Adjusting ENDF U235 and U238

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Subtitle

Why the ENDF/B-VII average benchmark C/E for uranium-fueled benchmarks is so close to 1.000.

Answer: U235 ENDF/B-VI.3, 4, 5 and U238 ENDF/B-VII (not so much) were adjusted to make <k>=1 at all enrichments.

Some Opinions about Evaluation

- You can't ***measure*** cross sections well enough for reactor design purposes.
- You can't ***calculate*** cross sections well enough for reactor design purposes.
- When you do measure them, or do calculate them, you have no ***objective*** way of determining their accuracy.
- The only ***objective*** measure of quality is the agreement between differential and integral data.

Some Opinions about Evaluation

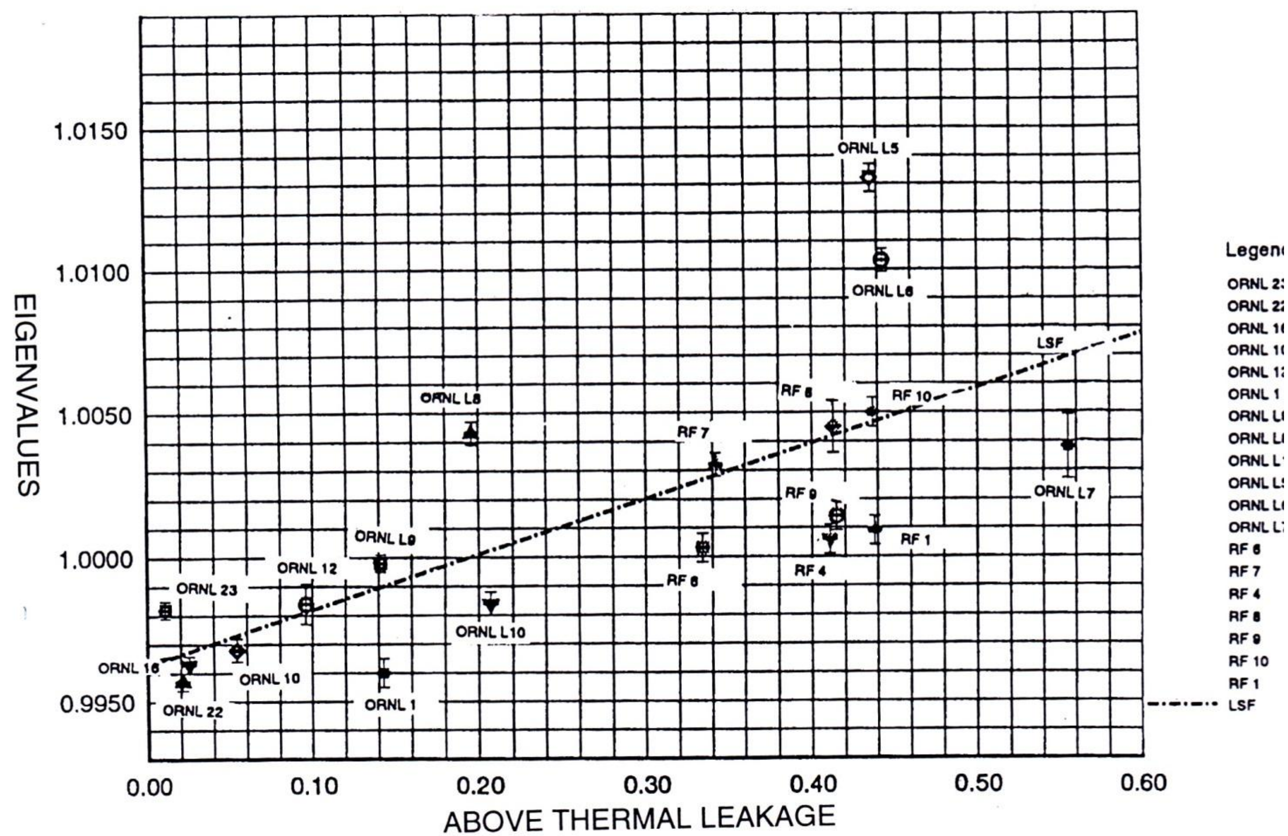
- ***They could both be wrong*** ... but even when they are, it’s still the best you can do ... and for most purposes it’s good enough.
- Experimental measurements establish a “volume”, not a “value”... and the evaluator is free to move about inside that “volume” to optimize ***the integral agreement***. It is “never” where the ***experimental average*** is.

Some History

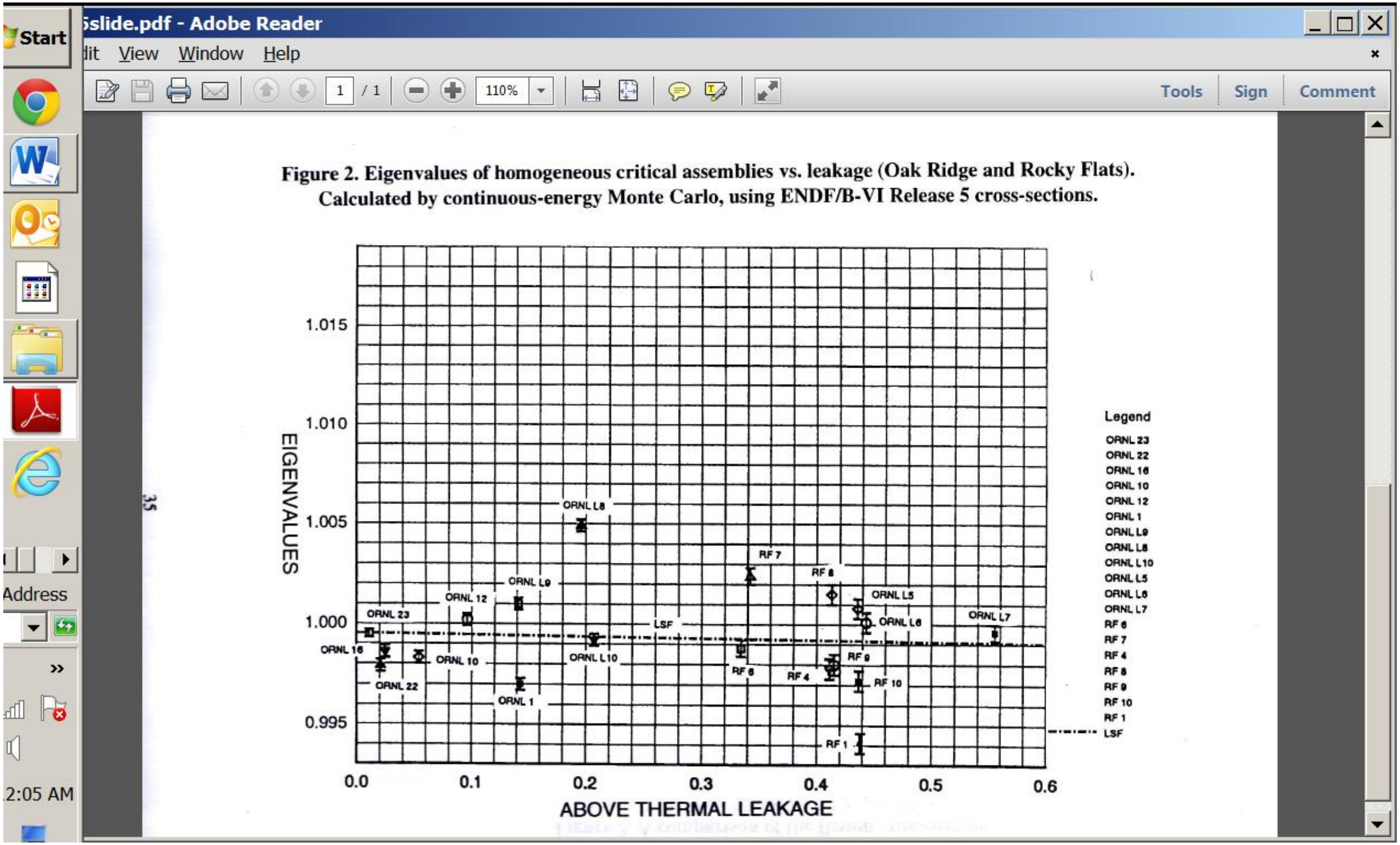
- Before ENDF/B-VI.0 (~1990) things worked OK by the standards of that era.
- ENDF60 U235 resonances done by ORNL (Leal et al) using a new R-matrix code SAMMY. High-energy by LANL, et al.
- The CSEWG thermal benchmark committee (Jud Hardy) pointed out that the capture resonance integral (132 barns) was 10 barns below the integral value so thermal benchmarks were high.

More history

Figure 1. Eigenvalues of homogeneous critical assemblies vs. leakage (Oak Ridge and Rocky Flats). Calculated by continuous-energy Monte Carlo, using ENDF/B-VI Release 0 cross-sections.



More history



More history

- ENDF61 and 62 fixed drooping eta but still had a rising trend with leakage.
- Skip Kahler pointed out that K1 was low relative to the “integral” value.
- In 1992 I noticed two things:

  1. DeSaussure’s measured capture cross section was significantly lower than the measurement of DeSaussure and Perez.

More history

2. The average radiation width in Mughabghab, 35 meV, was below the average obtained by actually averaging the values in the file. It had been used by Luiz in ENDF/B-VI.0-2.

- By trial and error with NJOY the capture integral went from 132 barns to 142 when $<\Gamma_\gamma>$ went from 35 meV to 38.2. Later, Mick Moxon analyzed ~15 individual resonances and decided that $<\Gamma_\gamma>$ was 38.2 meV. It will be hard to change that value because it harmonizes integral and differential data, which is the best you can objectively do.

Phase 1 => Phase 2

- In the big picture, that was “Phase 1 – ***Analysis***” .. figuring out where the important errors were.
- “Phase 2” was ***“Manufacture a credible file that works.”*** The details of how ENDF/B-VI.3 was put together are given in a Lockheed-Martin report KAPL-4825 (DOE/TIC-4500-R75). This is a brief overview.
- The first goal was to find ***adjusted resonance parameters*** that would increase epithermal alpha, the capture-to-fission ratio, from it’s low 0.48 to the integral value ~0.51.

More History

- It took about a year, working with Larry Weston, Jack Harvey, and Mick Moxon on the resonance parameters and with Skip Kahler, R.Q. Wright, and Jim Weinman who did the benchmarking.
- What finally worked was an iterative procedure applied to each ENDF/B-VI.2 resonance: Γ_n , Γ_γ , and Γ_f . The three widths were altered so as to achieve three changes:

Phase 2 - I

- 1. A new capture area ***carefully-designed*** to remedy the capture deficit.
- 2. A new fission area ***designed*** to keep the cross section at the low end of the measured range.
- 3. A peak-height constraint, meeting Weston's desire to treat his fission cross sections as equal to the total cross sections. If σ_t is the peak total and σ_f is the peak fission after adjustment and σ_{t0} , σ_{f0} are the original values, then

$$(\sigma_t-\sigma_{t0})/\sigma_{t0} = (\sigma_f-\sigma_{f0})/\sigma_{f0}$$

- It worked well. The results looked just like real cross sections.

Phase 2 - II

- Phase 2 also included an adjustment to K1, which is nu-fission **minus** absorption, using thermal Maxwellian averages to define capture and fission and a single value of thermal nubar.
- The desired change was from 721.2 to 723.0. At the time, the Standards value was 719.5. Note the role of the Standards, like the Atlas, in causing the low RIgamma and K1.
- To stay as close to the Standards as possible we started from those values and increased nubar and fission while decreasing capture, iteratively.

Phase 2 - III

- The adjustments were all done to the resonance parameters, in this case to the nine negative-energy ones.
- To account for the different uncertainties in the Standards values we imposed a condition on each step in the iteration: Each increment had to be the ***same percentage of its Standards uncertainty*** as the others.
- At each step we altered the capture and fission widths, made a new ENDF file and let NJOY give the 2200 m/s values.

Phase 2 - IV

- From those we calculated what nubar would give us the desired K1. Then we looked at how the changes related to their uncertainties and iterated again.
- The process converged at ***one-half of a standard deviation***, which coincidentally is where Allan Carlson said he would draw the line.
- The above work took about two years but finally matched the crucial quantities and cured the problems with ENDF/B-VI.0-2.

Phase 2 – V. What Release 3 Fit Correctly, Showing that it was Possible

1. RI_{γ}, RI_{f}, and epithermal α.
2. Experimental fission cross sections at the low end.
3. Experimental capture cross sections at the high end.
4. Fast benchmarks, inherited from Release 2.
5. Thermal benchmarks, fixing the Release 2 problems.
6. Moxon's $\langle \Gamma_{\gamma} \rangle = 38.2$ meV
7. Czirr self-indication experiments, same as Release 2.
8. "Standards" thermal cross sections, to 0.5 sigma.
9. Improved intermediate-spectrum benchmarks (Wright)
10. Improved fuel-cycle calculations (A. Jonsson)

Phase 3 – Replace Release 3 with a Conventional Reich-Moore Analysis ***that Works as Well***

- Subgroup 18 worked on this for about 4 years – Mick Moxon with REFIT and Luiz Leal with SAMMY, trying to do it without overt adjustment, ***but that is just not possible.***
- What finally worked was to bite the bullet and ***build the integral adjustments into SAMMY.***
- Even that wasn't enough and ***an adjustment to thermal nubar*** was required. The final product , ENDF/B-VI.5, is resistant to change, as the work of SG 29 showed, and is why it is still alive in VII.1

One slide on U238

- When we fixed U235 it uncanceled a previously-masked error in U238… a 600 pcm reactivity deficit that wreaked havoc with LEU's.
- Subgroup 22 took on that challenge. We got half of it from LANL and BRC who softened the inelastic spectrum and half from adjusting the average radiation width .. Although not without a real effort to avoid it.
- Derrien worked for years to get it from a normal SAMMY analysis. Courcelle came to ORNL and gave it another try. ***Unfortunately, the best fit to integral agreement is not the experimental average.***