H-2 & UO2 Data Testing at AECL

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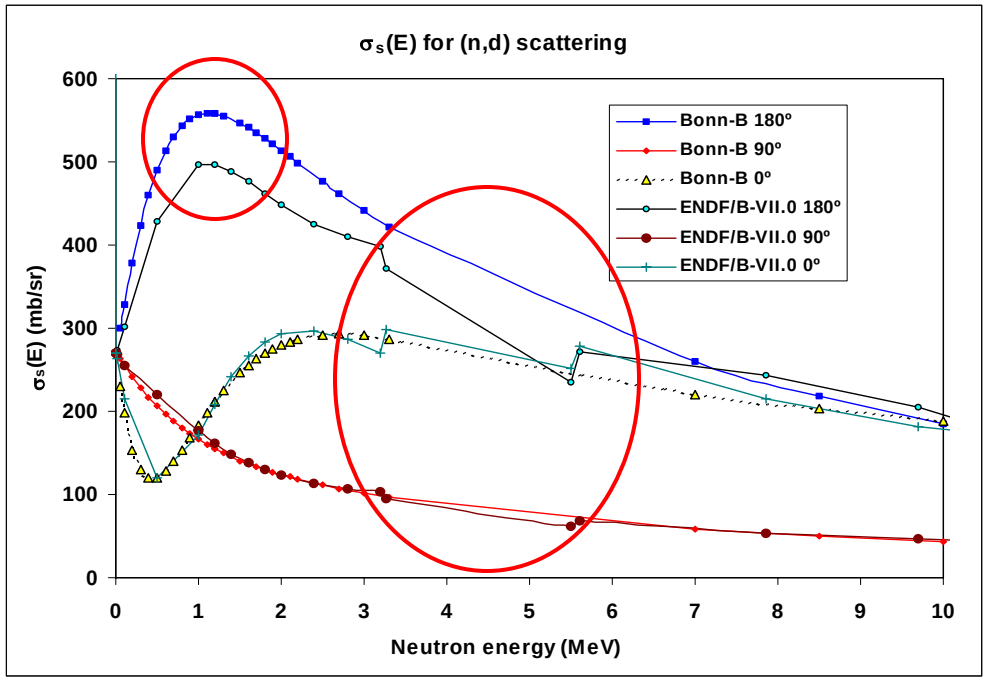
AECL EACL

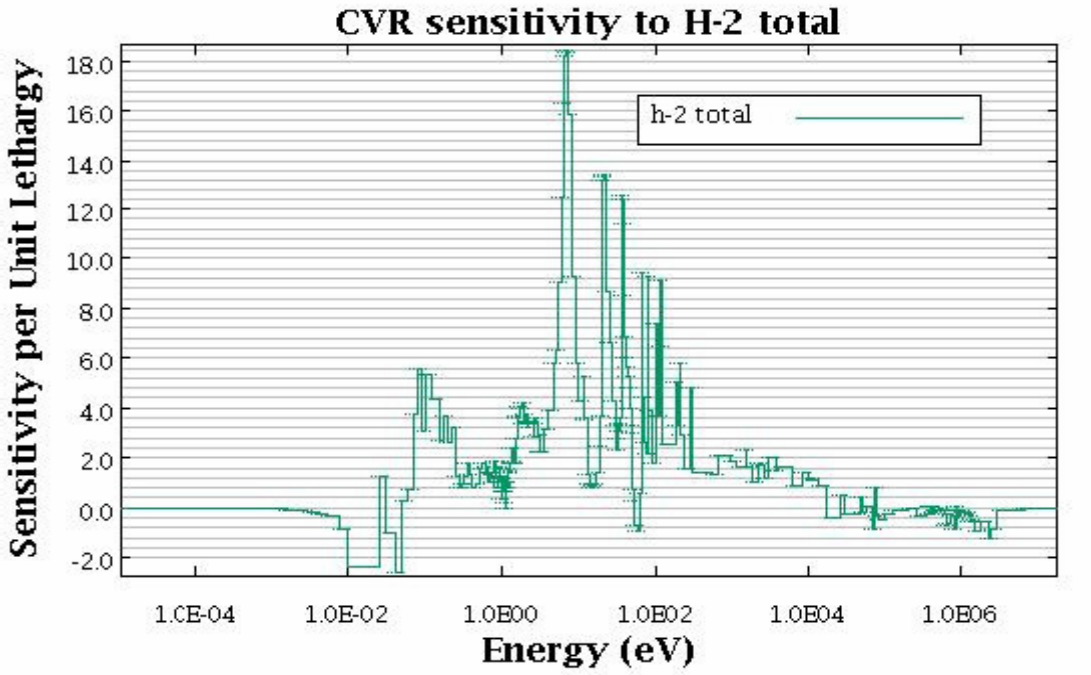
Nuclear-theory calculations for ^{2}H *(L. Canton - Universita di Padova; J. Svenne - University of Manitoba & Winnipeg Institute for Theoretical Phyiscs)*

- Earlier work showed significant differences between ENDF/B-VI.5 to VII.0 & theory, especially at backward scattering angles at ~1 MeV
- Discontinuities in ENDF data in the 3 to 6 MeV range
- Noticeable impact of different ENDF ^{2}H data files on HEU critical measurements (~10 mk) & ZED-2 Coolant Void Reactivity (CVR) bias (~0.6 mk)



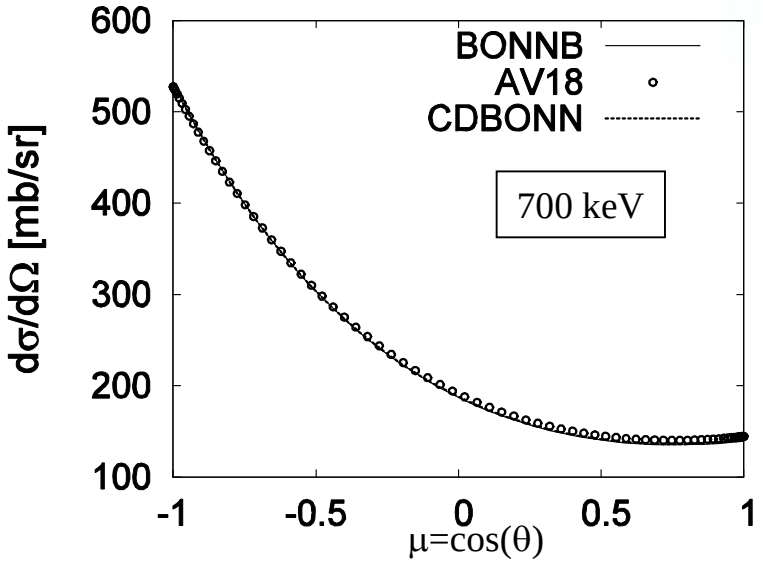
^{2}H sensitivity coefficient

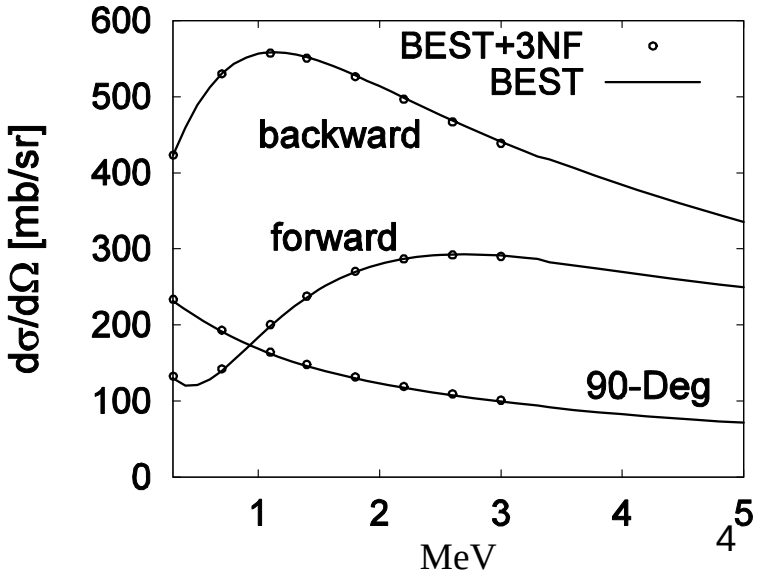
- **For ACR-700 CVR, ^{2}H elastic cross section has the largest sensitivity (~34.2) based on TSUNAMI (but can't address angular dependence):** ***Sensitivity Analysis of Reactivity Responses Using One-Dimensional Discrete Ordinates and Three-Dimensional Monte Carlo Methods,*** *M.L. Williams, J.C. Gehin & K.T. Clarno, PHYSOR-2006*
- **Similar results for ZED-2 CVR TSUNAMI analyses**
- **Confirms ZED-2 CVR experiments as a useful test of ^{2}H data**



New nuclear-theory calculations

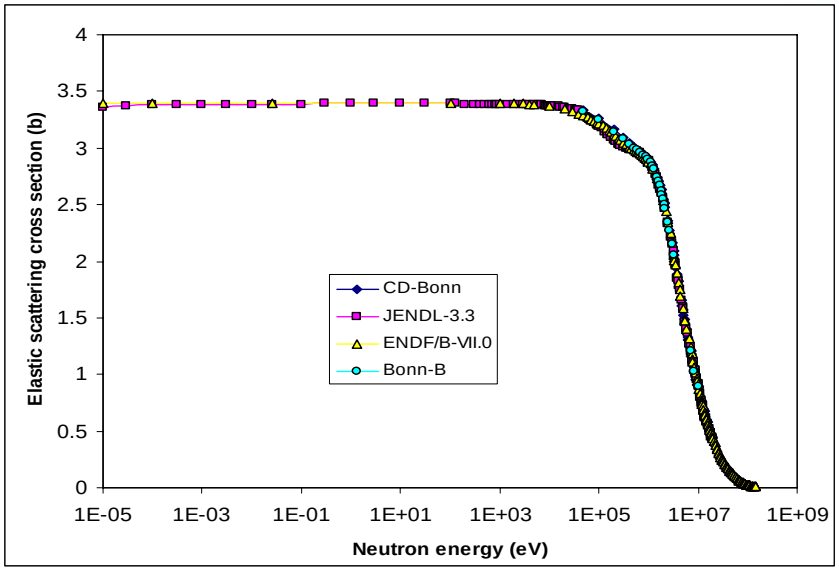
- Based on solving the Faddeev equation using the formulation by Alt-Grassberger-Sandhas (AGS)
- Various potentials: BonnB, CDBonn, AV18, BEST2000, CDBest2000: little impact on $\sigma_{elastic}(E,\mu)$
  - Additional BonnB $\sigma_{elastic}(E,\mu)$ data from 3 to 10 MeV
  - New CDBonn $\sigma_{elastic}(E,\mu)$ data from 50 keV to 29 MeV
- 3-nucleon forces (3NF): little impact on $\sigma_{elastic}(E,\mu)$
- See:
  - *Analysis of neutron deuteron scattering for science and atomic applications*, L. Canton, K.S. Kozier & J.P. Svenne, The 2nd International Conference Current Problems in Nuclear Physics and Atomic Energy,June 9 - 15, 2008, Kyiv, UKRAINE
  - *Nuclear Theory – Nuclear Power*, J.P. Svenne, L. Canton, and K.S. Kozier, Latvian Journal of Physics & Technical Sciences,Vol. 45, No. 4, 2008
- To come: magnetic interaction, extension to lower energies

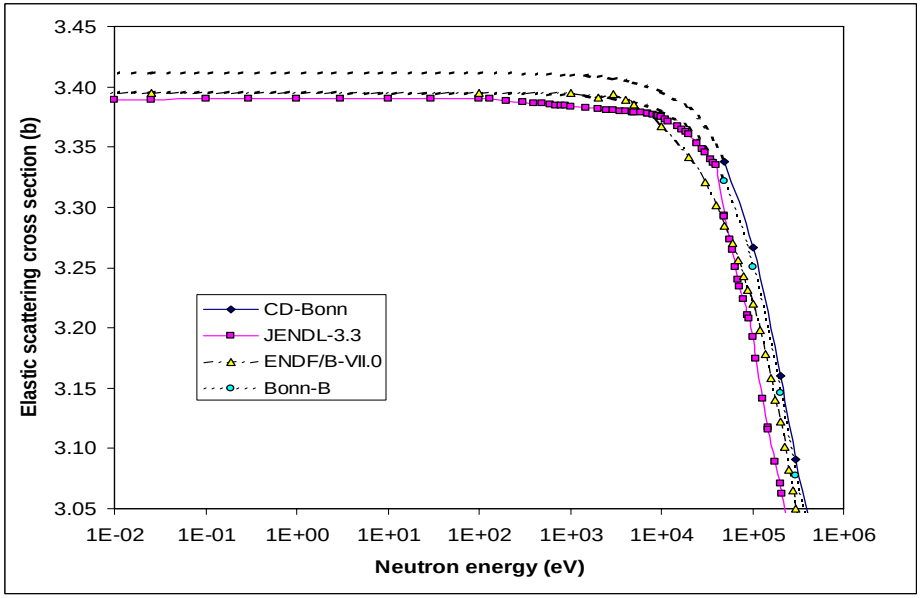


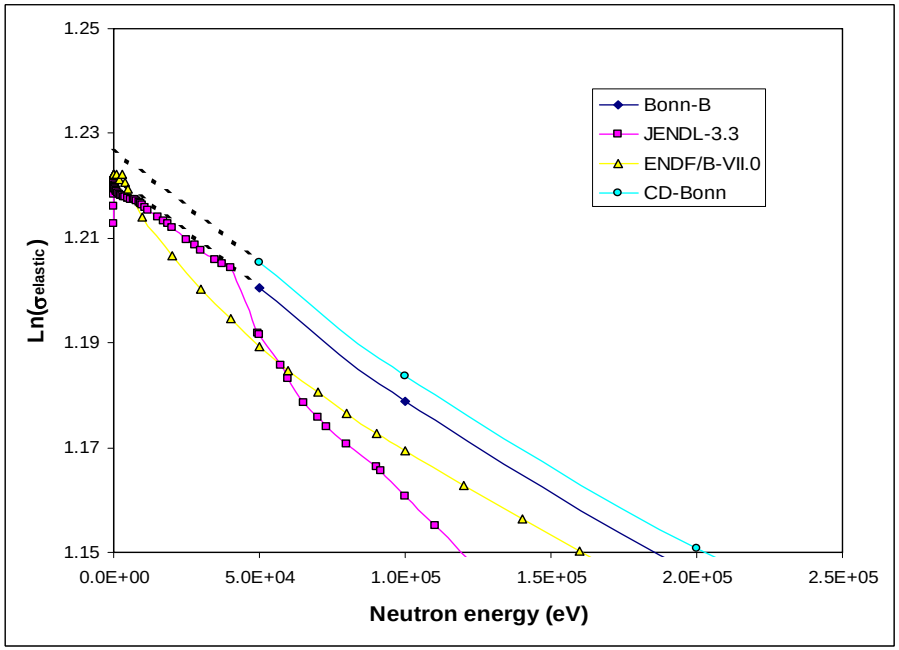


^{2}H elastic scattering cross section comparison (unprocessed ENDF data)

- Small noticeable differences between Bonn-B & CD-Bonn data at low energies (~1%); good agreement between Bonn-B & ENDF/B-VII.0
- Linear extrapolation of Ln($\sigma_{elastic}$) vs E at low energies (?)
- Drop in JENDL-3.3 $\sigma_{elastic}$ at low E due to being based on $\sigma_{total} - \sigma_{capture}$ (?)

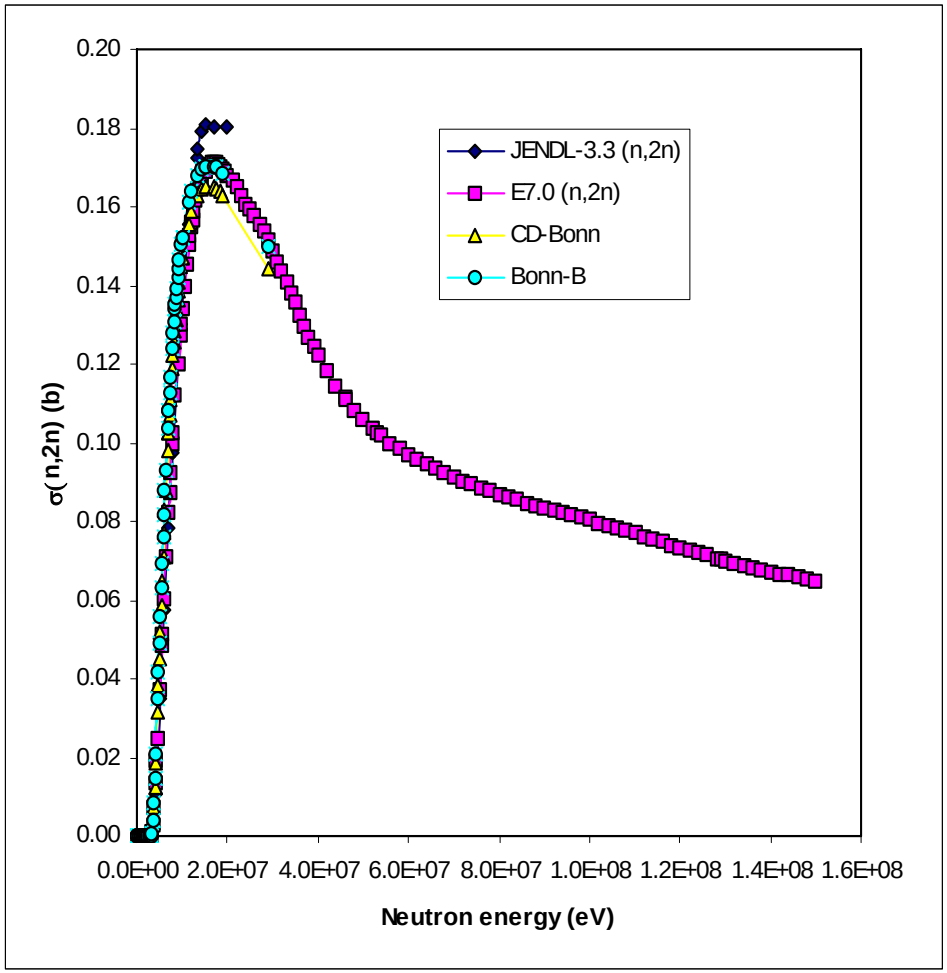


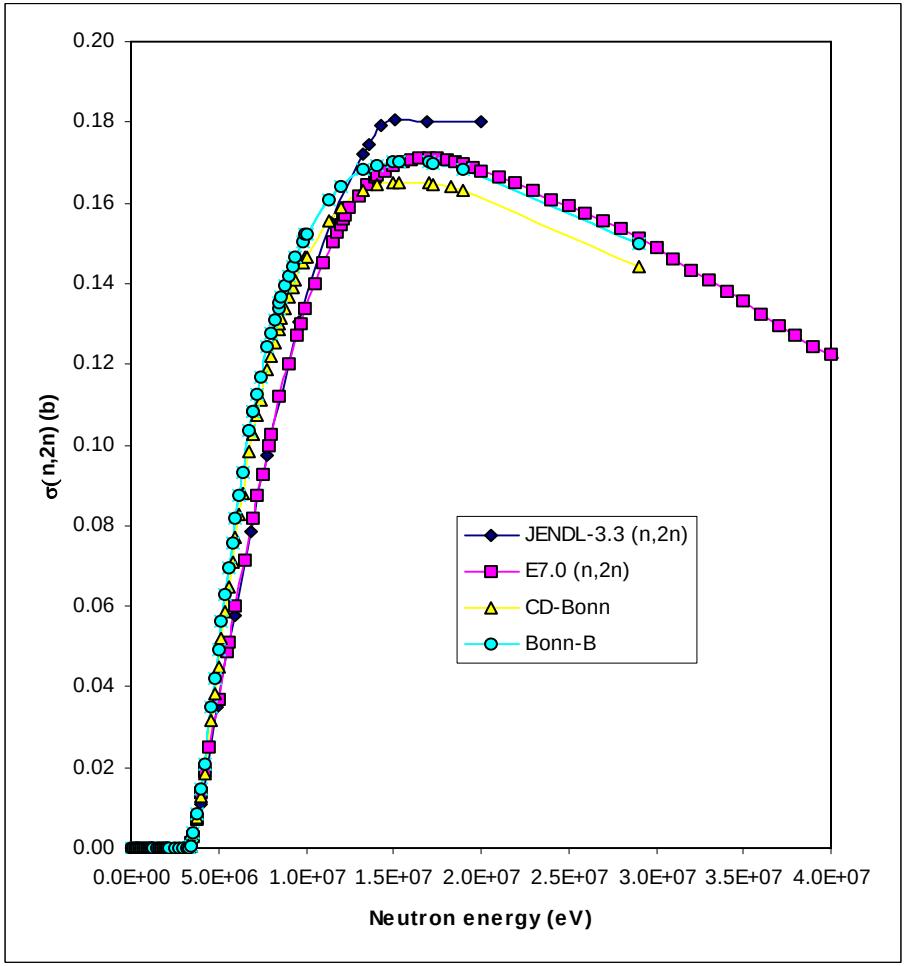




^{2}H (n,2n) cross section comparison

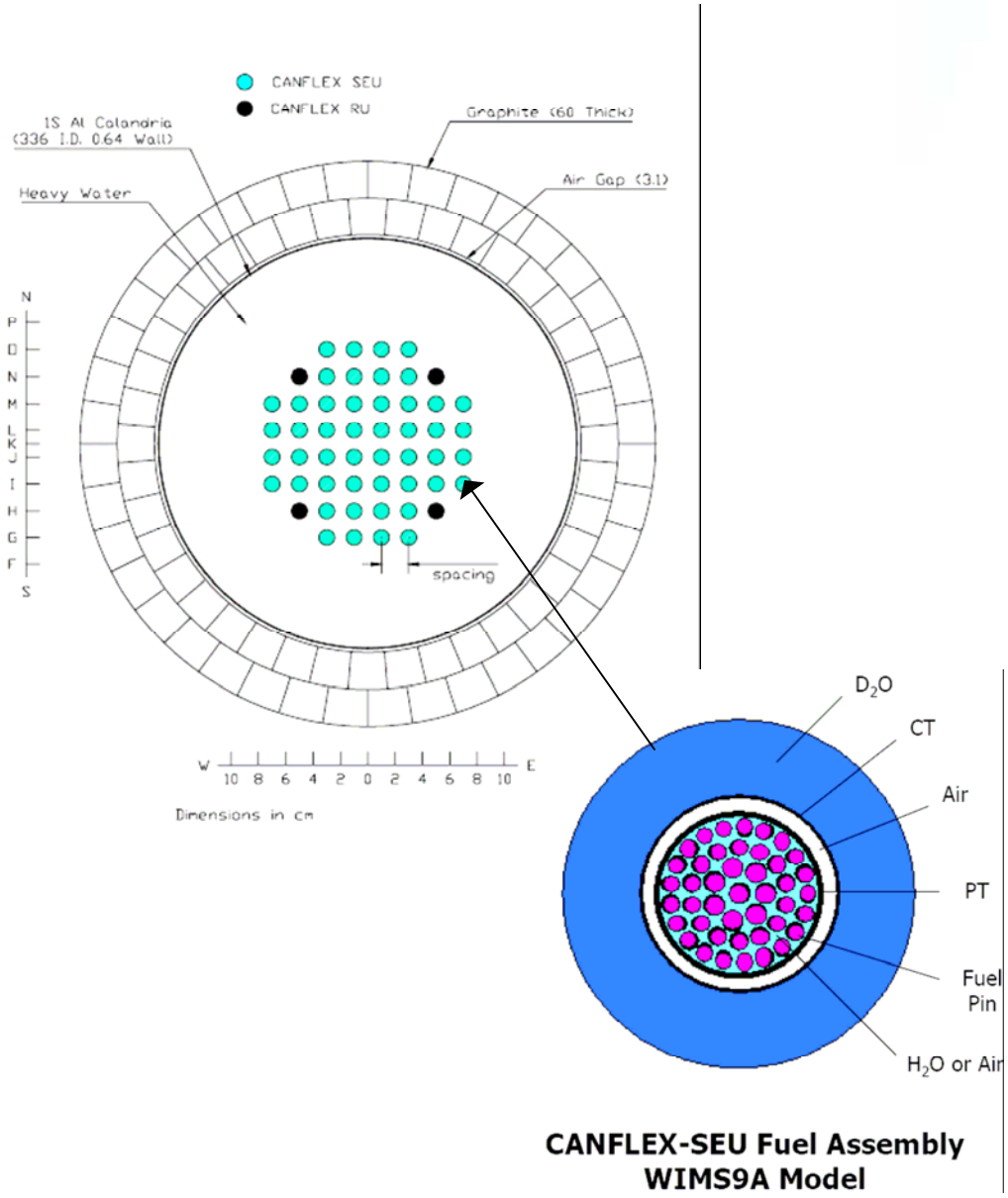
- Notable differences between theory & ENDF/B-VII.0 between 5 & 15 MeV
- Fair agreement between Bonn-B & CD-Bonn in this energy range





H_2O/air-cooled Low Enriched Uranium experiments

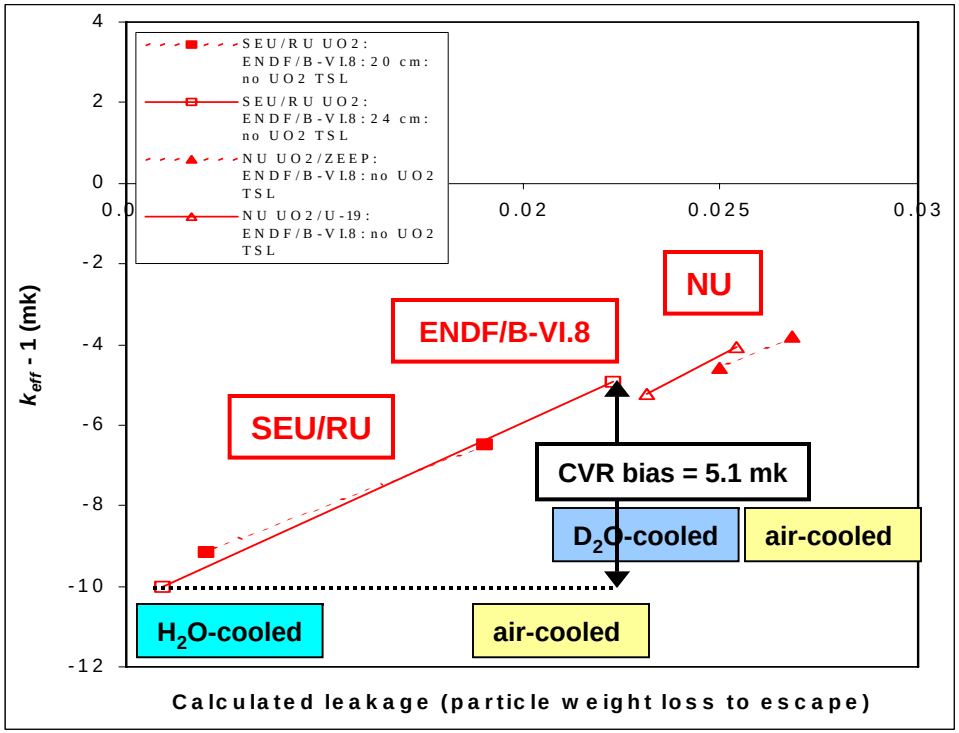
- 52 fuel channels arranged in a square lattice with a spacing of 20 cm or 24 cm.
- Channel consists of five 43-pin fuel assemblies surrounded by CANDU-sized aluminum PT/CT:
  - 48 channels use 0.95% SEU
  - 4 channels use 0.96% RU (recovered uranium)
- H_2O or air (void) coolant.
- D_2O moderator height adjusted to achieve criticality.
- Cu and In-Al foil activation measurements performed axially and radially.



CANFLEX-SEU Fuel Assembly WIMS9A Model

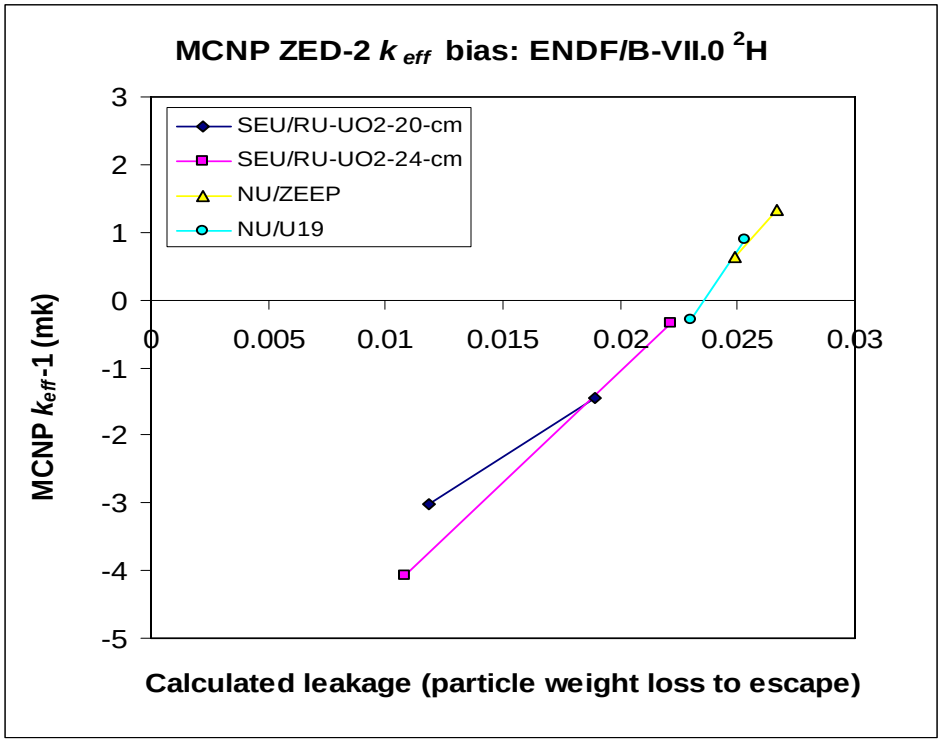
Results: Dependence of k_{eff} bias on calculated leakage

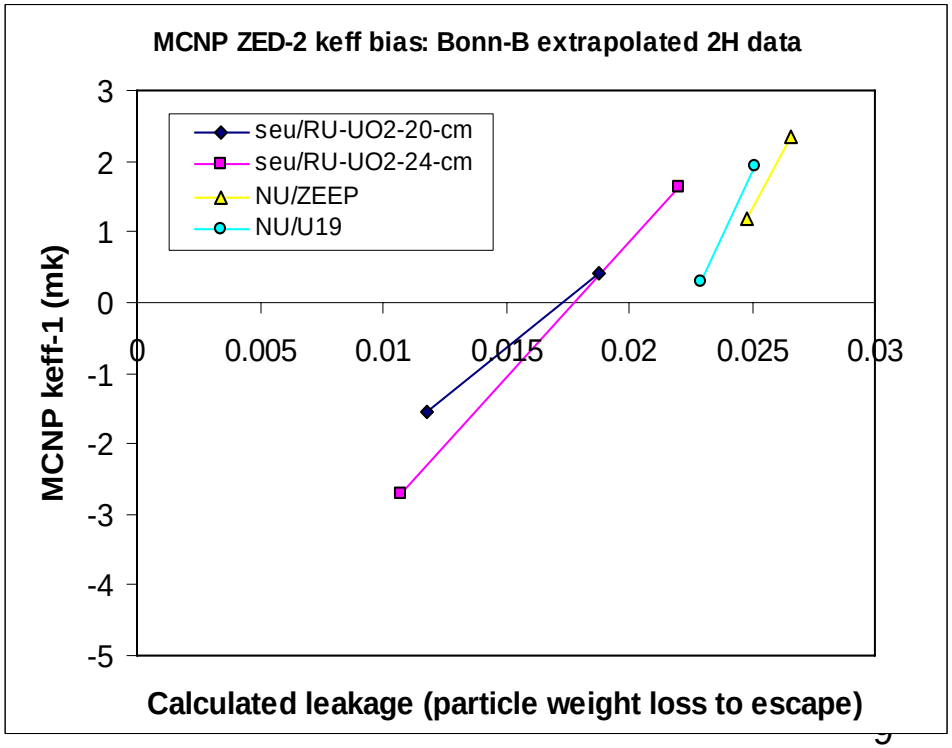
- Systematic trend (r^2=0.99) with leakage despite different: enrichment, fuel bundle design, coolant, lattice pitch & arrangement, booster fuel
- Suggests a common cause or nuclear data issue



Preliminary ZED-2 CVR bias results for new ^{2}H data

- Lowest MCNP ZED-2 CVR simulation bias with ENDF/B-VII.0; strong correlation with leakage (r^2=0.98) despite differences in enrichment, coolant, fuel bundle geometry, lattice pitch & arrangement; but larger spread (-4.1 to +1.3 mk)
- Substituting CD-Bonn P(E,μ) only into ENDF/B-VII.0 makes worse
- Substituting CD-Bonn or Bonn-B $\sigma_{elastic}$(E) data to 50 keV & $\sigma_{(n,2n)}$(E) makes worse again; similar if extrapolate CD-Bonn or Bonn-B data to 0 MeV





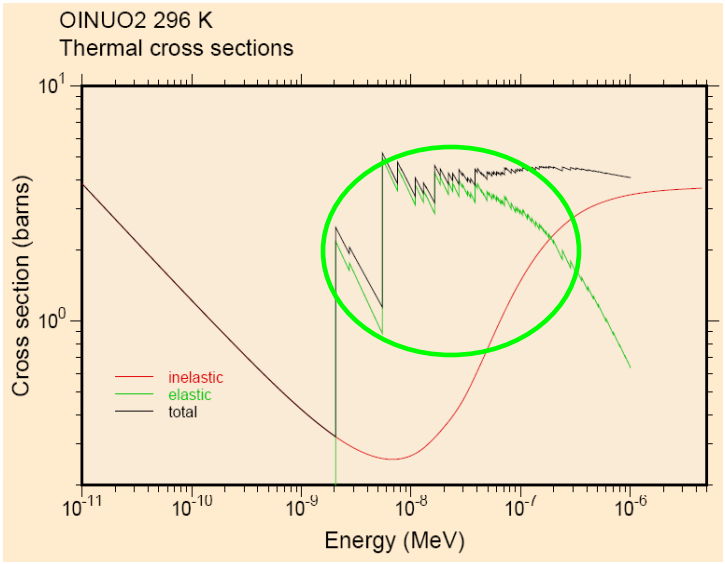
ZED-2 CVR bias ^{2}H comparison (mk)

Case	ENDF/B-VII.0	ENDF/B-VII.0 + CD-Bonn P(E,m)	JENDL-3.3	Bonn-B + ENDF/B-VII.0 (<50 keV)	Bonn-B extrapolated	CD-Bonn extrapolated
SEU/RU UO_2: 20-cm air/H_2O	1.59	1.96	1.68	1.96	1.96	2.26
SEU/RU UO_2: 24-cm air/H_2O	3.73	3.92	4.25	4.24	4.34	4.50
NU-UO_2/ZEEP: air/D_2O	0.68	1.02	1.20	1.10	1.15	0.96
NU-UO_2/U-19: air/D_2O	1.19	1.47	1.70	1.55	1.65	1.53
Average	1.80	2.09	2.21	2.21	2.27	2.31

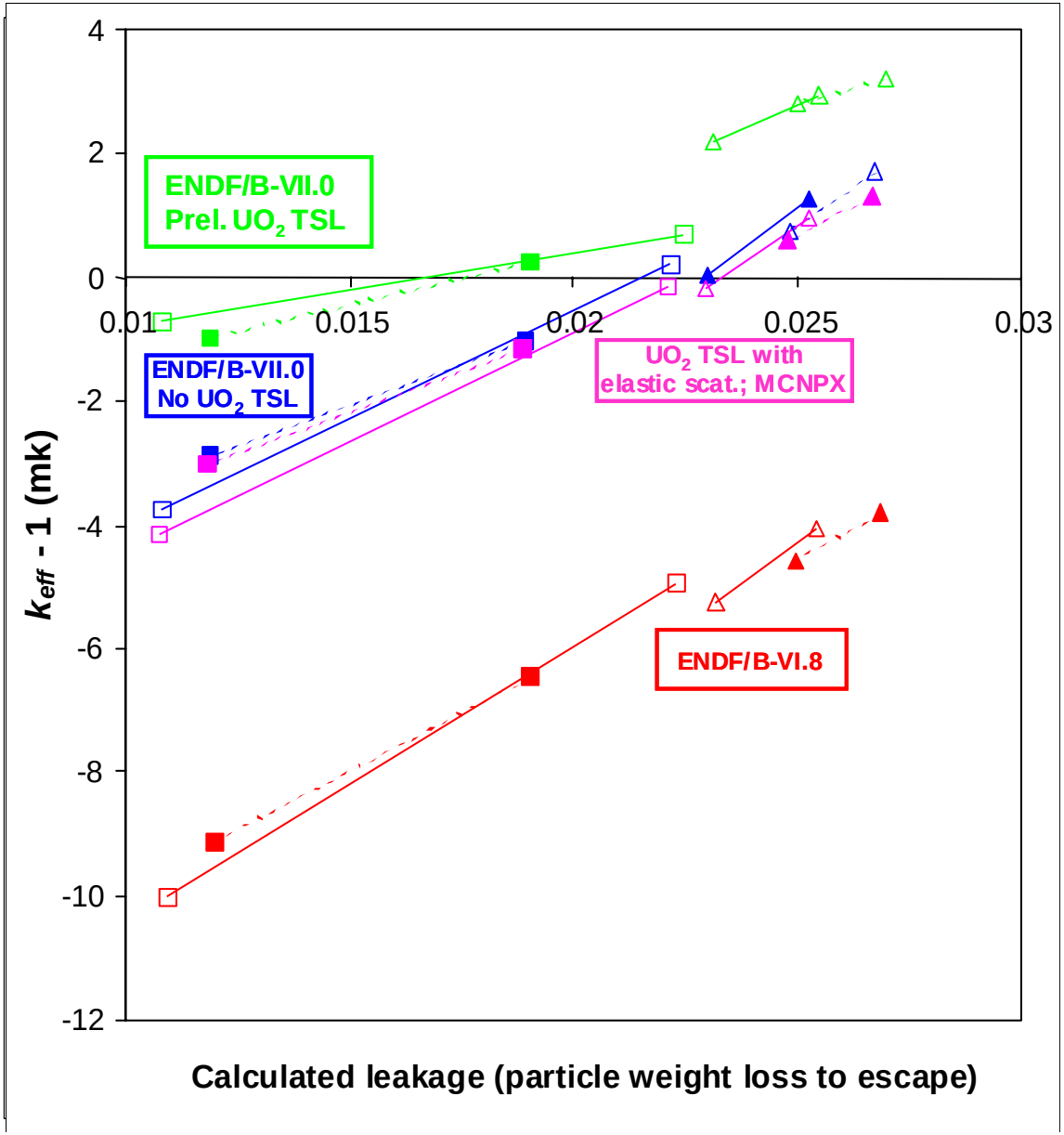
- Good News: ZED-2 CVR bias results are sensitive to the ^{2}H data
- Not so good: new ^{2}H data from nuclear theory makes the bias worse
  - Magnetic interaction important(?)
  - A problem with ZED-2 measurements: Al tube impurities(?): extend comparisons to DCA data in ICSBEP
  - A problem with other data or processing: ^{235}U, ^{238}U, TSL …(?)
- Confirms the need for new (n,d) cross section measurements

Impact of ENDF/B-VII.0 & UO2 TSL on ZED-2 results

- Substantial (~6 mk) reduction of k_{eff} bias with ENDF/B-VII.0; small reduction in CVR bias (~1.1 mk)
- Significant additional k_{eff} & CVR bias reduction using preliminary UO_2 TSL ACE files



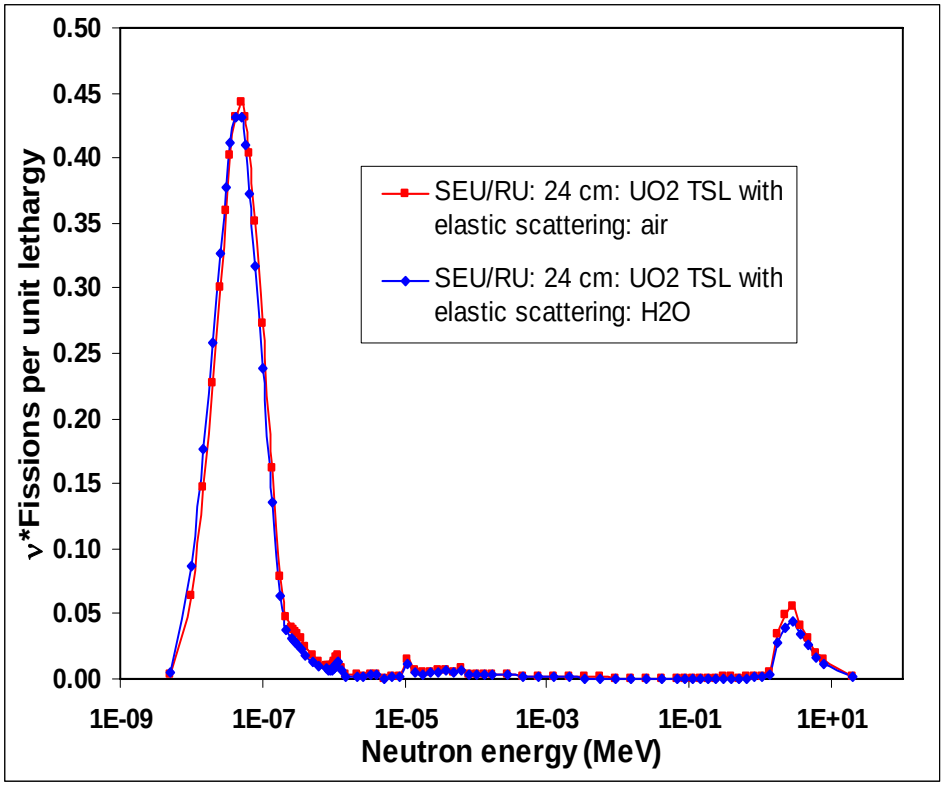
- ***But***, little reactivity sensitivity to UO_2 TSL data with ACE files that include coherent elastic scattering *(I. Hill – AECL & J.V. Donnelly – NSS)*
- Confirmed results using MCNPX & LANL TSL ACE files with improved thermal scattering treatment

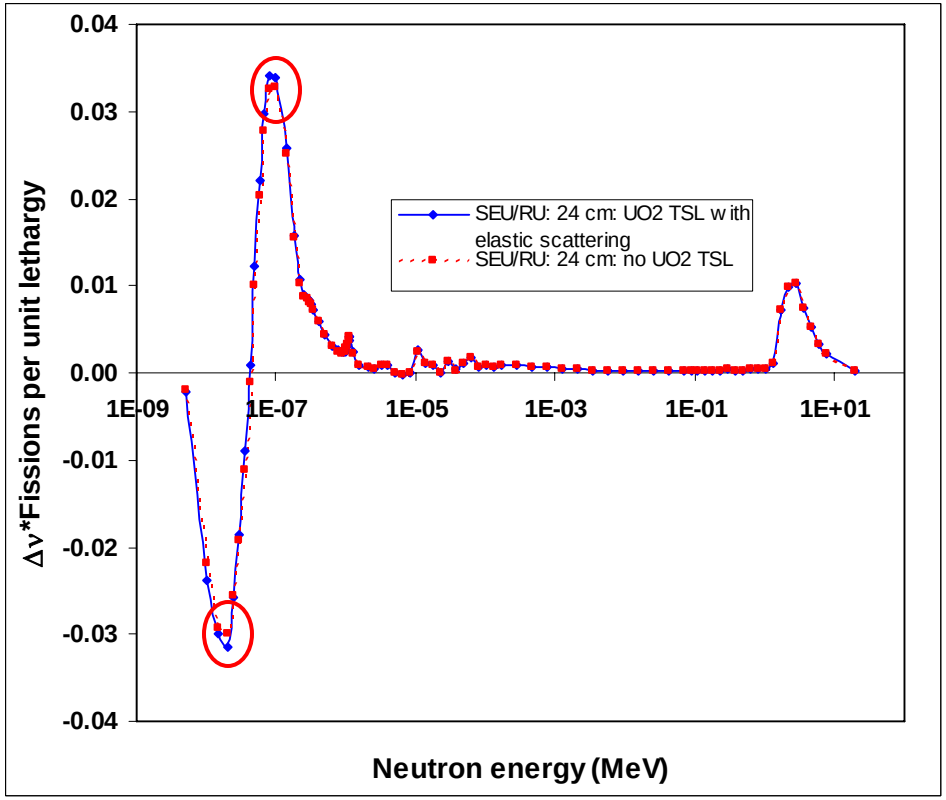


Energy dependence of ZED-2 CVR bias: SEU/RU 24-cm pitch

Track-length MCNP5 k_{eff} – based on fission-yield tallies

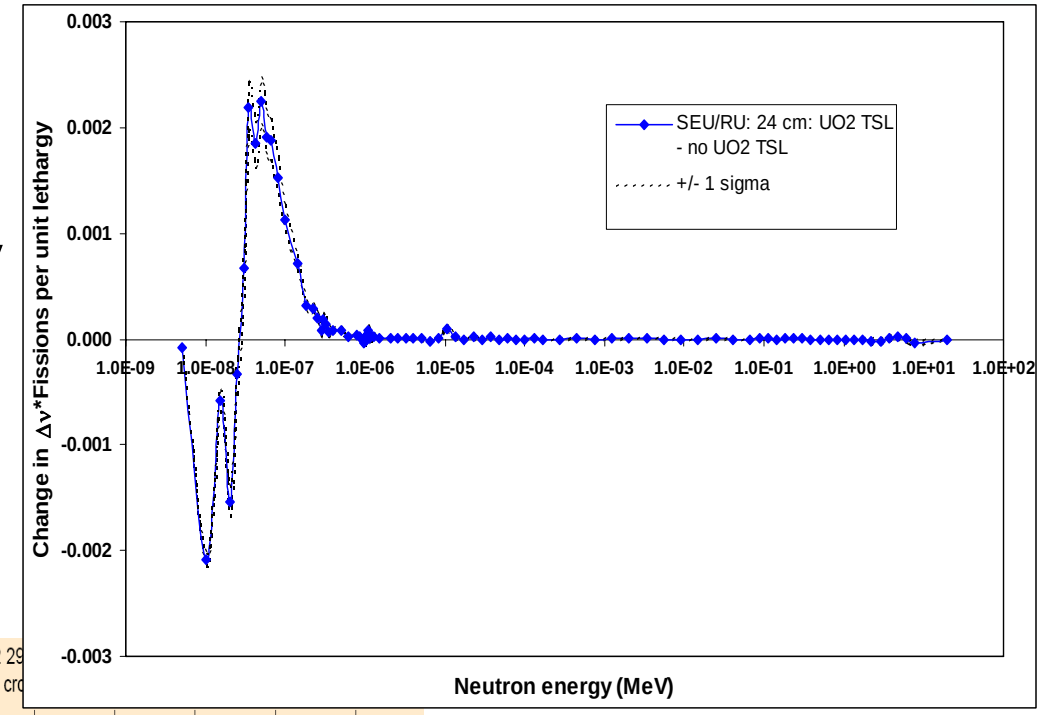
CVR (Δk_{eff}) simulation bias – negligible reactivity sensitivity to UO_2 TSL data

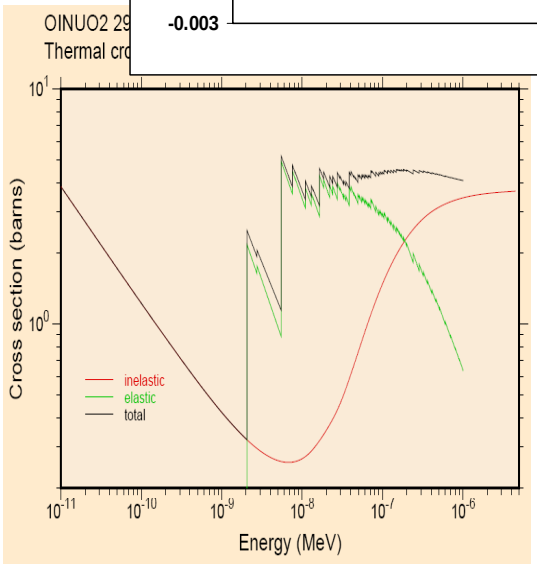




Energy dependence of reactivity impact of UO_2 TSL data

- ***But*, low impact of UO_2 TSL data on SEU/RU CVR bias is due to cancellation of positive & negative reactivity impacts of ~2.8 mk each at thermal energies above & below ~$3x10^{-8}$ MeV**





Conclusion

- New ^{2}H data from modern nuclear theory calculations
  - Extended to include various potentials; 3NF; $\sigma_{elastic}(E,\mu)$; $\sigma_{(n,2n)}(E)$; 50 keV to ~20 MeV
  - But do not reduce/resolve simulation biases for ZED-2 integral measurements
  - Magnetic interaction important(?), or something else …
- UO_2 TSL data appear to have little net reactivity impact (<0.1 mk), when elastic component included, due to cancellation of larger positive & negative reactivity contributions at low energies
- Need to be able to process TSL data in NJOY at arbitrary temperatures & replicate the LANL TSL ACE files *(see also "Thermal Scattering Data and Criticality Safety", W. Haeck and N. Leclaire, PHYSOR'08)*