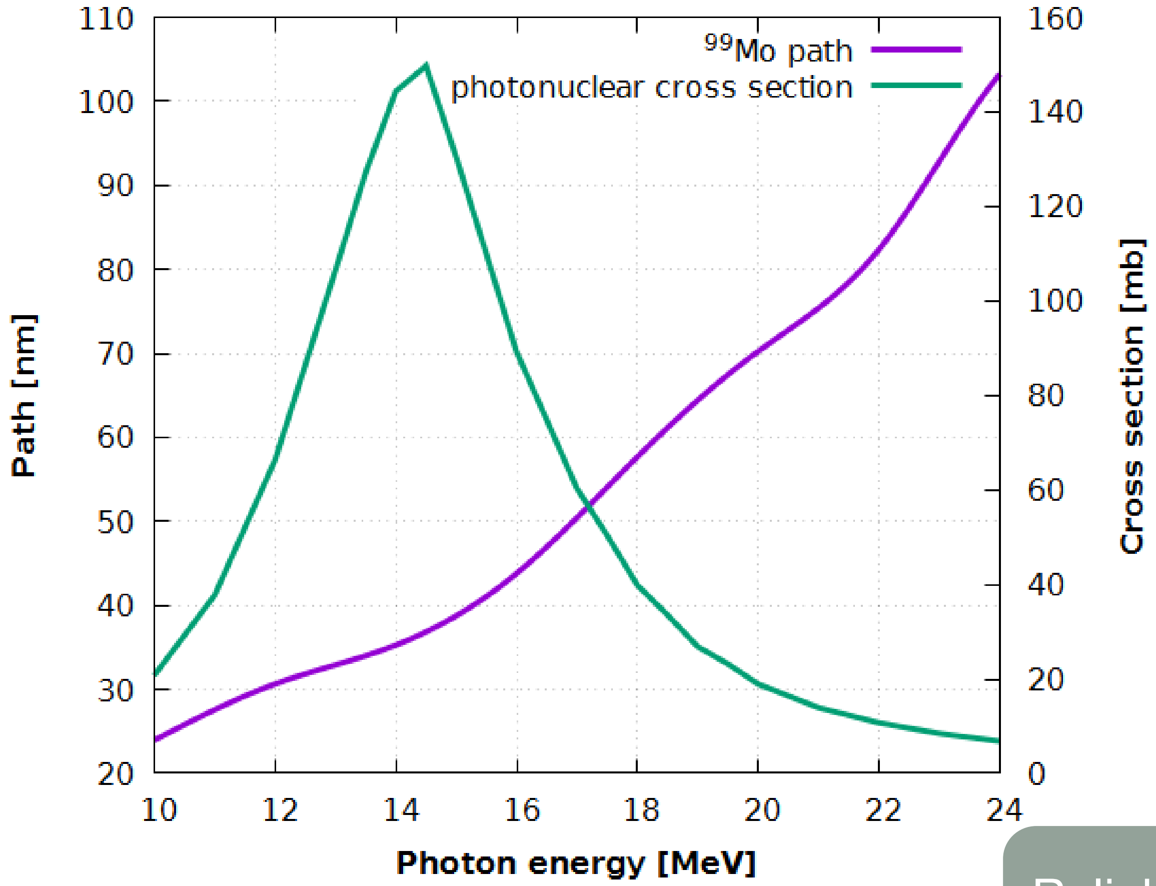
Screened Nuclear Recoil Model

- Exact simulation of ion scattering on screened Coulomb potential
- Simulation of the recoil nuclei
- Results comparable to TRIM simulation

1. M.H Mendenhall., R.A Weller. **Algorithms for the rapid computation of classical cross sections for screened coulomb collisions**, *Nucl. Instr. Meth. B (1991)* 11

2. M.H. Mendenhall, R.A. Weller, **An algorithm for computing screened Coulomb scattering in Geant4**, *Nucl. Instr. Meth. B 227 (2005) 420*

^{99}Mo path calculation (ethylene glycol)



TALYS

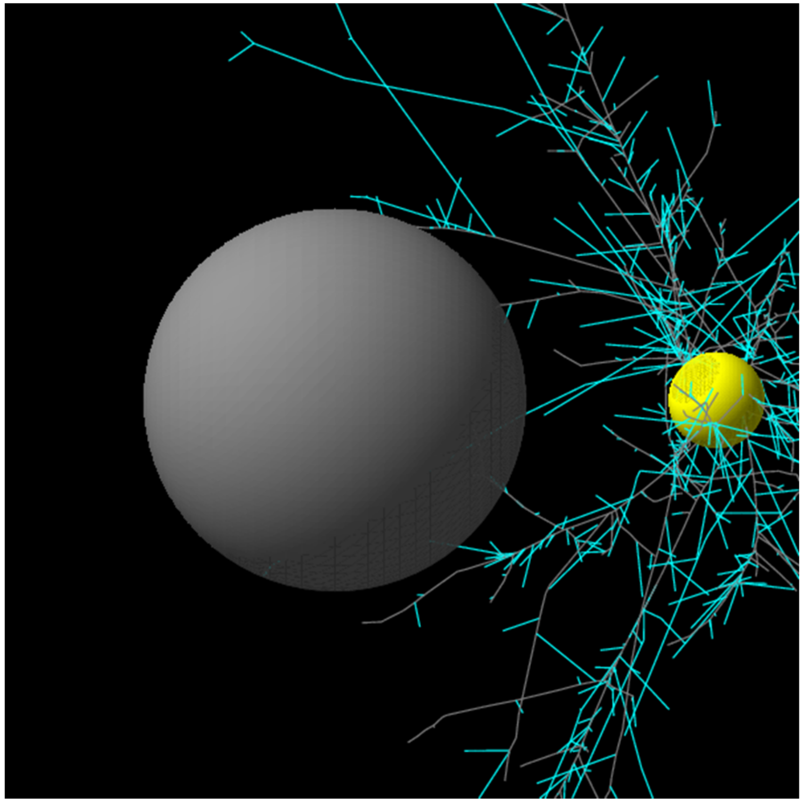
- Calculation of the recoil spectra (10-30 MeV)

GEANT4

- Calculation of the mean free path of recoil nuclei

Reliable distance between particles surfaces is 25-50 nm

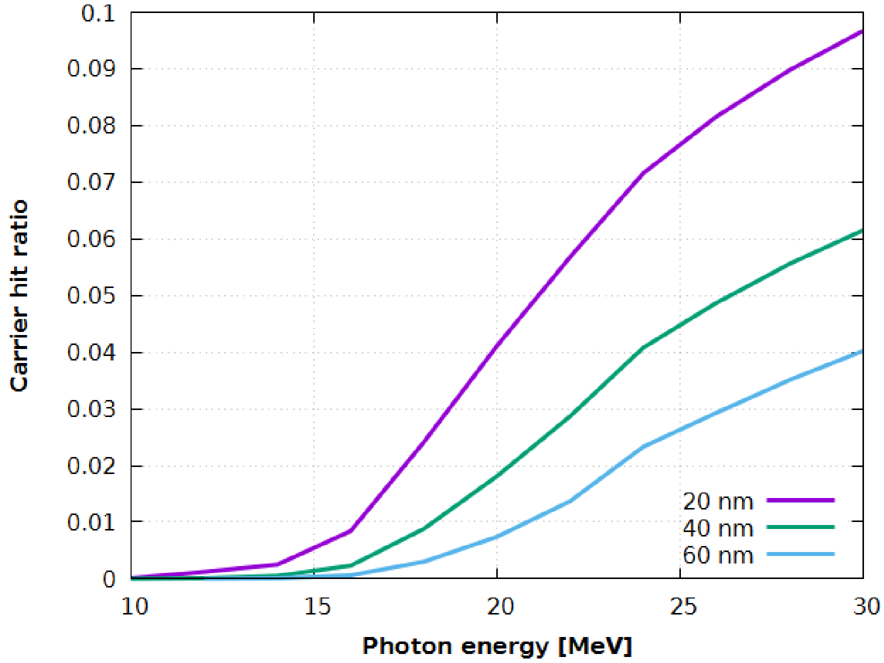
Simulation of the recoil nuclei transport

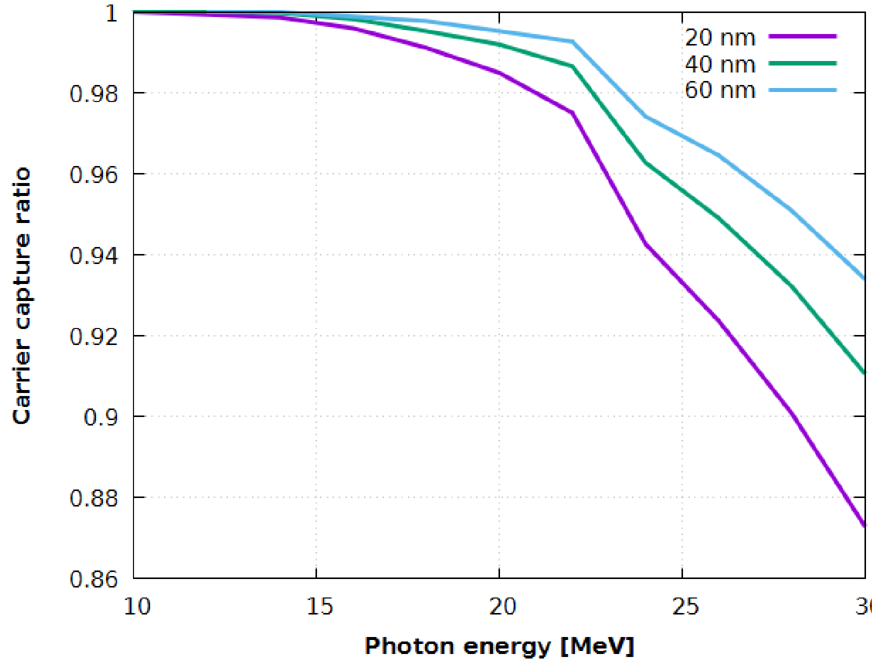


GEANT4 Simulation

- 40 nm nanoparticle (pure ^{100}Mo, MoO_3)
- 160 nm carrier particle - clinoptilolite $(Na,K,Ca)_{2\text{-}3}Al_3(Al,Si)_2Si_{13}O_{36}\cdot 12H_2O$
- Ambient liquid – ethylene glycol
- Photon energies 10-30 MeV
- Distance between molybdenum nanoparticle and carrier: 20, 40, 60 nm (distances between surfaces)

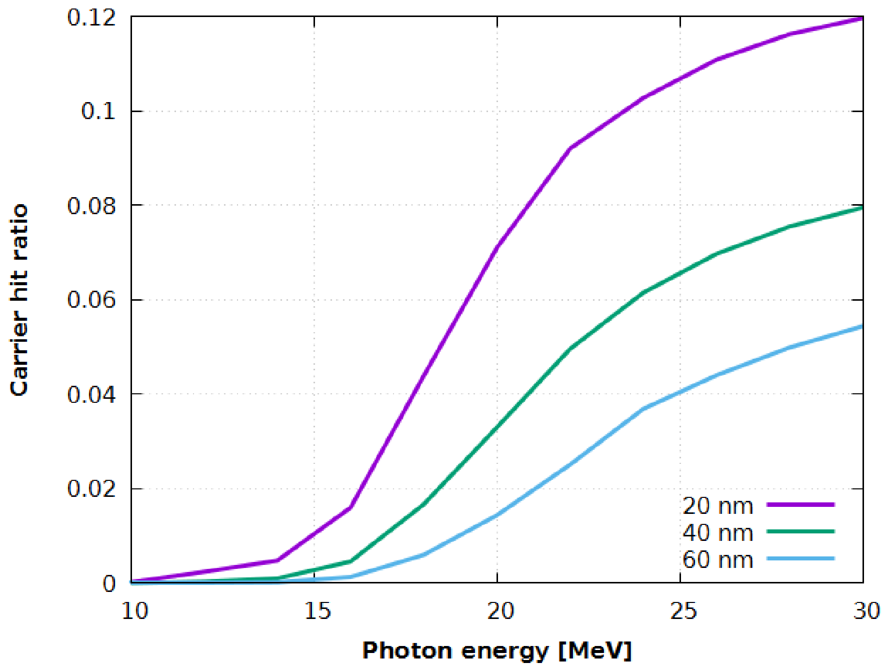
Results – ^{100}Mo nanoparticles

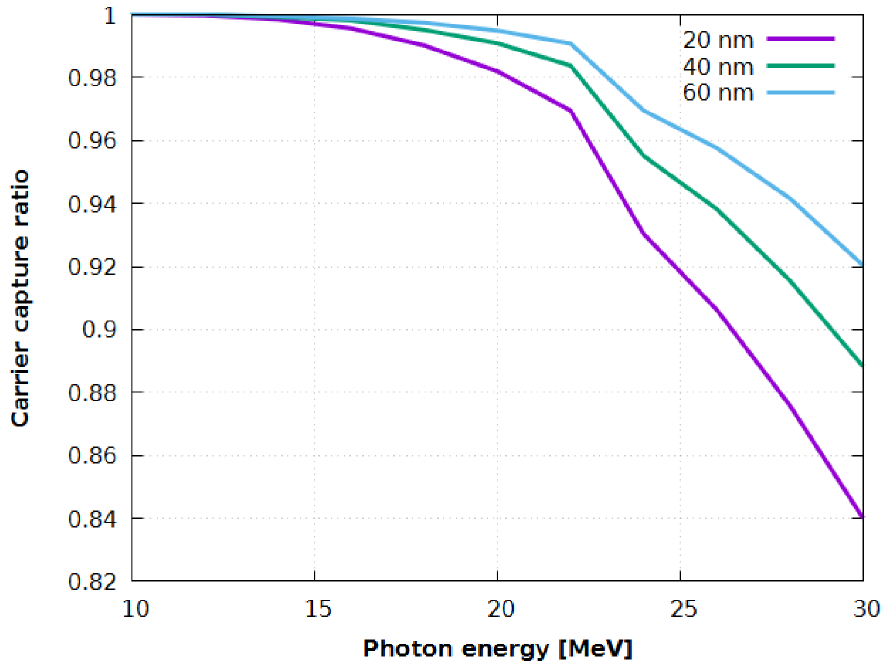




- For the high energy photons 10% of the created ^{99}Mo nuclei hit the carrier particle
- For the Giant Dipole Resonance (GDR) energies (12-18 MeV) hit ratio is below 2%
- For the GDR energies almost all ^{99}Mo nuclei (≈99%)are captured by the carrier

Results – MoO_3 nanoparticles





- For the high energy photons 12% of the created ^{99}Mo nuclei hit the carrier particle
- For the Giant Dipole Resonance (GDR) energies (12-18 MeV) hit ratio is below 3%
- For the GDR energies almost all ^{99}Mo nuclei (≈98-99%)are captured by the carrier

Conclusions

Results	For the photon energies of 12-18 MeV (maximum cross section of ^{99}Mo production) ≈1-2% of ^{99}Mo nuclei hit the carrier
	The clinoptilolite carrier has high capturing efficiency – up to 98-99% of ^{99}Mo nuclei are captured
	For efficient capturing the distance between the surfaces of molybdenum nanoparticle and carrier particle must be 25-50 nm
	Recoil ^{99}Mo nuclei from several molybdenum nanoparticles hitting the carrier particle could provide high specific activity
Problems	The optimum concentration of the carrier particles and molybdenum particles needs to be defined
	The optimal size of carrier particles needs to be defined