FROM RESEARCH TO INDUSTRY

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PERSPECTIVES ON THE PRODUCTION OF ^{99}MO IN THE FRAMEWORK OF IFMIF/ELAMAT PROJECT

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CONTEXT - ^{99}MO/^{99M}TC

- ^{99m}Tc is worldwide used in more than 80% of nuclear medicine procedures
  - Short half-live (6 hours)
  - Production mainly based on the radioactive decay of ^{99}Mo ($T_{1/2}$=66 hours)
- Production of ^{99}Mo based on fission method in nuclear research reactors
  - 5 reactors represent more than 90% of the total production
  - These reactors are more than 40 years old
- Medical isotopes crisis occurred in 2009
  - Shutdown of Petten in Netherland
  - Shutdown of Chalk river in Canada

→ **Serious concern on ^{99}Mo supply**

- International agencies (IAEA, OECD) recommendations:
  - Increasing of diversity and redundancy of ^{99}Mo supply (especially small & medium scale facilities)
  - Conversion technology: HEU -> LEU (security & non-proliferation)

Competitiveness of accelerator-based neutron source for the production of ^{99}Mo using non-fission method ?

GENERAL CONSIDERATIONS

- World demand:
  - ^{99m}Tc: 160000 doses per day, ~25 mCi per doses, namely ~4000 Ci per day
  - ^{99}Mo: 10000 6-days Ci per week

6-days Ci: Activity unit in Ci, 7 or 8 days after the end of irradiation (transportation, sample processing)

- Producer facility size for the production of ^{99}Mo:
  - Small : < 7400 6-days GBq / week
  - Medium : 7400 6-days GBq / week -> 37000 6-days GBq / week
  - Large : > 37000 6-days GBq / week

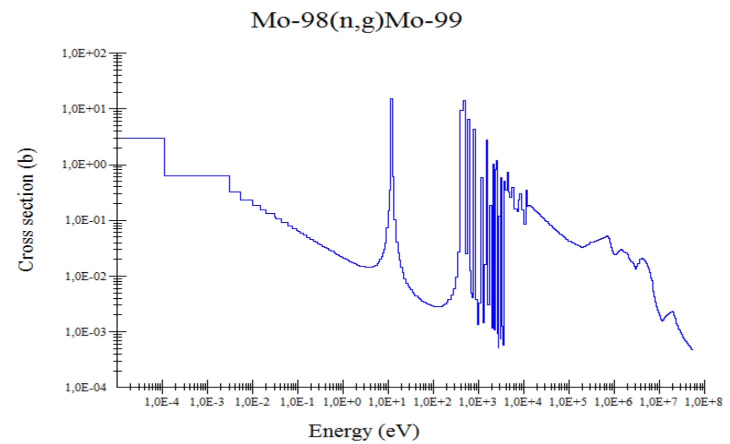
- Radioisotopic purity:
  - Final product administrated to patients
  - Radiological contaminants as low as possible

Keys parameters studied: total activity, specific activity, radioisotopic purity

^{99}MO - NEUTRON PRODUCTION ROUTES

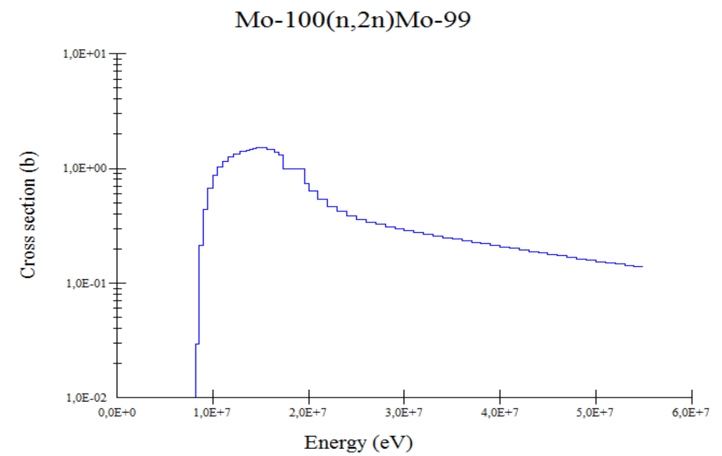
- Two reactions in case of non-fission method, based on Mo sample:
  - ^{98}Mo(n,γ)^{99}Mo
  - ^{100}Mo(n,2n)^{99}Mo

- ^{98}Mo(n,γ)^{99}Mo:
  - Thermal & epithermal neutrons
  - Already used in nuclear research reactors



Requirements for accelerator-based neutron source:
  - Thermal neutron flux > 10^{14} $cm^2.s^{-1}$
  - Moderator

- ^{100}Mo(n,2n)^{99}Mo:
  - High-energy neutrons (threshold~8MeV)
  - Maximum cross section ~14 MeV



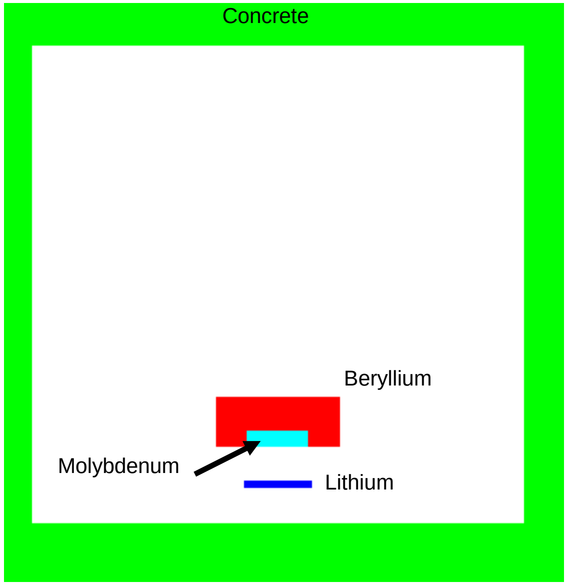
This fits perfectly with IFMIF/ELAMAT neutron source characteristics

METHODOLOGY, ASSUMPTIONS

- Transport code: MCNPX 2.7.b
  - Neutron scattering library: ENDF/B-VII.1
  - Deuteron/Lithium interaction: Bertini model

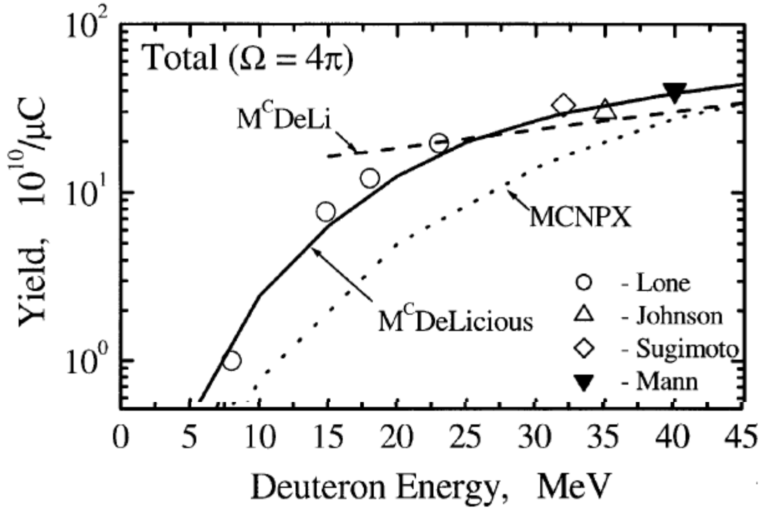
- Activation code: FISPACT 2007 (EAF 2007 neutron library)

- Assumptions (simplified geometry):
  - Beam:
    - Intensity: 125 mA
    - Energy: 40 MeV
    - Footprint: 50 mm x 200 mm
  - Mo sample:
    - 50 mm x 200 mm
    - 10 mm thick (470 grams for MoO_3, 1022 grams for ^{met}Mo)
    - Localisation: 10 cm behind Lithium target (keep place for irradiation module)
    - Moderator: Beryllium, 100 mm thick
  - Activation calculations:
    - No impurities considered
    - Irradiation time: 6 days (weekly production)
    - Cooling time: 8 days (sample processing)

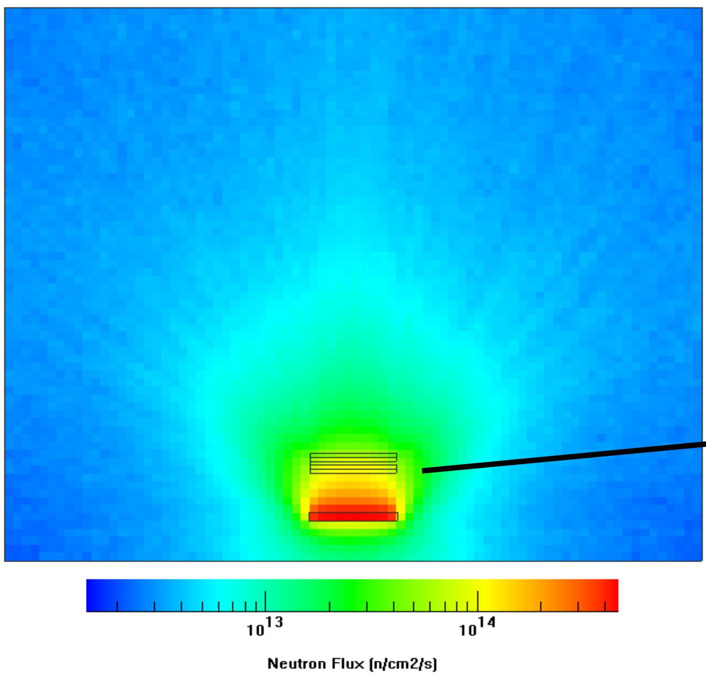


NEUTRON FLUXES

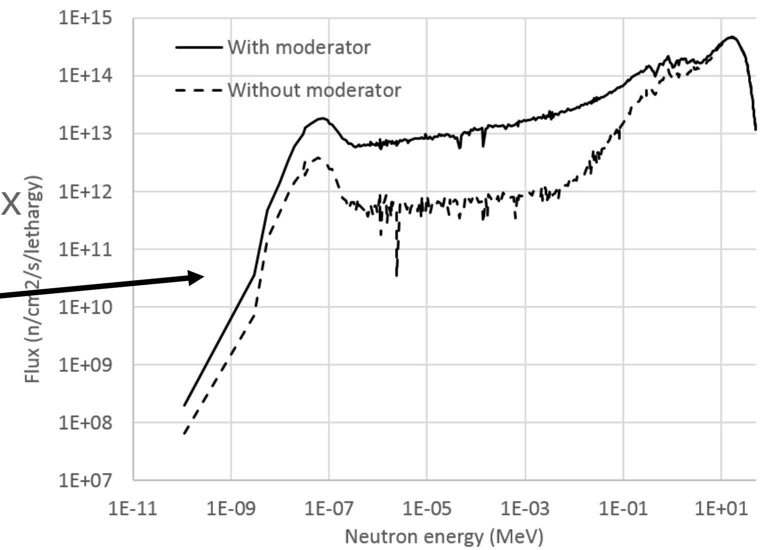
- Neutron rate in 4Pi:
  - Simulation: 3.75 10^{11} neutrons.µC^{-1}
  - Experiment: 4 10^{11} neutrons.µC^{-1}
- Strong enhancement of thermal (x4) and epithermal (x10) neutrons with Beryllium moderator (10 cm thick)



Simakov, J. Nuc. Mat. 307-311 (2002), pp. 1710-1714

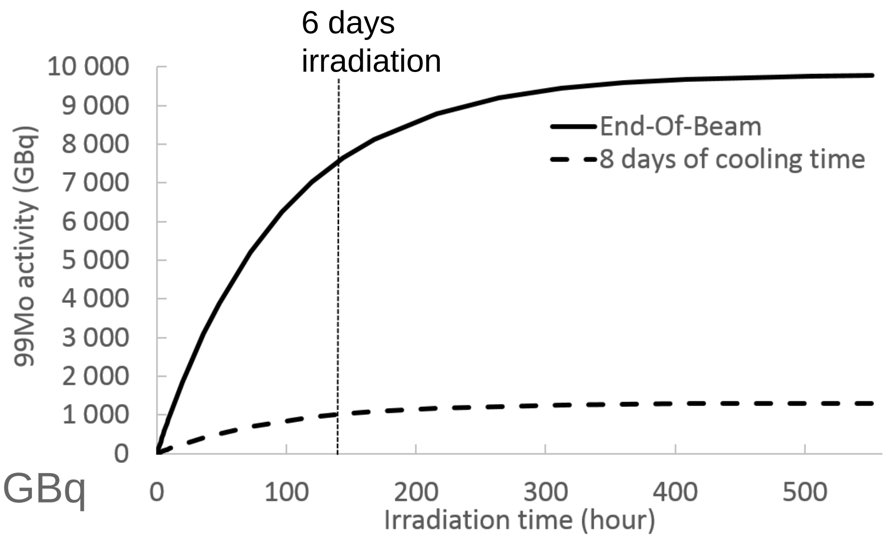


Mean neutron flux in Mo sample



^{99}MO PRODUCTION – TOTAL ACTIVITY

- Mo sample:
  - Natural isotopic abundance
  - Oxide form
  - 470 grams (10 mm thick)
  - Without moderator
- After 6 days irradiation, ^{99}Mo activity:
  - T0: 7650 GBq
  - 8 days cooling time: 1000 6-days GBq



Only 27% of the median value for the small scale facility (3700 6-days GBq)
91% from ^{100}Mo(n,2n)^{99}Mo

- Fulfill the facility size requirements:
  - Increasing of sample mass
  - Use of high-enriched sample (^{98}Mo, ^{100}Mo)

Sample masses (kg) to fulfil facility lower limit

Scale facility	$^{nat}MoO_3$	$^{98}MoO_3$	$^{100}MoO_3$
small (*)	1.71	4.61	0.19
medium	3.42	9.22	0.37
large	17.1	46.1	1.86

** mean value*

Specific activity: 2.1 GBq/g ^{nat}Mo, 0.8 GBq/g ^{98}Mo, 20 GBq/g ^{100}Mo

^{99}MO PRODUCTION – TOTAL ACTIVITY

- Mo sample with moderator:
  - Natural abundance
  - Oxide form
  - 470 grams (10 mm thick)
  - Be moderator (10 cm thick)

Sample masses (kg) to fulfil facility lower limit

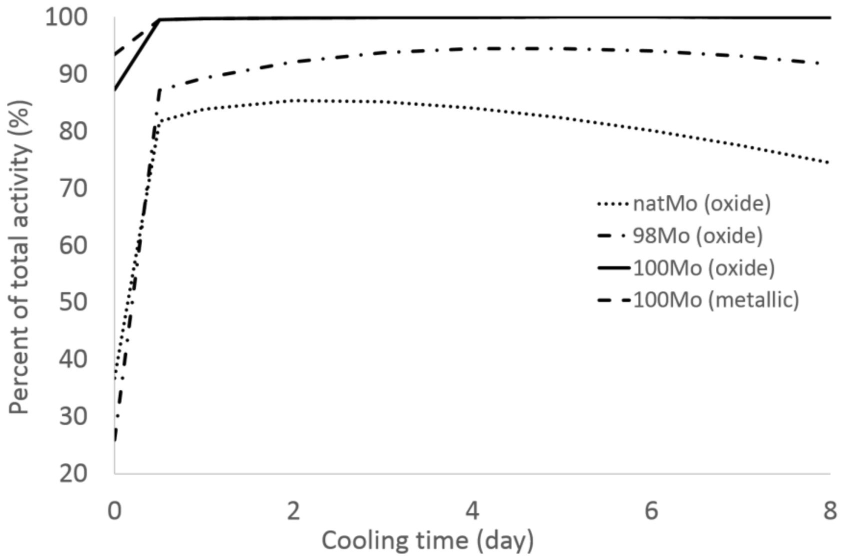
Scale facility	$^{nat}MoO_3$	$^{98}MoO_3$	$^{100}MoO_3$
small	1.13	0.71	0.18
medium	2.26	1.42	0.37
large	11.3	7.11	1.83

Effect on ^{nat}Mo and ^{98}Mo due to enhancement of ^{98}Mo(n,γ)^{99}Mo contribution

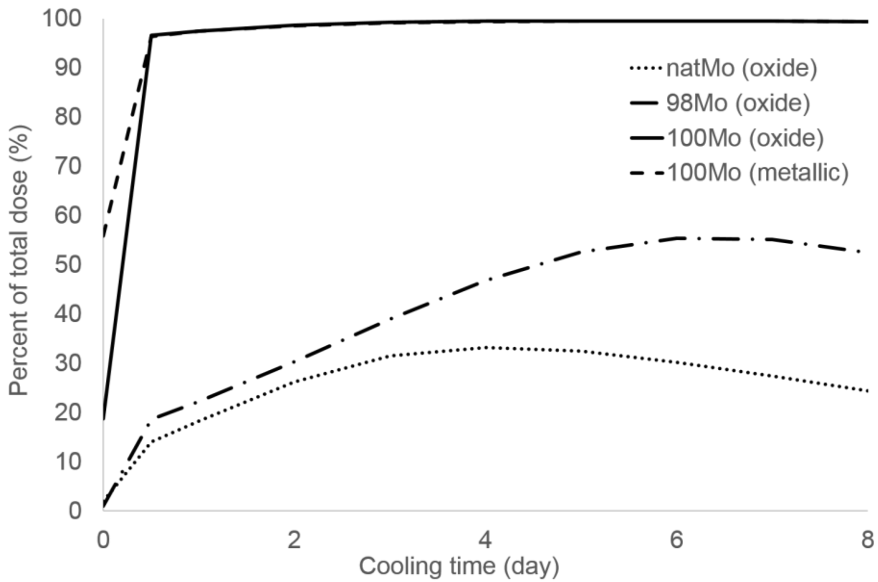
- With metallic sample instead of oxide: reduction of sample masses by 2/3
  - Small facility (3700 6-days GBq /week): 125 grams of ^{100}Mo
  - Medium facility (7400 6-days GBq /week): 250 grams of ^{100}Mo
  - Large facility (37000 6-days GBq /week): 1250 grams of ^{100}Mo

- With sample characteristics:
  - 200x50x10 mm3
  - 10 cm behind Li target ➡ **Medium scale facility**
  - Mass:1022 grams

^{99}MO PRODUCTION – RADIOISOTOPIC PURITY



- ^{99}Mo/^{99m}Tc contribution to the total activity and the total dose:
  - ^{98}Mo and ^{nat}Mo: large contribution of Nb isotopes to total dose rate (main contributor ^{92m}Nb after 4 days of cooling time)
  - ^{100}Mo sample: more than 99% in activity (12 hours) and dose (3 days)



Only ^{100}Mo sample provides high radioisotopic purity. Sample processing needed?

In other case (^{nat}Mo and ^{98}Mo), extraction of contaminants are needed if possible.

CONCLUSION

- ^{99}Mo activity evaluated in the framework of IFMIF/ELAMAT project
  - Sample dimensions: 200x50x10
  - 10 cm behind Lithium target & irradiation module
  - 470 grams for oxide form, 1022 grams for metallic form

- Advantages:
  - Not the primary goal of the facility
  - Neutron activation: sample mass adjustment if available space

- ^{100}Mo sample is the most efficient route for the production of ^{99}Mo (specific activity: 2.1 GBq/g ^{nat}Mo, 0.8 GBq/g ^{98}Mo, 20 GBq/g ^{100}Mo, oxide form, without moderator)
  - Small scale facility: 190 grams of $^{100}MoO_3$ (125 grams for $^{100}Mo_{met}$)
  - Medium scale facility: 380 grams of $^{100}MoO_3$ (250 grams for $^{100}Mo_{met}$)
  - Large scale facility, 1800 grams of $^{100}MoO_3$ (1250 grams for $^{100}Mo_{met}$)

- ^{100}Mo sample provides a high radioisotopic purity compared to ^{nat}Mo & ^{98}Mo
  - Sample processing needed for labelling for ^{100}Mo?
  - Recycling of ^{100}Mo needed due to the expensive cost

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