Comparative Assessment of Spallation 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.

Placeholder: facility model image

Figure 1: Conceptual view of the NSC KIPT neutron-source facility.

Source: project references and institutional materials.

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.

Placeholder: large facility photograph

Figure 2: NSC KIPT installation in operational context.

Source: public project communications and literature references.

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.

Placeholder: photonuclear spectrum (I)

Figure 3: Representative photonuclear spectrum: component I.

Placeholder: photonuclear spectrum (II)

Figure 4: Representative photonuclear spectrum: component II.

Source: established photonuclear-reaction literature.

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.

Placeholder: subcritical assembly model image

Figure 5: Functional model of the subcritical assembly and neutron multiplication.

Source: reactor-physics references for ADS systems.

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

- Physics list optimized for hadronic and neutron transport in this energy range.
- 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	Continuous-wave, 100 kW average power

Source: simulation input configuration.

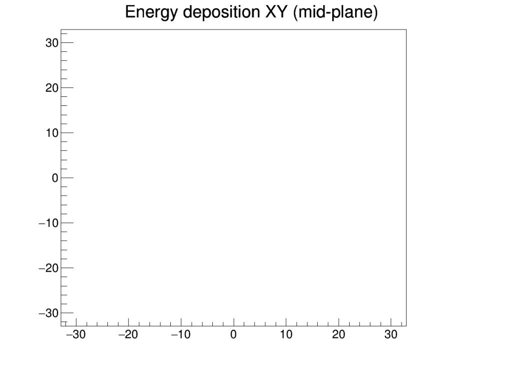
Geant4 implementation: target engineering model

- Layered plate assembly with cooling gaps and cladding.
- Candidate materials: **W-Ta** and **U-Mo**.
- Geometry tuned for thermal management and neutron production stability.

- plate thickness range: 2.5–9.5 mm,
- plate footprint: 65.8 mm,
- cooling gap: 2 mm,
- total target assembly thickness: 120 mm.

Source: simulation geometry model.

Beam–target interaction visualization



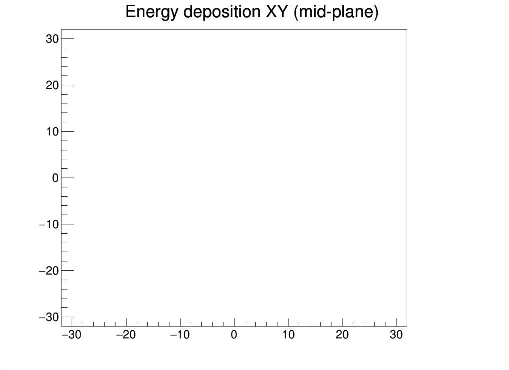


Figure: comparative beam-interaction evolution in two target designs.

Source: own Geant4 simulation results.

Comparative KPI summary (per primary electron)

Metric	W-Ta	U-Mo
Neutron yield (track-based)	0.00798	0.02669
Photon yield (track-based)	0.6728	1.6825
Neutron boundary output	0.02196	0.04418
High-energy photon indicator	3.7238	3.9245

Source: own Geant4 simulation results and benchmark-oriented comparison practice.

Photon spectra in the 4.5–30 MeV region

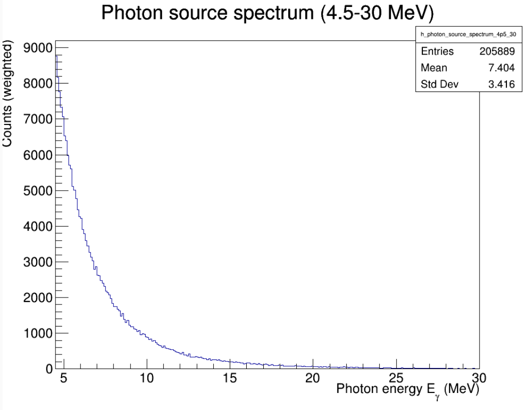


Figure 6: Photon spectrum for W-Ta target.

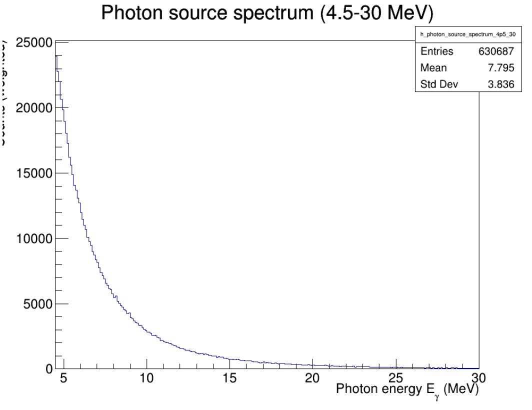


Figure 7: Photon spectrum for U-Mo target.

Source: own Geant4 simulation results.

Photon spectra on linear scale

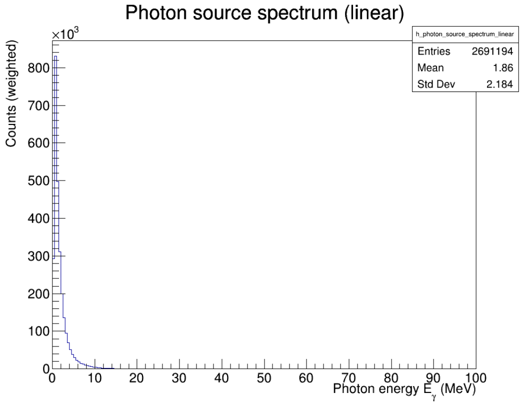


Figure 8: Linear-scale photon spectrum for W-Ta.

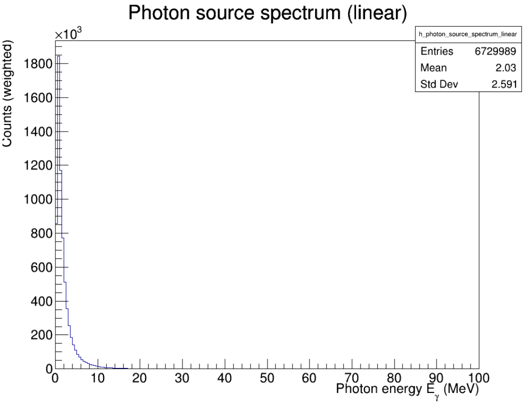


Figure 9: Linear-scale photon spectrum for U-Mo.

Source: own Geant4 simulation results.

Neutron output on linear scale

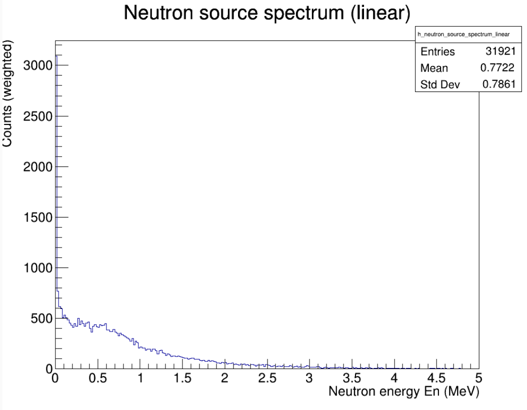


Figure 10: Linear-scale neutron spectrum for W-Ta.

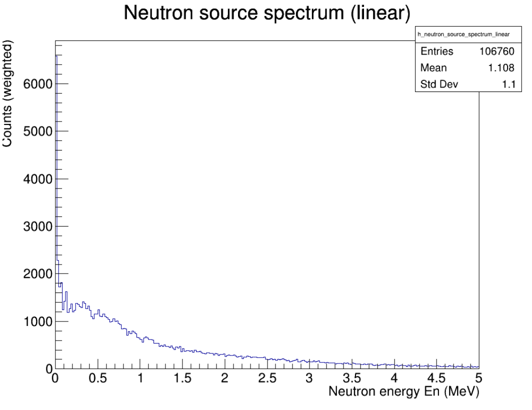


Figure 11: Linear-scale neutron spectrum for U-Mo.

Source: own Geant4 simulation results.

Neutron side-leakage pattern

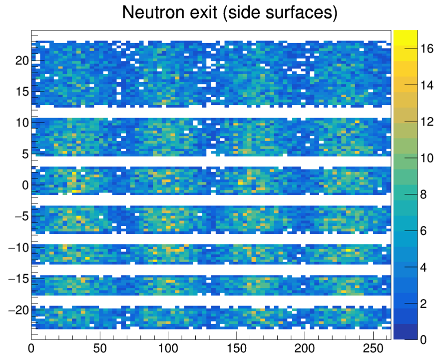


Figure 12: Side-leakage map for W-Ta target.

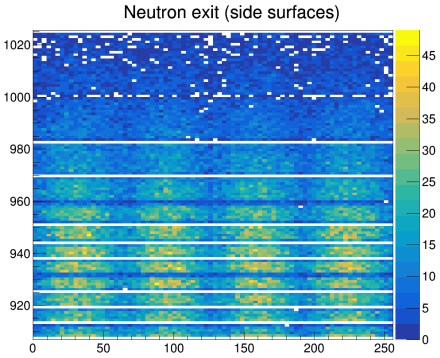


Figure 13: Side-leakage map for U-Mo target.

Source: own Geant4 simulation results.

Hydrogen gas-production proxy by plate

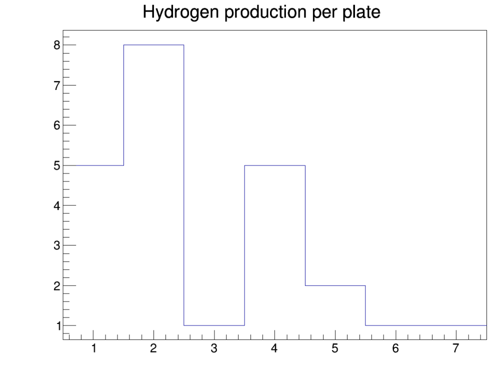


Figure 14: Hydrogen-production indicator for W-Ta.

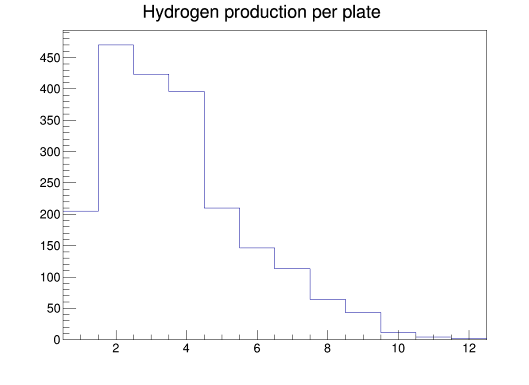


Figure 15: Hydrogen-production indicator for U-Mo.

Source: own Geant4 simulation results.

Helium gas-production proxy by plate

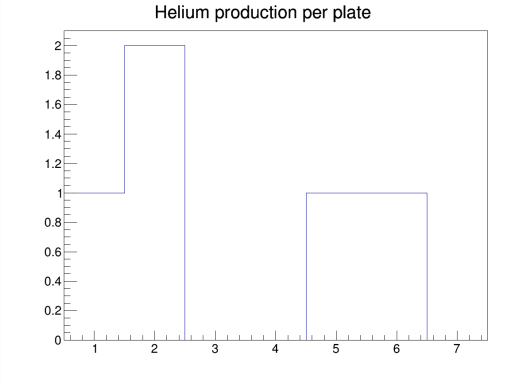


Figure 16: Helium-production indicator for W-Ta.

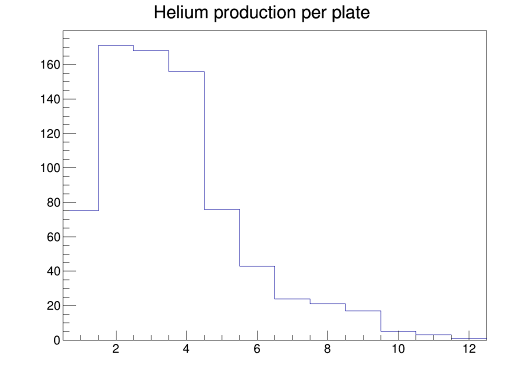


Figure 17: Helium-production indicator for U-Mo.

Source: own Geant4 simulation results.

Radiation-damage proxy by plate

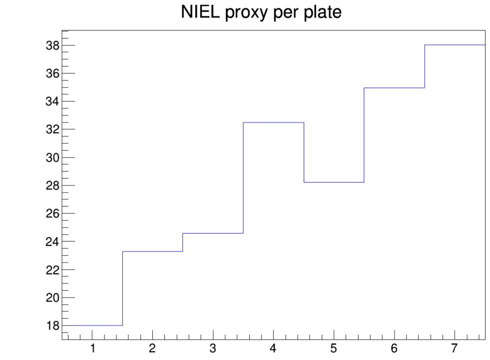


Figure 18: NIEL-based damage indicator for W-Ta.

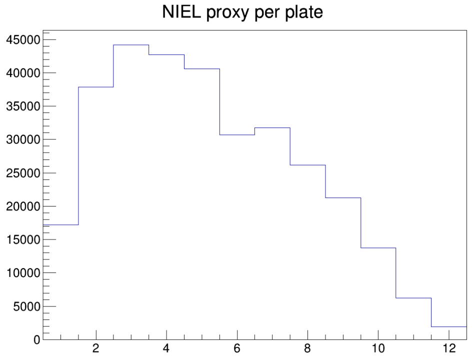
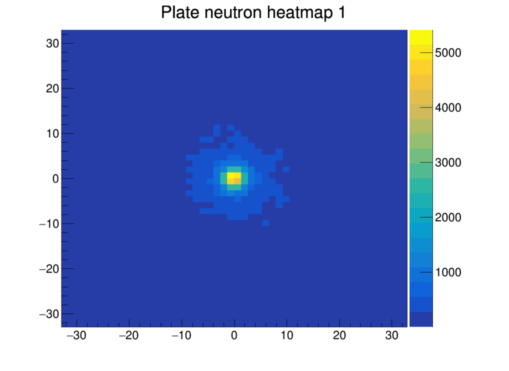


Figure 19: NIEL-based damage indicator for U-Mo.

Source: own Geant4 simulation results.

Neutron heatmap evolution (animation)



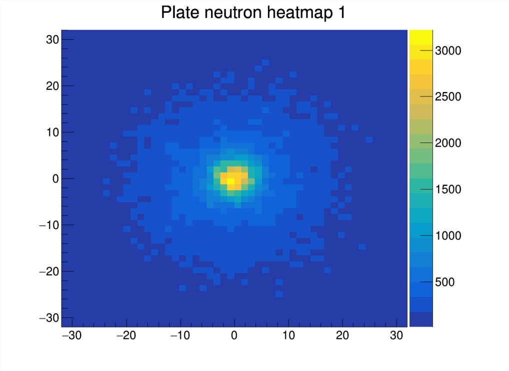


Figure: temporal evolution of plate-level neutron field distribution.

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

- Geant4 Collaboration, *Geant4—a simulation toolkit*, NIM A 506 (2003) 250–303.
- ADS and NSC KIPT literature corpus summarized in project reference notes.
- Benchmark values and historical context from reviewed published sources.
- Numerical and visual results: own Geant4 simulation campaign.

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