

Supplementary Table S1 | Geant4 11.2.2 particle transport simulation results for all nineteen runs of the RADIANT shield

Layer-wise mean energy deposition (MeV per primary event) and primary particle transmission statistics from Geant4 11.2.2 Monte Carlo simulation (QGSP\_BIC\_HP physics list; high-precision neutron transport; 1,000,000 primary events per run; fixed seed 12345). **Transmission (%)**: primary particles exiting the shield with positive z-momentum. **Attenuation (%)**: = 100 – Transmission (%). **Total MeV/event**: sum of mean layer depositions. **Scint. Frac. (%)**: fraction of total deposited energy in Layer 3 (scintillation layer); not applicable (N/A) for Al comparison runs. **Bold text and blue highlighting**: complete stopping (≥99.99% attenuation). **Green highlighting**: angular dependence study runs. **Yellow highlighting**: aluminium comparison runs. **Layer assignments (RADIANT)**: L0 = W (1.0 mm); L1 = HBGPE (10.0 mm); L2 = Al 6061 (1.5 mm); L3 = Scintillation epoxy (5.0 mm); L4 = Graphene-PCL (3.0 mm); L5 = Kapton HN (0.5 mm). **Al comparison runs**: L0–L5 = six equal 3.5 mm aluminium slices (21.0 mm total).

| Run ID | Particle | Energy    | Angle | Shield   | Transmitted<br>(of 1,000,000) | Trans.<br>(%) | Atten.<br>(%) | Total<br>MeV/event | L0 W<br>(MeV) | L1 HBGPE<br>(MeV) | L2 Al<br>(MeV) | L3 Scint<br>(MeV) | L4 G-PCL<br>(MeV) | L5 Kapton<br>(MeV) | Scint.<br>Frac. (%) |
|--------|----------|-----------|-------|----------|-------------------------------|---------------|---------------|--------------------|---------------|-------------------|----------------|-------------------|-------------------|--------------------|---------------------|
| P1     | Proton   | 10 MeV    | 0°    | RADIANT  | 0                             | 0.00          | 100.00        | 9.9993             | 9.9993        | 0.0000            | 0.0000         | 0.0000            | 0.0000            | 0.0000             | 0.00                |
| P2     | Proton   | 100 MeV   | 0°    | RADIANT  | 958,673                       | 95.87         | 4.13          | 30.0153            | 7.4176        | 9.0979            | 2.7245         | 6.4082            | 3.7392            | 0.6279             | 21.35               |
| P3     | Proton   | 1 GeV     | 45°   | RADIANT  | 937,552                       | 93.76         | 6.24          | 15.6164            | 4.4746        | 4.7388            | 1.3649         | 3.0926            | 1.6757            | 0.2697             | 19.80               |
| E1     | Electron | 0.1 MeV   | 0°    | RADIANT  | 0                             | 0.00          | 100.00        | 0.0604             | 0.0604        | 0.0000            | 0.0000         | 0.0000            | 0.0000            | 0.0000             | 0.00                |
| E2     | Electron | 1 MeV     | 45°   | RADIANT  | 0                             | 0.00          | 100.00        | 0.5691             | 0.5681        | 0.0005            | 0.0001         | 0.0003            | 0.0001            | 0.0000             | 0.05                |
| E3     | Electron | 10 MeV    | 0°    | RADIANT  | 58,741                        | 5.87          | 94.13         | 7.4754             | 4.3793        | 1.9460            | 0.4131         | 0.5783            | 0.1428            | 0.0159             | 7.74                |
| G1     | Gamma    | 0.1 MeV   | 0°    | RADIANT  | 101                           | 0.01          | 99.99         | 0.0908             | 0.0907        | 0.0000            | 0.0000         | 0.0000            | 0.0000            | 0.0000             | 0.02                |
| G2     | Gamma    | 1 MeV     | 45°   | RADIANT  | 817,599                       | 81.76         | 18.24         | 0.2124             | 0.1071        | 0.0465            | 0.0139         | 0.0291            | 0.0138            | 0.0021             | 13.68               |
| A1     | Alpha    | 25 MeV/n  | 0°    | RADIANT  | 0                             | 0.00          | 100.00        | 99.4776            | 99.4392       | 0.0303            | 0.0018         | 0.0042            | 0.0019            | 0.0002             | 0.00                |
| A2     | Alpha    | 250 MeV/n | 0°    | RADIANT  | 928,822                       | 92.88         | 7.12          | 61.1742            | 17.0415       | 18.5327           | 5.4529         | 12.2202           | 6.7995            | 1.1273             | 19.98               |
| N1     | Neutron  | 1 MeV     | 0°    | RADIANT  | 801,032                       | 80.10         | 19.90         | 0.3410             | 0.0055        | 0.2256            | 0.0017         | 0.0643            | 0.0407            | 0.0032             | 18.86               |
| N2     | Neutron  | 14 MeV    | 0°    | RADIANT  | 903,451                       | 90.35         | 9.65          | 0.7564             | 0.0247        | 0.3857            | 0.0435         | 0.1686            | 0.1172            | 0.0167             | 22.29               |
| P2a    | Proton   | 100 MeV   | 15°   | RADIANT  | 957,323                       | 95.73         | 4.27          | 31.2313            | 7.6844        | 9.4578            | 2.8363         | 6.6896            | 3.9073            | 0.6559             | 21.42               |
| P2b    | Proton   | 100 MeV   | 30°   | RADIANT  | 951,379                       | 95.14         | 4.86          | 35.4925            | 8.6060        | 10.6968           | 3.2283         | 7.6631            | 4.5311            | 0.7671             | 21.59               |
| P2c    | Proton   | 100 MeV   | 45°   | RADIANT  | 937,182                       | 93.72         | 6.28          | 45.6023            | 10.6195       | 13.5250           | 4.1515         | 10.0812           | 6.1628            | 1.0622             | 22.11               |
| P2d    | Proton   | 100 MeV   | 60°   | RADIANT  | 699,096                       | 69.91         | 30.09         | 77.4439            | 15.3464       | 20.9579           | 6.8817         | 18.7781           | 13.2237           | 2.2562             | 24.25               |
| AL1    | Proton   | 100 MeV   | 0°    | Al 21 mm | 946,010                       | 94.60         | 5.40          | 38.4794            | 5.6484        | 5.9184            | 6.1867         | 6.5074            | 6.8756            | 7.3429             | N/A                 |
| AL2    | Electron | 10 MeV    | 0°    | Al 21 mm | 22,608                        | 2.26          | 97.74         | 9.2958             | 1.5859        | 1.9373            | 2.2244         | 1.9951            | 1.1977            | 0.3553             | N/A                 |
| AL3    | Neutron  | 1 MeV     | 0°    | Al 21 mm | 907,020                       | 90.70         | 9.30          | 0.0193             | 0.0032        | 0.0033            | 0.0033         | 0.0033            | 0.0032            | 0.0030             | N/A                 |

■ P = proton; E = electron; G = gamma; A = alpha; N = neutron; AL = aluminium comparison.

■ Alpha energies given as MeV/nucleon; total kinetic energy = energy per nucleon × 4.

■ Mean statistical uncertainty: ±3.1% across all runs; maximum ±5.4%.

■ Source code, macro files, and per-event CSV output: <https://doi.org/10.5281/zenodo.20435654>