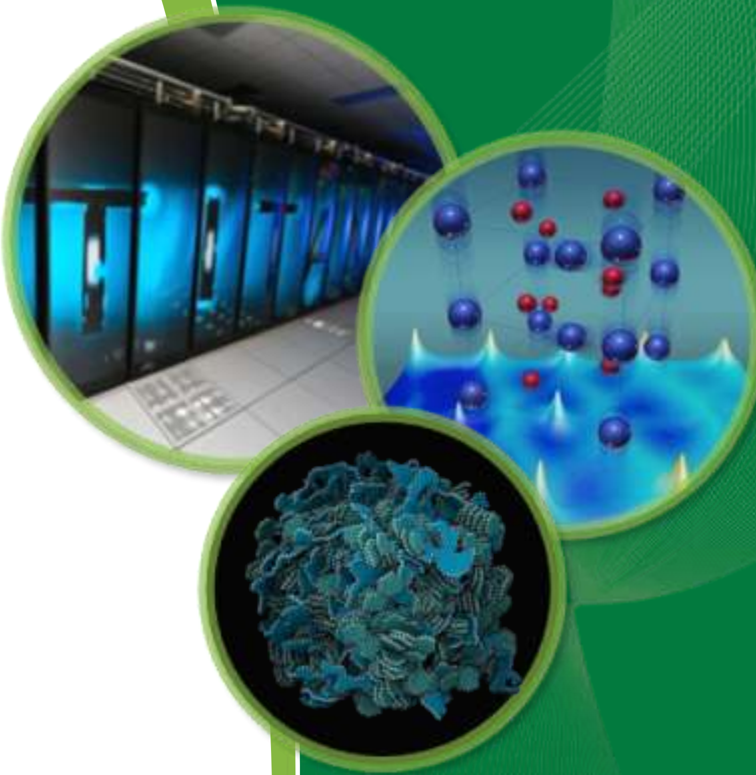
Analysis Capability and Data Needs Identified During the Evaluation of the SILENE CAAS Benchmarks



Presented by:

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I must recognize the contributions of my collaborators

- Oak Ridge National Laboratory
  - Design, measurements, documentation, and evaluation
  - T. M. Miller, C. Celik, M. E. Dunn, J. C. Wagner, and K. L. McMahan
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Outline

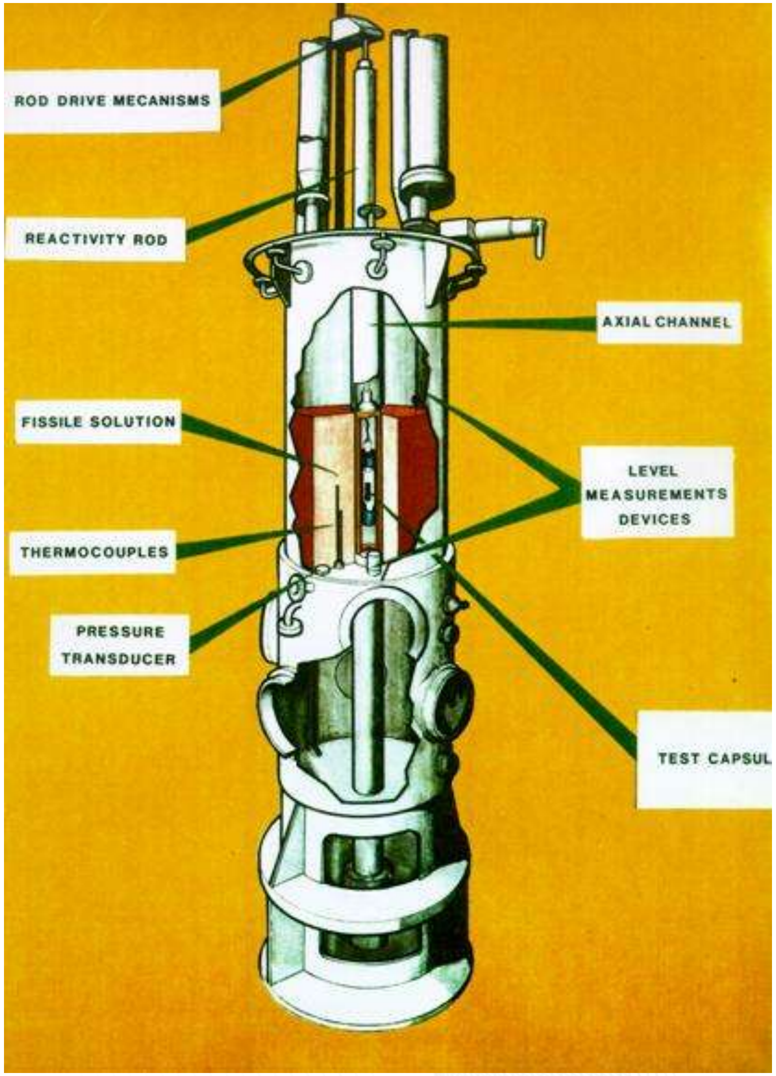
- BRIEF overview of experiment
- Data needs
  - Easy simulation of delayed neutrons and photons for shielding scenarios
  - Gamma production data
- Comparison of leakage spectra from pulses 1 and 3
- Summary and Conclusions

References (for more details)

- ICNC 2011 paper discussing the first experiment (pulse 1)
- NCSD 2013 paper discussing the second and third experiments (pulses 2 and 3)
- ICNC 2015 paper discussing concrete compositions
- ICSBEP evaluation of the first experiment was published at the end of 2015 and revised in 2016
- Evaluations of the second and third experiments published at the end of 2016

Introduction to SILENE

- Annular core
  - Internal cavity diameter 7 cm
  - Outer fuel diameter 36 cm
  - Typical critical height ~35 – 45 cm
- Uranyl Nitrate fuel Solution
  - ~93% ^{235}U
  - ~71 g of uranium per L
- Power level ranges from 10 mW to 1000 MW
- Three operating modes
  - Single pulse
  - Free evolution
  - Steady State

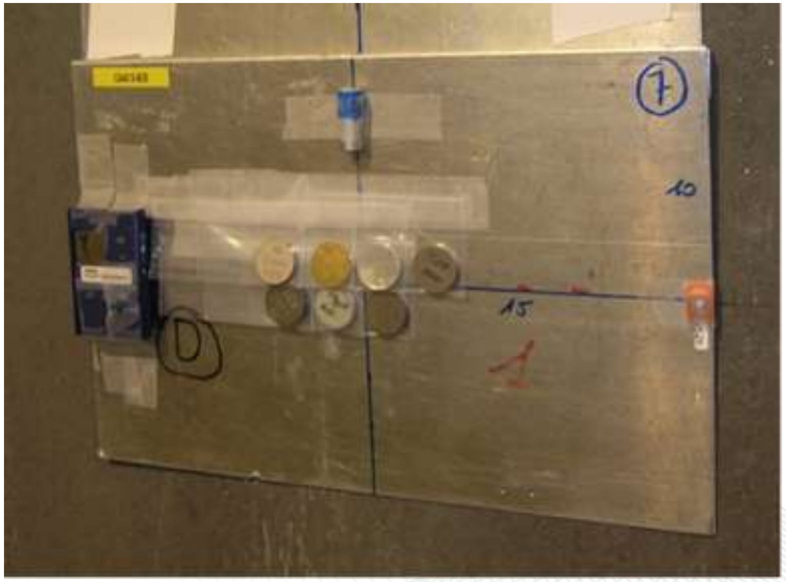


Photographs of bare SILENE and pulse 1 cell configuration

Photographs of collimators and detectors

Photographs of the free-field location and neutron activation foils

Photographs of scattering box and detectors



Experimental configurations (6)

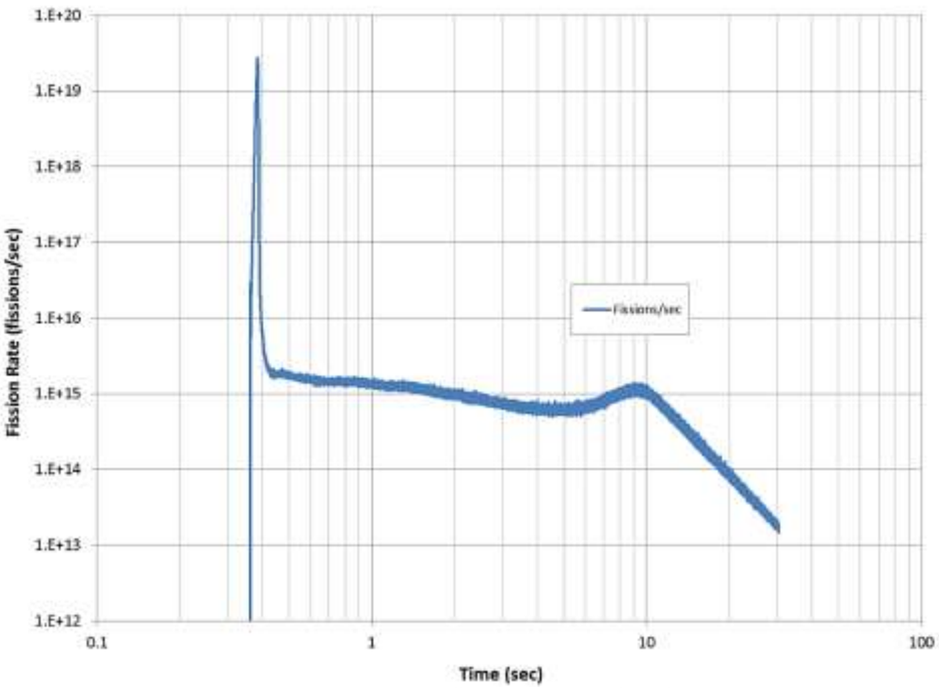
- Differences for pulse 3
  - SILENE polyethylene reflector
  - Collimator B – ~3 in. BoroBond

Delayed gamma contributions to pulse 1 TLD doses (1/3)

- The calculated TLD doses include prompt fission gammas and secondary gammas from neutron capture and inelastic scattering
  - Missing gammas from the decay of fission and activation products
- ORNL used ORIGEN to help estimate the contribution of delayed gammas to the collimator A TLD dose for pulse 1
- LLNL used the delayed gamma feature in COG to estimate the contribution of fission product gammas to all the TLDs
- These are estimates because the details about the solution draining from SILENE are not available
  - When did the solution start to drain and at what rate?

Delayed gamma contributions to pulse 1 TLD doses (2/3)

- The ORIGEN and COG estimates of fission product gamma doses assumed all the fuel was present for 30 seconds and then all drained immediately (a step function)
- MCNP6 ACT card shows promise, but not operational for this scenario



  - Critical system requires the NONU card to suppress multiplication (already included in source)
  - ACT card cannot produce fission product gammas with NONU card

Delayed gamma contributions to pulse 1 TLD doses (3/3)

- Collimator A delayed gamma doses using ORIGEN source

	Dose (Gy)	Rel. Unc.	Dose (Gy)	Rel. Unc.	Dose (Gy)	Rel. Unc.
Time (sec)	30.3		149		3600	
Fuel	9.500E-01	0.0043	0.000E+00	0.0000	0.000E+00	0.0000
Foils	2.120E-05	0.0062	5.270E-06	0.0026	2.500E-06	0.0021
Other	7.650E-04	0.0101	4.190E-04	0.0116	2.440E-06	0.0167
Total	9.508E-01	0.0043	4.243E-04	0.0115	4.940E-06	0.0083
Time (sec)	7200		10800		**Total**	
Fuel	0.000E+00	0.0000	0.000E+00	0.0000	**9.500E-01**	**0.0043**
Foils	1.170E-06	0.0021	5.470E-07	0.0021	**3.069E-05**	**0.0043**
Other	1.830E-06	0.0176	1.430E-06	0.0186	**1.190E-03**	**0.0077**
Total	3.000E-06	0.0108	1.977E-06	0.0135	**9.512E-01**	**0.0043**

  - 0.951 Gy from delayed gammas, mostly fission products, which is a 20% increase over no delayed gammas (comparison to simulation)
  - 27% under prediction of dose without delayed gammas, 13% with (comparison to measurement)

- Prompt + Delayed doses using COG delayed gamma fission product source

Location	Prompt + Delayed Dose (Gy)	Rel. Unc.	Ratio: with delayed / without delayed (simulation)	Ratio Rel. Unc.
Collimator A	5.810	0.0221	1.10	0.0304
Collimator B	0.999	0.0523	1.09	0.0728
Free Field	4.960	0.0236	1.16	0.0327
Scattering Box 1	0.639	0.0676	1.10	0.0934
Scattering Box 2	0.537	0.0743	1.01	0.1020
Scattering Box 3	1.610	0.0397	1.17	0.0547
Scattering Box 4	1.630	0.0393	1.13	0.0542

Barium gamma production data

- ENDF, JENDL, and CENDL do not contain any gamma production data for the naturally occurring isotopes of barium
  - ENDF does contain gamma production data for Ba-133
- JEFF contains gamma production data for Ba-134
- Collimator B shield for pulse 1 is barite concrete, which is ~32wt% barium
- The TENDL library based on models does contain gamma production data for barium
- Replacing the ENDF barium neutron cross sections with the TENDL neutron cross sections increases the calculated TLD dose in collimator B 7.6%

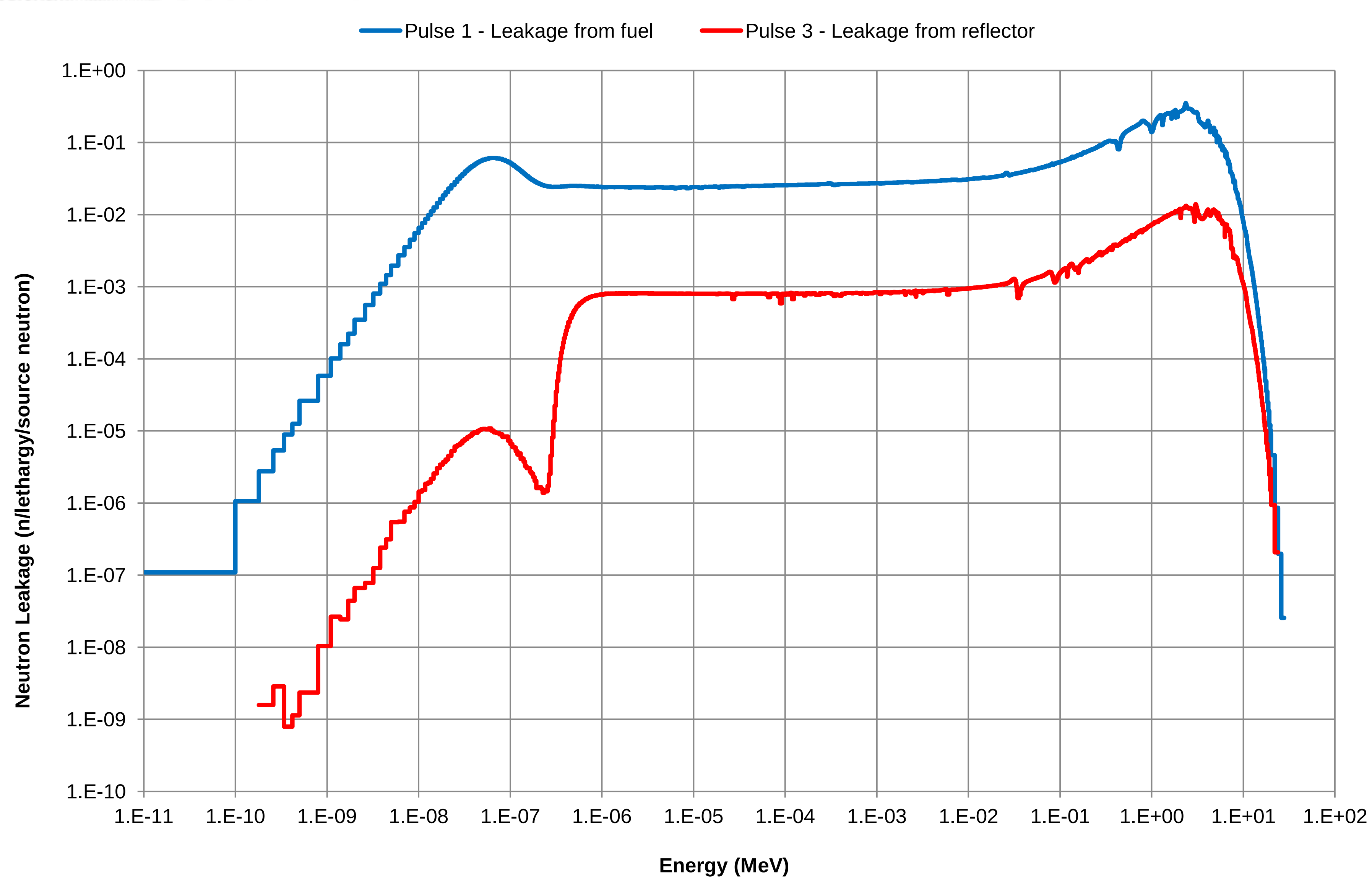
Cadmium gamma production data (1/2)

- Most of the evaluated data libraries based on measurements do not contain gamma production data for all cadmium isotopes
  - CENDL contains an elemental evaluation
- The polyethylene reflector / shield for pulse 3 has 0.7 mm of cadmium on the inner and outer surfaces
- Available gamma production data by cadmium isotope
  - Cd-106 (1.25 atom%): ENDF, JENDL, TENDL
  - Cd-108 (0.89 atom%): JENDL, TENDL
  - Cd-110 (12.49 atom%): JEFF, JENDL, TENDL
  - Cd-111 (12.8 atom%): ENDF, JEFF, JENDL, TENDL
  - Cd-112 (24.13 atom%): JENDL, TENDL
  - Cd-113 (12.22 atom%): JEFF, JENDL, TENDL
  - Cd-114 (28.73 atom%): JENDL, TENDL
  - Cd-116 (7.49 atom%): JENDL, TENDL

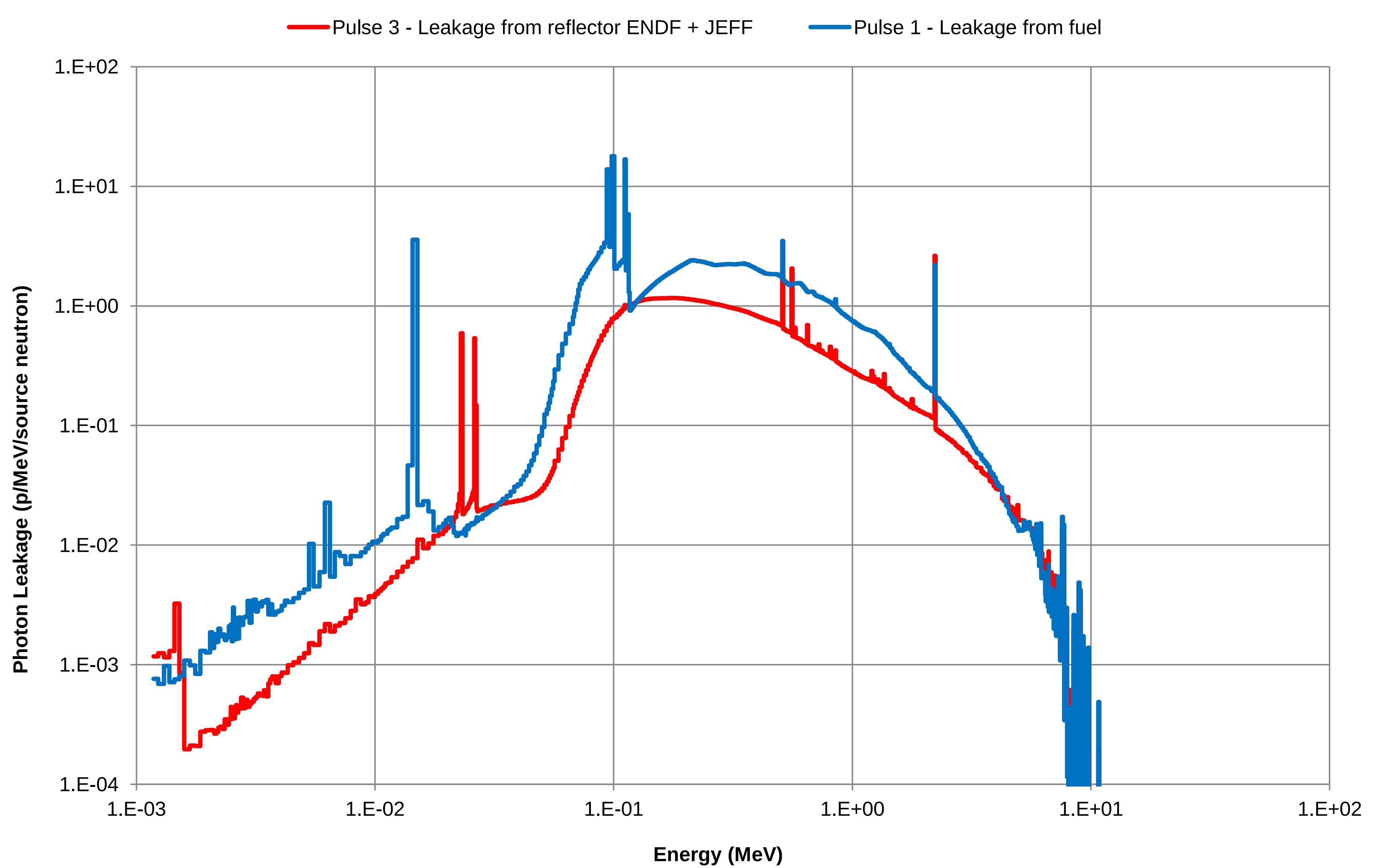
Cadmium gamma production data (2/2)

- When using cadmium neutron cross sections available in ENDF, pulse 3 TLD doses underestimated by 30 – 40%
  - Cd-106, Cd-111 (14.05 atom%)
- When adding JEFF cadmium neutron cross sections pulse 3 TLD doses underestimated by 10 – 20%
  - ENDF + Cd-110, Cd-113 (38.76 atom%)
- Adding the remaining isotope evaluations from JENDL and TENDL with gamma production data does not significantly change the calculated doses

Comparison of neutron leakage (pulse 1 & 3)



Comparison of photon leakage (pulse 1 & 3)



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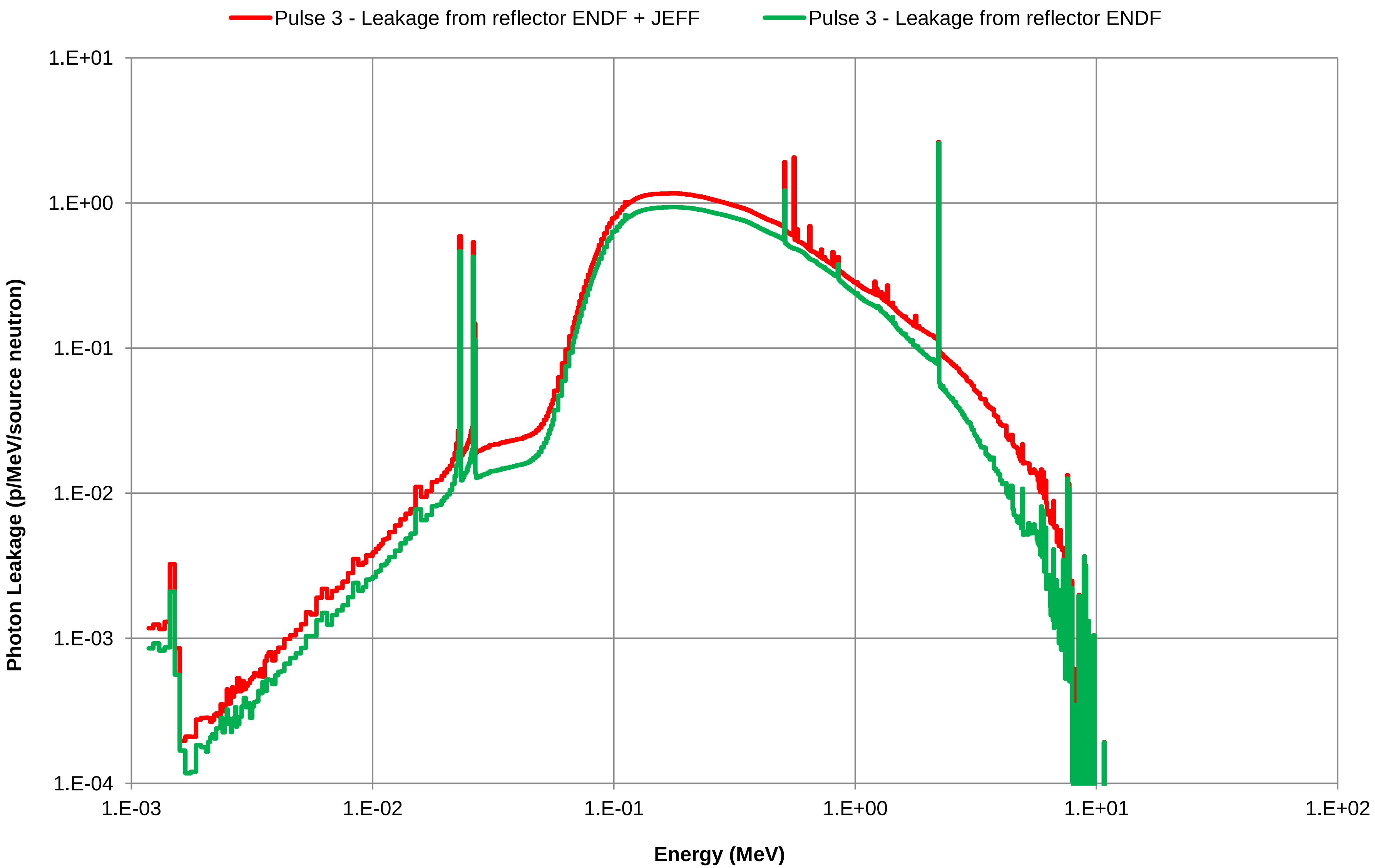
Comparison of photon leakage (pulse 3 Cd gamma production)



Summary and Conclusions

- The evaluation of all 3 SILENE CAAS benchmarks have been published and are publicly available
- We have identified a couple of data needs
  - Delayed fission product gammas within the available transport codes (to simplify the life of criticality safety analyst)
  - Improved gamma production data – lots of isotopes have none
  - The most egregious example is Cd-113

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