Comparative Assessment of Target Materials

Neutron Source NSC KIPT: A Geant4 Simulation Study

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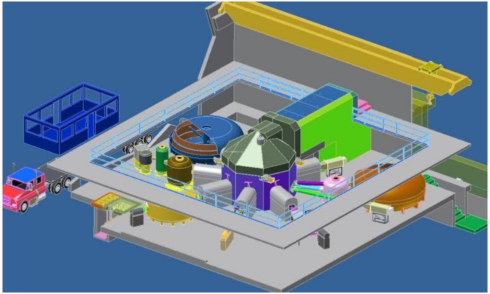
Roadmap (5 minutes)

1. NSC KIPT neutron source: concept and mission.
2. Physical basis of neutron generation.
3. Research objective and comparison logic.
4. Geant4 implementation: beam and target engineering.
5. Comparative results and practical implications.

What is the NSC KIPT neutron source?

- NSC KIPT is an **Accelerator-Driven System (ADS)** for neutron science.
- Mission: fundamental research, isotope production, and applied nuclear studies.
- The facility combines a high-power electron LINAC with a subcritical assembly nsc-kipt-brochure-2004.

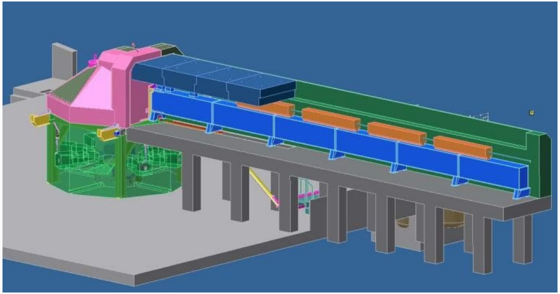


Caption: Model of the Neutron Source and the building where it is located.

Source: NSC KIPT brochure nsc-kipt-brochure-2004.

Context and status

- The project was developed in international collaboration with strong scientific and engineering support.
- Commissioning activities established the physical start-up baseline.
- Current stage focuses on safe operation and data-informed optimization nsc-kipt-brochure-2004.



Caption: Detailed model of the Neutron Source.

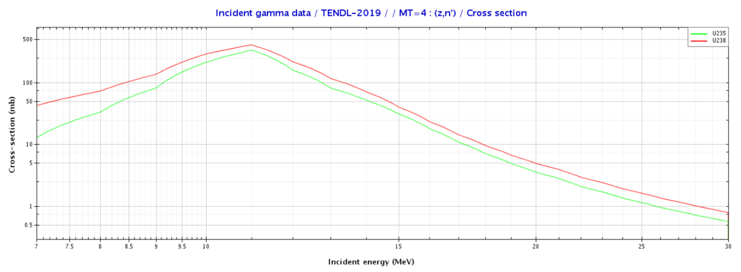
Source: NSC KIPT brochure nsc-kipt-brochure-2004.

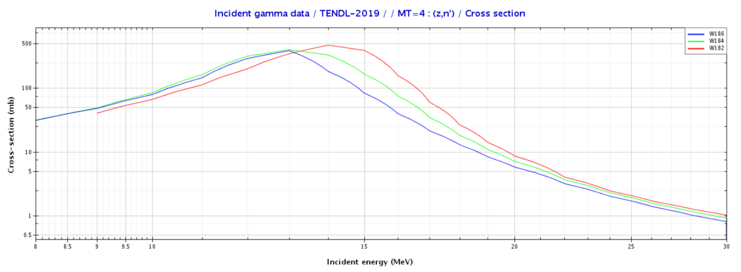
Physics behind NSC KIPT neutron source

- Neutron production chain in the target:

$$e^- \to \gamma \to (\gamma, n) \to n$$

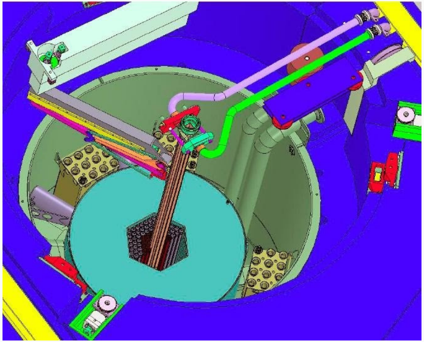
- High-energy electrons generate bremsstrahlung photons in heavy target plates.
- Photonuclear interactions produce primary neutrons with broad spectral distributions koning2019tendl.





Subcritical assembly principle

- The source drives a **subcritical** core ($k_{\text{eff}} < 1$).
- Neutron multiplication is described by
$$M = (1 - k_{\text{eff}})^{-1}.$$
- Beam-off condition inherently terminates the fission chain vodin2013nsc.



Caption: 3D Subcritical assembly model.

Source: NSC KIPT status paper vodin2013nsc.

Goal of this work

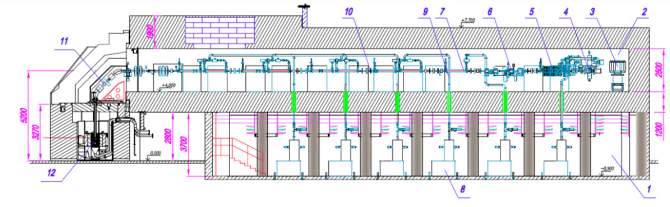
- Perform a **comparative Geant4 assessment** of W-Ta and U-Mo targets.
- Quantify neutron productivity together with engineering risk proxies.
- Derive an evidence-based recommendation for target selection.

Primary comparison metrics:

- neutron output at model boundaries,
- high-energy photon intensity,
- plate-wise damage and gas-production indicators.

Source: simulation campaign and referenced benchmark values.

Geant4 implementation: beam and accelerator conditions



Caption: Layout of linac and subcritical assembly.

Source: NSC KIPT status paper vodin2013nsc.

- Physics list optimized for hadronic and neutron transport in this energy range using Geant4 geant4.
- Electron beam defined with realistic energy spread, spot size, and angular divergence.

Beam energy	100 MeV
Relative energy spread	1%
Transverse beam size (σ_x, σ_y)	1 mm, 1 mm
Angular divergence ($\sigma_{\theta x}, \sigma_{\theta y}$)	1 mrad, 1 mrad
Operation mode	CW, 100 kW average power

Geant4 implementation: target engineering model

W-Ta target (7 plates, startup configuration)

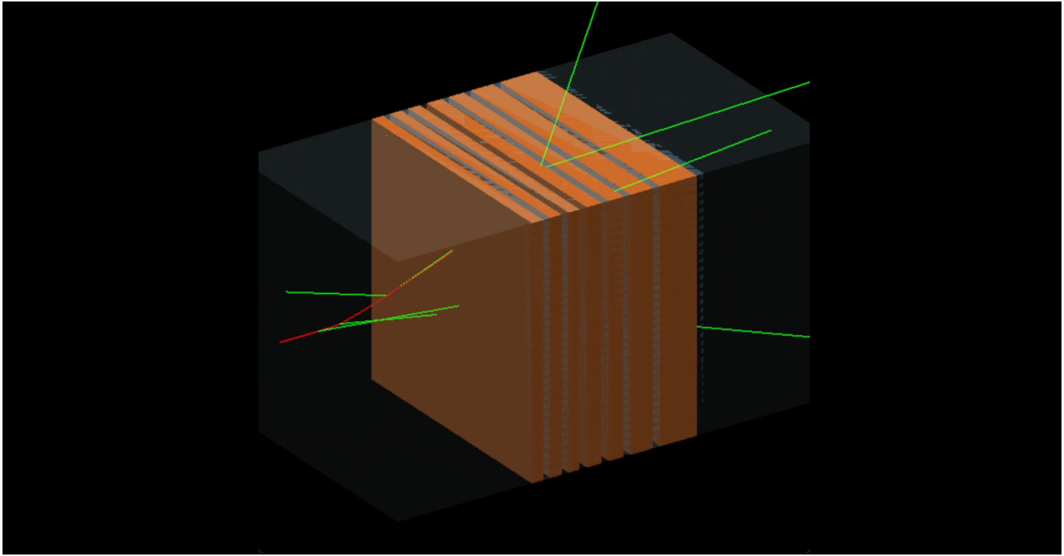
- 7 square W plates; active cross-section: 65.8 mm $\times$ 65.8 mm ($\sim$66 mm $\times$ 66 mm with cladding).
- Plate thickness profile (mm): 2.5, 2.5, 2.47, 3.53, 3.58, 5.55, 9.5.
- Ta cladding: $\sim$0.25 mm–0.27 mm with Ti interlayer: 30 µm–40 µm.
- Inter-plate water gaps: 1.75 mm–2.0 mm.
- SAV-1 Al-alloy square housing: inner 66 mm$\times$66 mm, wall 2 mm.

U–7%Mo target (12 plates, high-flux option)

- U–7%Mo alloy selected for improved radiation tolerance.
- 12 plates, thicknesses (mm):
  - 2.5, 2.5, 2.5, 2.5, 3.0, 3.0,
  - 4.0, 5.0, 7.0, 10.0, 14.0, 22.5.
- Cladding $\sim$0.7 mm–1.0 mm (design/manufacturing dependent).
- Variable cooling gaps: 1.0 mm, 1.75 mm, and 3.0 mm.

Common elements: **2 mm Al entrance window** and **237 mm He chamber** behind the plate stack to displace water and increase useful neutron flux to the subcritical zone.

Beam–target interaction visualization



Comparative KPI summary (per primary electron)

Metric	W-Ta	U-Mo
Primary electrons simulated, N_e	1.0e7	1.0e7
Photons above 5 MeV per electron	3.72338	3.92482
Total neutrons generated per electron	0.0302579	0.0585394
Neutrons exiting model boundary per electron	0.0220162	0.0444019
Neutron flux at model exit, n/s ($\times N_e/s$)	1.3740e14	2.7716e14
Reference neutron flux (literature), n/s	1.88×10^{14}	3.01×10^{14}

Source: own Geant4 simulation results; literature reference values from vodin2013nsc$_{f}ull(Utarget$:3.01$\times 10^{14}$ n/s, W target: 1.88×10^{14} n/s).

Photon spectra in the 4.5–30 MeV region

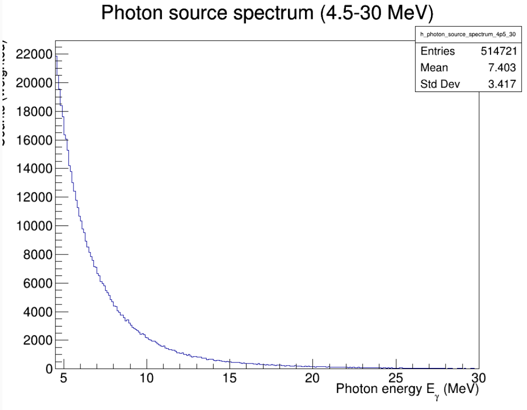


Figure 1: Photon spectrum for W-Ta target.

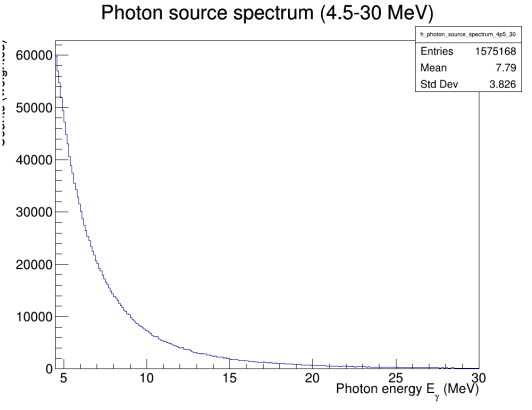


Figure 2: Photon spectrum for U-Mo target.

Source: own Geant4 simulation results.

Photon spectra on linear scale

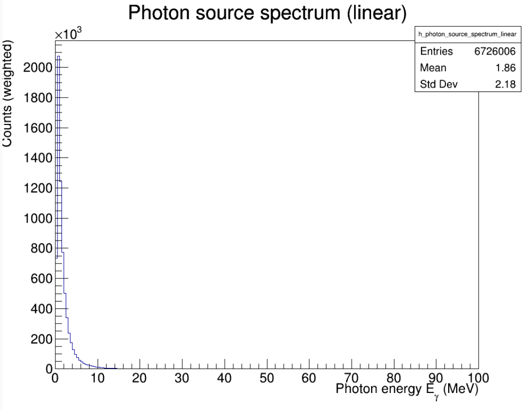


Figure 3: Linear-scale photon spectrum for W-Ta.

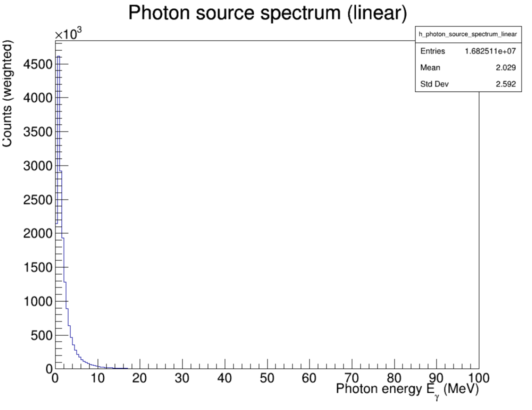


Figure 4: Linear-scale photon spectrum for U-Mo.

Source: own Geant4 simulation results.

Neutron output on linear scale

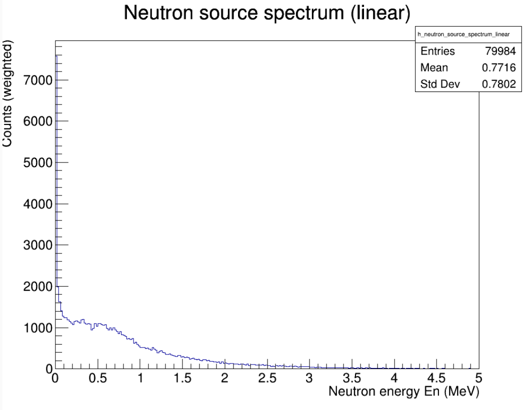


Figure 5: Linear-scale neutron spectrum for W-Ta.

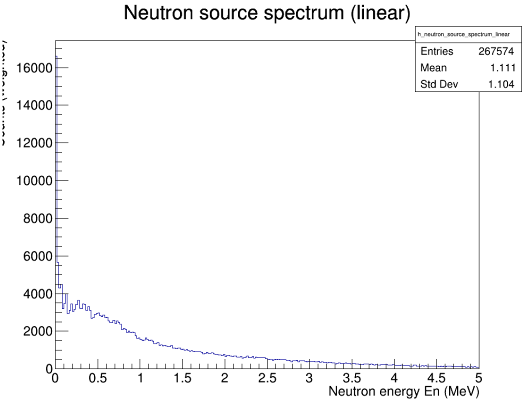


Figure 6: Linear-scale neutron spectrum for U-Mo.

Source: own Geant4 simulation results.

Neutron side-leakage pattern

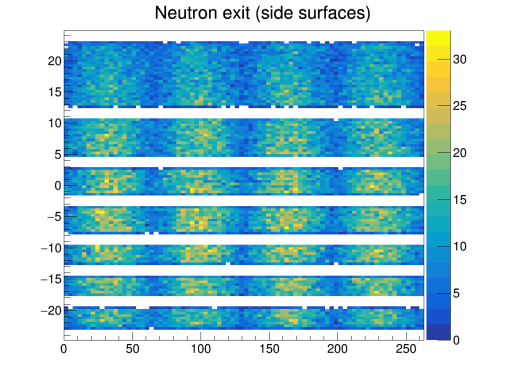


Figure 7: Side-leakage map for W-Ta target.

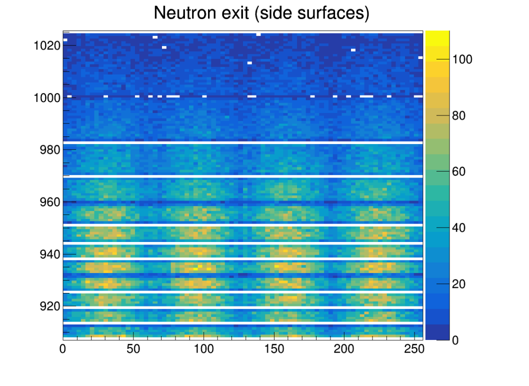


Figure 8: Side-leakage map for U-Mo target.

Source: own Geant4 simulation results.

Hydrogen gas-production proxy by plate

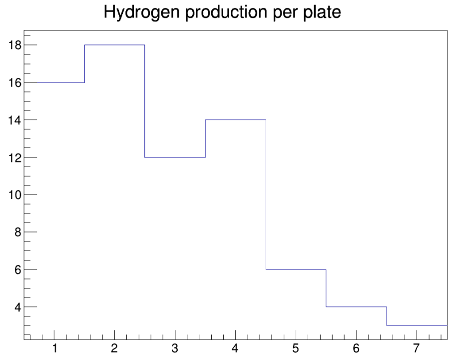


Figure 9: Hydrogen-production indicator for W-Ta.

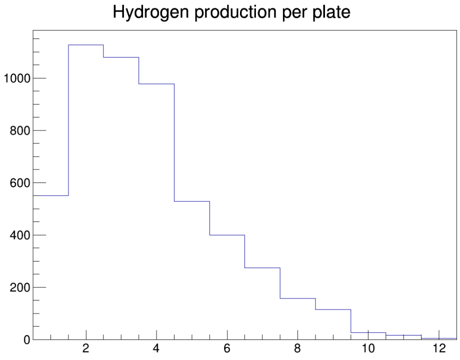
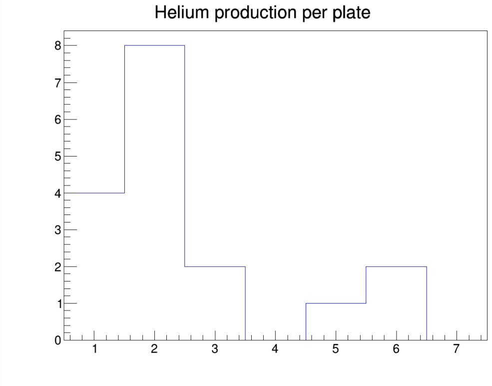


Figure 10: Hydrogen-production indicator for U-Mo.

Source: own Geant4 simulation results.

Helium gas-production proxy by plate



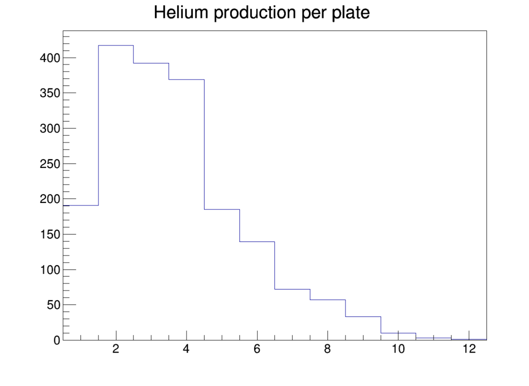


Figure 11: Helium-production indicator for W-Ta. **Figure 12:** Helium-production indicator for U-Mo.

Source: own Geant4 simulation results.

Radiation-damage proxy by plate

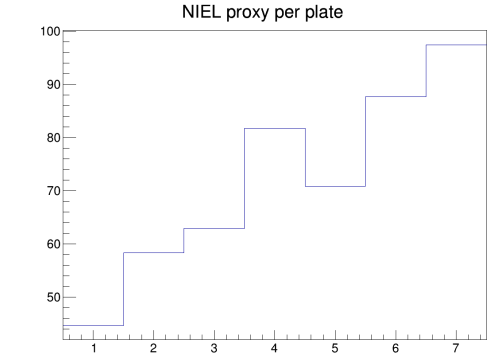


Figure 13: NIEL-based damage indicator for W-Ta.

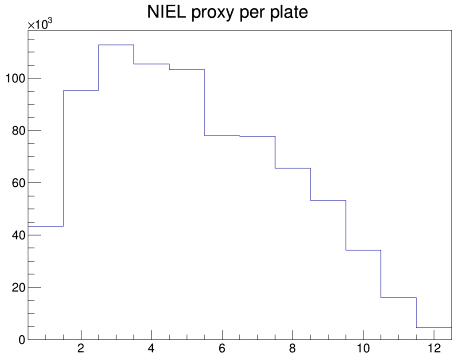
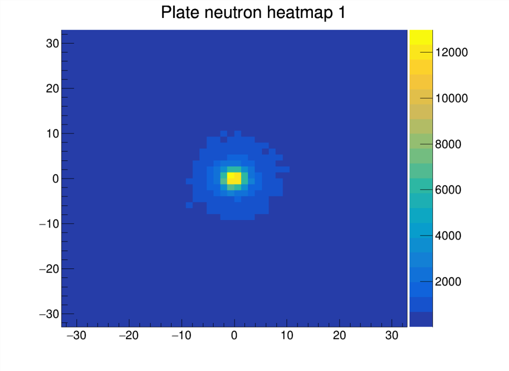


Figure 14: NIEL-based damage indicator for U-Mo.

Source: own Geant4 simulation results.

Neutron heatmap evolution (animation)



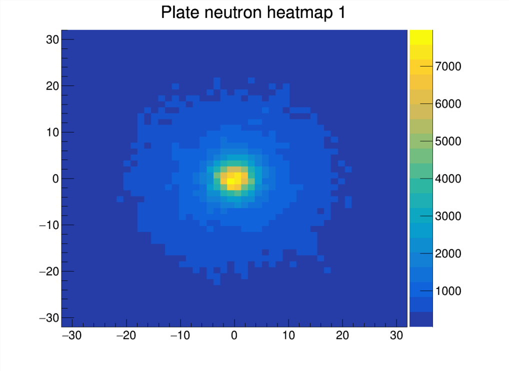


Figure: temporal evolution of plate-level neutron field distribution.

Source: own Geant4 simulation results.

Conclusion

- The comparison framework provides physically consistent evidence for material selection.
- U-Mo demonstrates higher neutron productivity indicators in this simulation campaign.
- Final selection must balance neutron gain with thermal and radiation-damage constraints.

References i

- NSC “Kharkiv Institute of Physics and Technology” (2004).
  ***Nuclear facility “Neutron source based on a subcritical assembly driven by an electron accelerator”* [Brochure].**
- Koning, A. J., Rochman, D., Sublet, J.-C., Dzysiuk, N., Fleming, M., and van der Marck, S. (2019).
  ***TENDL-2019: TALYS-based evaluated nuclear data library*.**
  Nuclear Research and Consultancy Group (NRG).
- Vodin, A. N., Demchenko, P. A., Zelinsky, A. Yu., et al. (2013).
  NSC KIPT neutron source status.
  Problems of Atomic Science and Technology, 88(6), 3–9.

Vodin, A. N., Demchenko, P. A., Zelinsky, A. Yu., Karnaukhov, I. M., Neklyudov, I. M., Peev, F. A., Pugachev, G. D., and Ushakov, I. V. (2013).
NSC KIPT neutron source status.
Problems of Atomic Science and Technology, 88(6), 3–9.

Agostinelli, S., et al. (2003).
Geant4—a simulation toolkit.
Nuclear Instruments and Methods in Physics Research Section A, 506(3), 250–303.