Secondary Gamma Production

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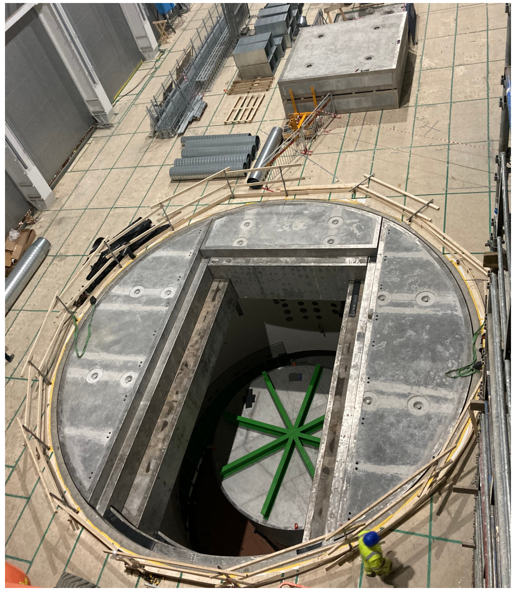
What problems am I solving?
What data am I using?

- Applications
  - Shielding for high energy accelerators
    - Shielding around a spallation target and along neutron beamlines
    - Shielding along a proton accelerator
  - Shielding for criticality safety
    - Shielding at fissile material facilities
    - Detector response to criticality accidents

Installing bunker shielding blocks at ESS

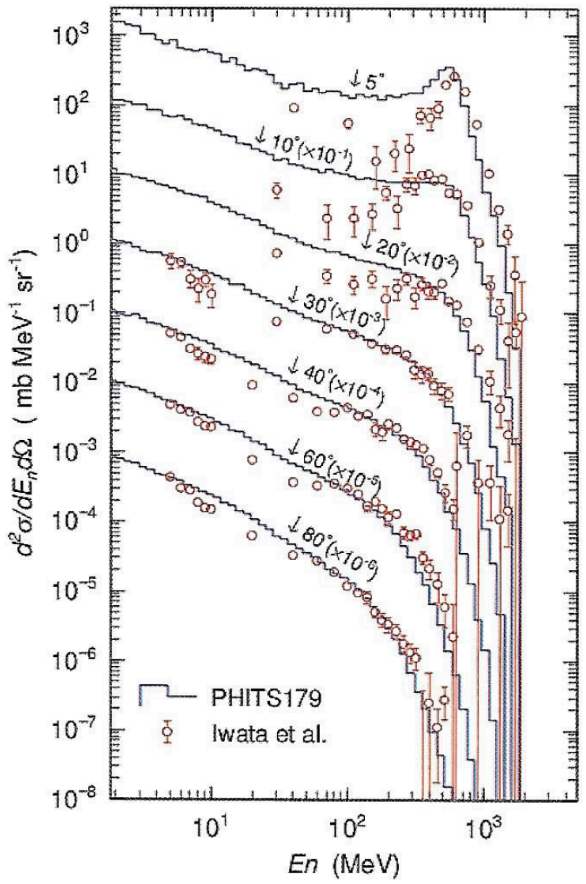
- Cross sections
  - Less than 20 MeV
    - ENDF/B, including thermal scattering kernels
    - Usually processed by NJOY (MCNP) or AMPX (SCALE)
  - Greater than 20 MeV
    - Some ENDF/B
    - A little TENDL (currently 2019)
    - Mostly nuclear models (CEM, Bertini, and associated evaporation models)

ESS open shielding monolith



How do I validate data / codes

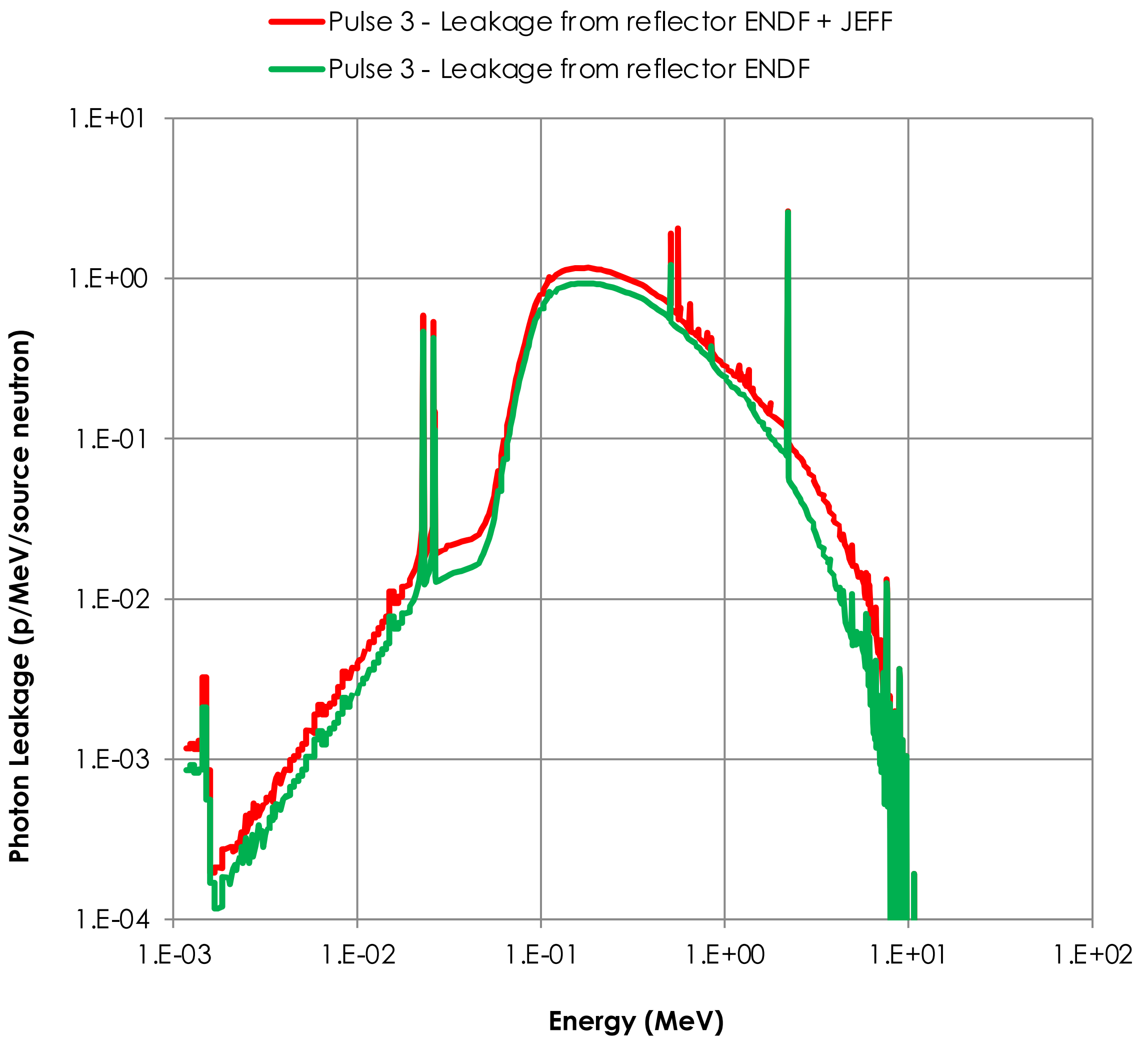
- In my experience, validation like that done by criticality safety practitioners is not common in the shielding community
- At fission / fusion facilities the benchmarks in SINBAD and the alarm / shielding portion of the ICSBEP handbook are useful
- SINBAD and the text by Nakamura and Heilbronn (*Handbook on Secondary Particle Production…*) have benchmarks relevant to accelerator facilities
- Otherwise, there are many individual conference papers and journal articles, but these descriptions are not always complete enough for benchmarking
- Rather than perform validation and determine a bias, most facilities requiring shielding analysis specify a “safety factor”
  - I have seen safety factors range from 20% to 5



Comparison of double differential neutron production cross sections for 600 MeV/A Ne on Pb (Nakamura and Heilbronn)

Data Problem: missing gamma production data

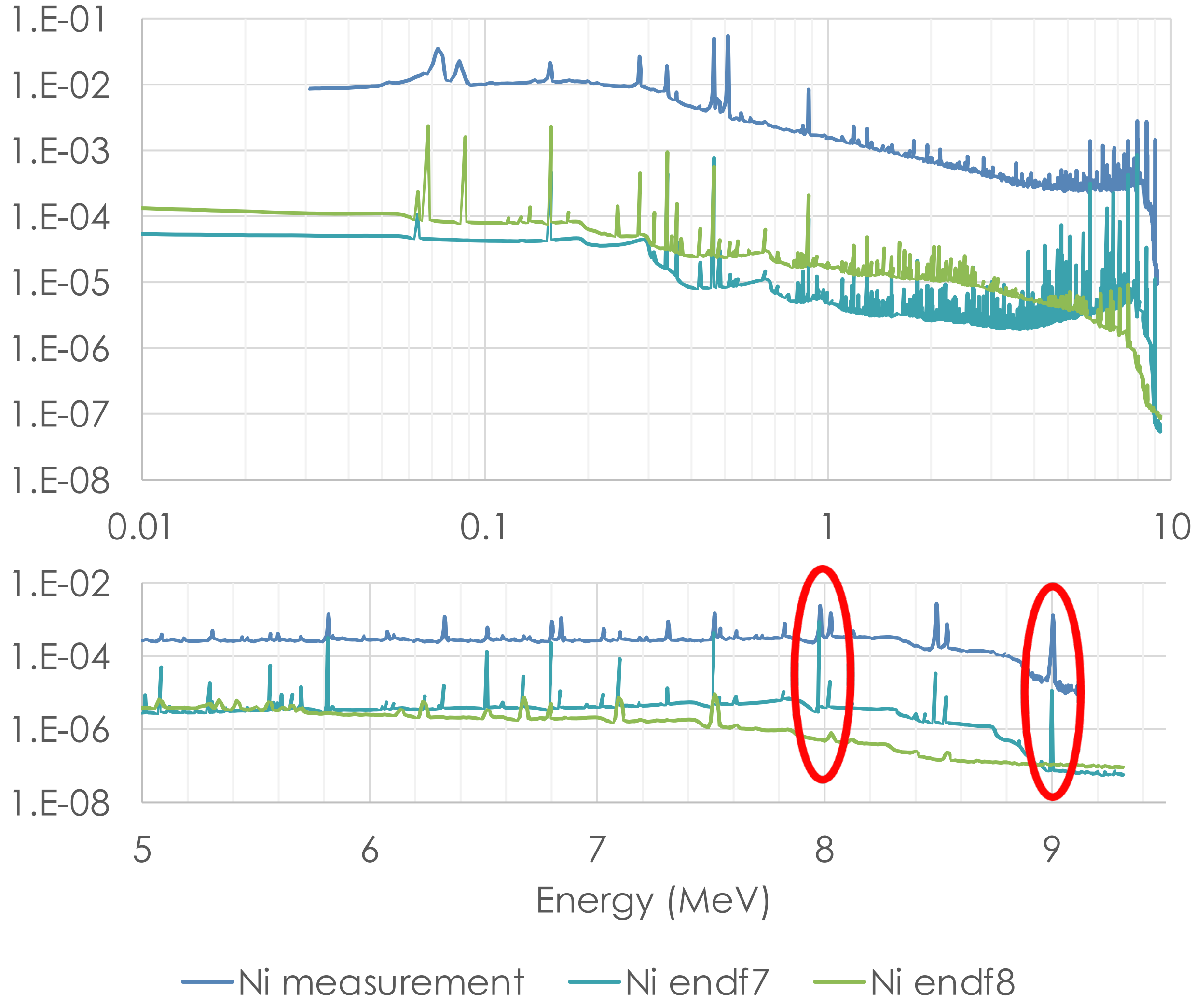
- ENDF (7 and 8) only has gamma production data for Cd-106 & 111. JEFF has these plus 110 and 113.
  - Cd-113 is a well know strong thermal absorber
- ALARM-TRAN-CH2-SHIELD-001 (ICSBEP) compares gamma dose measurements (TLD) and simulations
  - Simulations with ENDF underestimate the dose 30-40%
  - Simulations with JEFF underestimate the dose 10-20%
  - One sigma uncertainties for the dose measurements are 7-9%



Data Problem: inconsistent gamma production data

- Shielding around an instrument at the end of a neutron beamline is often dominated by gamma production in the neutron supermirrors (Ni, Ti, Mo, etc.)
- Measurements were performed by ESS at ILL in France to benchmark simulations of gamma production in neutron supermirrors
  - The gamma production in Ni is very different between ENDF 7 and 8
  - Important characteristic lines present in ENDF 7 are not in 8 (IAEA STI/PUB/1263)
  - The overall energy release by capture gammas is the same
- You might be able to calculate an integral quantity (e.g., dose) correctly, but most likely one cannot reproduce spectra

Comparison between measurement and simulation with ENDF/B-VII.1 and VIII.0 (Normalization: simulations per source neutron, measurement arbitrary



Concluding Remarks

- Cross sections for gammas are mostly analytic, but cross sections to produce secondary gammas rely on neutron evaluations
- Benchmarks measuring integral quantities like gamma dose are helpful and needed
- Benchmarks that measure gamma spectra would be ideal
  - Be sure one can identify the element/isotope producing the gammas
  - Be sure the neutron energy is well defined