Comparative Assessment of Spallation Target Materials

Neutron Source NSC KIPT: A Geant4 Simulation Study

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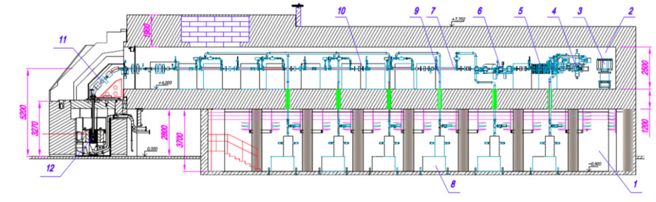
Roadmap (5 minutes)

1. What is NSC KIPT neutron source and why it matters.
2. Physics basis: electron-driven neutron generation in ADS.
3. Goal of this work and simulation strategy.
4. Geant4 model: beam + target configuration.
5. Comparative results for W-Ta and U-Mo targets.

1) What is the NSC KIPT neutron source?

- NSC KIPT is an **Accelerator Driven System (ADS)** for neutron science.
- Mission: neutron research, isotope production, and reactor-physics studies.
- The source combines a high-power electron LINAC and a subcritical assembly.



Source image: repository blueprint file.

1) Context and status

- Internationally developed by NSC KIPT with external partners.
- Physical start-up was completed before full-scale wartime disruption.
- Current priority: safe operation support and model-based optimization.

Why this study now:

- choosing the best target material affects neutron output and reliability,
- simulation reduces technical risk before full-power campaigns.

Literature basis: `Info_from referenses.md`.

2) Physics behind NSC KIPT neutron source

- Main chain in the target:

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

- 100 MeV electrons produce bremsstrahlung photons in heavy plates.
- Hard photons induce photonuclear reactions and generate primary neutrons.
- In U-Mo, additional photo-fission channels increase neutron production.

Sources: `Data/physics_model_principles.md`, `Info_from referenses.md`.

2) Subcritical assembly principle

- The neutron source drives a **subcritical** core ($k_{\mathrm{eff}} < 1$).
- Multiplication factor:

$$M = (1 - k_{\mathrm{eff}})^{-1}$$

- Safety principle: chain reaction is beam-dependent and stops with beam shutdown.
- Design trade-off: maximize neutron economy while preserving robust margins.

Literature basis: `Info_from referenses.md`.

3) Goal of this work

- Perform a **comparative Geant4 assessment** of W-Ta and U-Mo targets.
- Quantify neutron/photon yields and engineering risk proxies.
- Build an evidence-based recommendation for target selection.

Primary KPIs (per electron):

- `neutrons_model_exit_per_electron`
- `photons_above5MeV_per_electron`
- plate-wise: NIEL, H production, He production.

4) Geant4 model and configurable beam parameters

- Physics list: `QGSP_BIC_HPT`.
- Beam setup from `runmeta.json`:

Energy	100 MeV
Relative spread	1%
σ_x, σ_y	1 mm, 1 mm
$\sigma_{\theta x}, \sigma_{\theta y}$	1 mrad, 1 mrad
Power mode	CW, $P_{avg} = 100$ kW

Source: `Data/20260211_172835_W-Ta/runmeta.json`.

4) Target model and geometry in simulation

- Plate assembly with water gaps and Ta cladding.
- Target options compared: **W-Ta** and **U-Mo**.
- Key geometry controls from `runmeta.json`:

- plate thickness set: 2.5–9.5 mm,
- plate footprint: 65.8 mm,
- water gap: 2 mm,
- total assembly thickness: 120 mm.

Source: `Data/20260211_172835_W-Ta/runmeta.json`.

4) Beam visualization (GIF planned in final version)

Placeholder
A dedicated animated slide (GIF) for beam transport/interaction will be inserted in the final conference deck export.

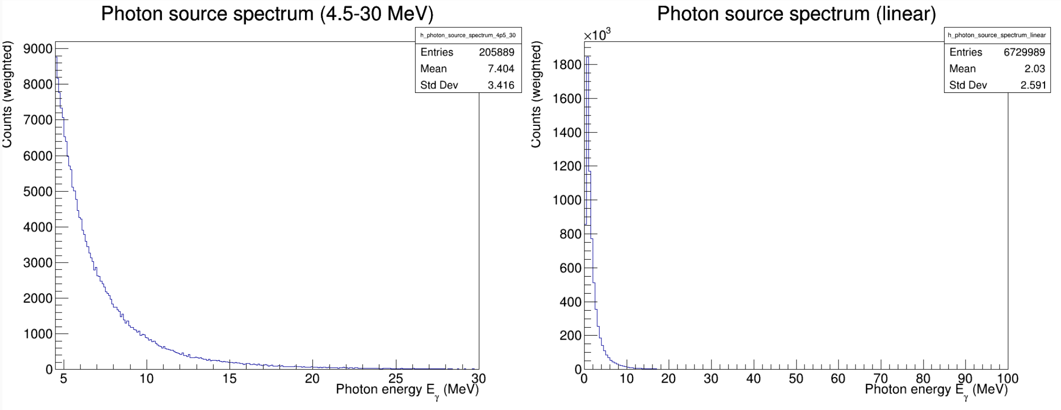
- Current static deck keeps this slot to preserve timing and narrative flow.
- Suggested source for GIF frames: plate and exit maps from simulation outputs.

5) Validation-style summary table (per primary electron)

Metric	W-Ta	U-Mo
neutrons_per_electron	0.00798	0.02669
photons_per_electron	0.6728	1.6825
n model exit / e	0.02196	0.04418
$\gamma(E > 5\,\text{MeV})$/e	3.7238	3.9245

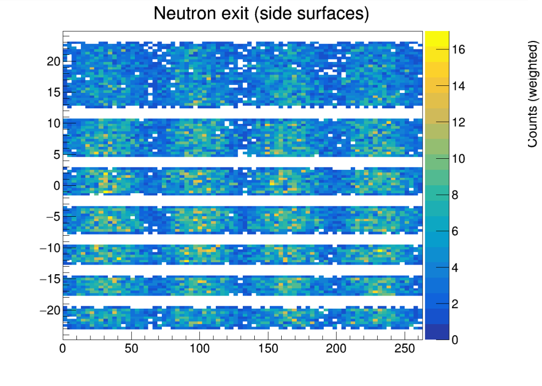
Source: `particle_yields_per_electron.json` for both targets.

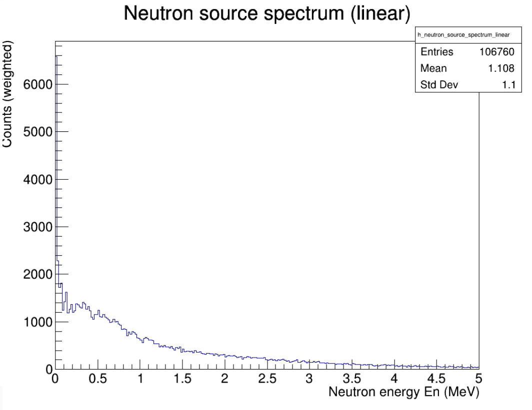
5) Photon spectra comparison (two required views)



Left: `photon_source_spectrum_4p5_30`. Right: `photon_source_spectrum_linear`.

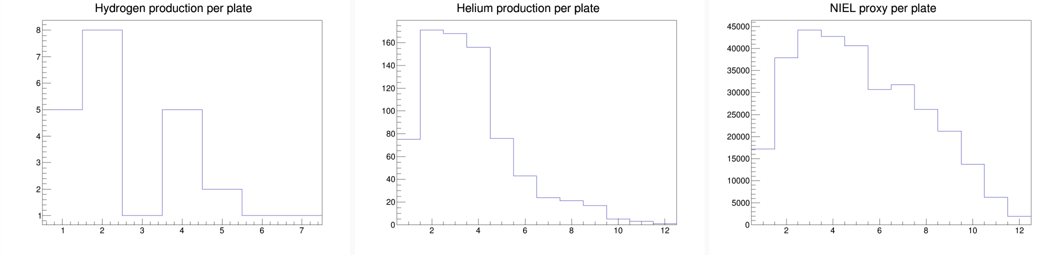
5) Neutron spectra/maps: side-surface and linear spectrum





Required items: `h2_neutron_exit_side_surface` and linear neutron spectrum.

5) Plate-level engineering proxies (W-Ta vs U-Mo)

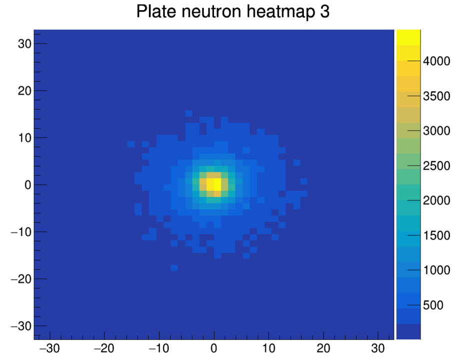


Required outputs: `h1_gas_h_plate`, `h1_gas_he_plate`, `h1_niel_plate`.

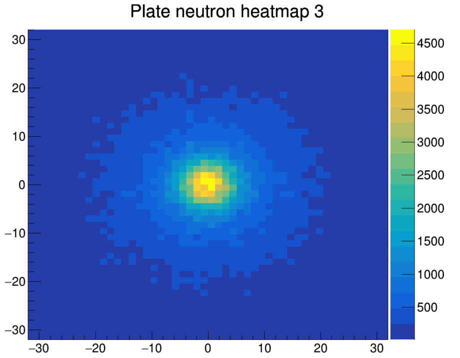
5) Neutron heatmap animation slot (GIF planned)

Placeholder for final visual

GIF assembled from `plate_neutron_heatmap_*.png` frames for both target options.



W-Ta frame



U-Mo frame

Conclusion

- The developed Geant4 workflow provides a consistent W-Ta vs U-Mo comparison.
- Current outputs show higher neutron productivity indicators for U-Mo.
- Final decision must balance yield vs thermal load and radiation damage proxies.
- Next step: finalize uncertainties and freeze the conference version of all figures.

References

- Geant4 Collaboration, *Geant4—a simulation toolkit*, NIM A 506 (2003) 250–303.
- Geant4 physics-list documentation (QGSP_BIC_HPT).
- Project physics notes: `Data/physics_model_principles.md`.
- Literature digest for NSC KIPT context and yields: `Info_from referenses.md`.
- Run outputs: `Data/20260211_172835_W-Ta/*`, `Data/20260212_072836_U-Mo/*`.