Update on Deuterium Data Issue

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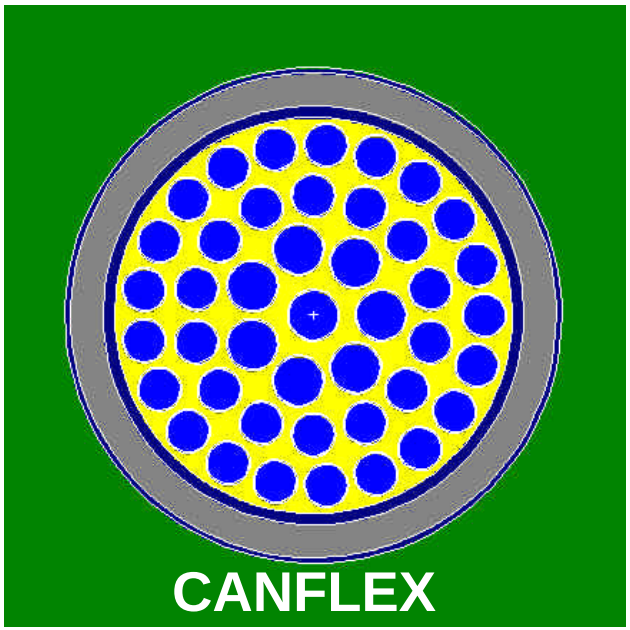
AECL

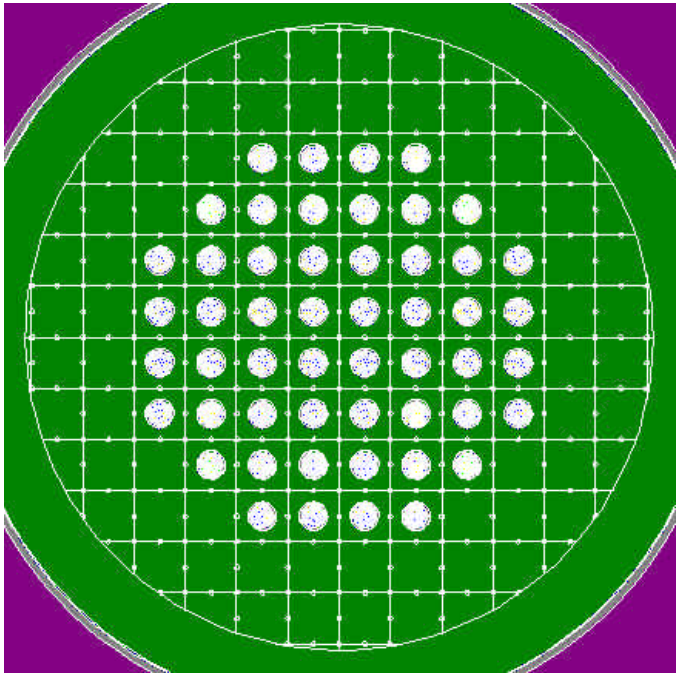
Background

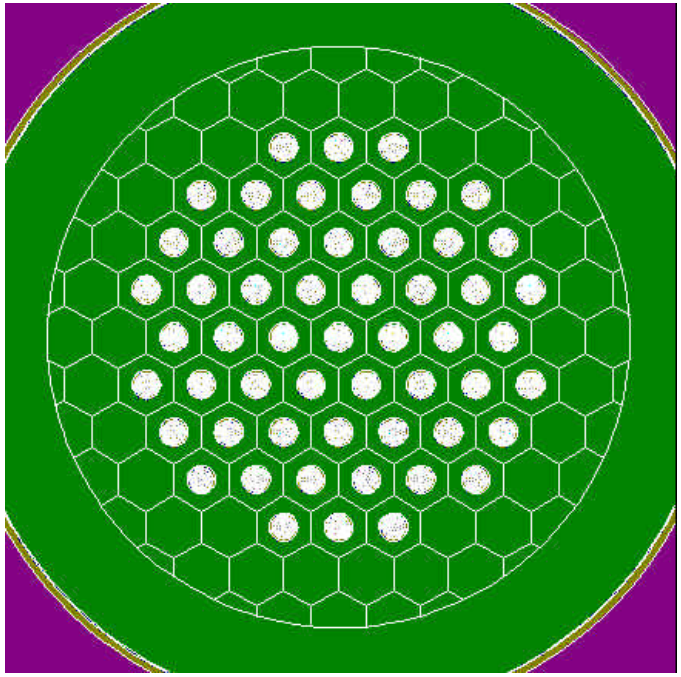
- **LANL** found MCNP k_{eff} for HEU D_2O Solution Thermal critical experiments (HST-004: D_2O reflected spheres; HST-020: unreflected cylinders) dropped by **~10 mk** for ENDF/B-VI.8 relative to ENDF/B-VI.4
  - Reported at CSEWG 2004 & confirmed by KAPL
  - **Reactivity impact is due to changes to (n,d) energy-angle elastic scattering probability distributions at E<3.2 MeV**
  - $k_{Calc.} - k_{Meas.}$ shows a large spread ~37 mk & rising trend with calculated leakage
  - HST experiments are old (1950s), high leakage (~40%)
- Chalk River Laboratories ZED-2 critical experiments for low-leakage, heterogeneous arrangements of Natural Uranium (NU) fuel rod lattices show
  - Low reactivity sensitivity (**<1 mk**), but a significant change in the MCNP D_2O **Coolant Void Reactivity (CVR)** bias of **0.6 mk** [full-core CANDU CVR bias typically ~+1.5 mk]
  - Lower CVR bias for ENDF/B-VI.8 (& VII.0) than ENDF/B-VI.4
  - Rising trend for $k_{Calc.} - k_{Meas.}$ with calculated leakage

ZED-2 Progress: Recent results

- Slightly Enriched Uranium (SEU): 0.95 wt% ^{235}U
- 43-element CANFLEX fuel geometry (greater subdivision)
- Square vs. hexagonal lattices; pitch = 20 to 24.5 cm
- H_2O & air 'coolant'; D_2O moderator

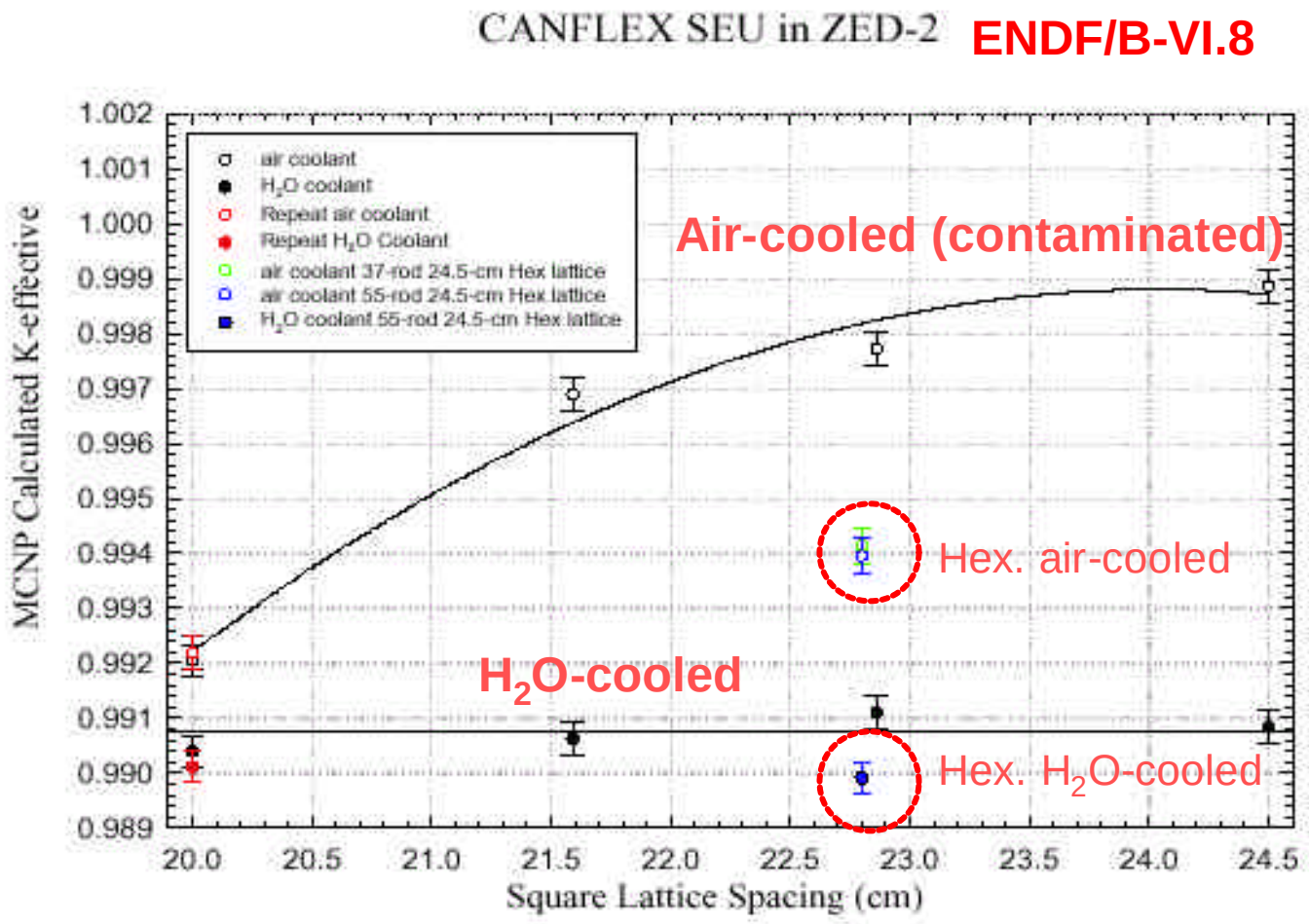






ZED-2 Progress: H_2O CVR results for SEU CANFLEX fuel

- Had observed increase of MCNP H_2O CVR bias to ~+8 mk with lattice pitch
- Investigation concluded air-cooled (voided channel) experiments likely contaminated by residual H_2O; procedures revised to air-dry fuel bundles
- New data show H_2O CVR bias of ~+2 mk at 20 cm & ~+3 mk at 24.5 cm pitch



Review of supporting experimental data

- **AECL engaged Larry Townsend, University of Tennessee to review (n,d) scattering experimental data £ 3.2 MeV & compare with ENDF/B-VI.8 & JENDL-3.3**
- **Findings:**
  - **Old data: >25 years, some >50 years**
  - **Sparse: nothing below 100 keV**
  - **Inconsistent: "consistency between experimental data sets was often lacking"**
  - **"In general, the experimental cross sections tend to favor larger cross section values at back angles and the trend, except for the Adair data at low energies, is for the cross sections to rise more steeply as m ® -1"**
- **Recommendations:**
  - **"Measurements of elastic scattering differential cross sections at incident neutron energies from 200 keV through 3 MeV are suggested"**
  - **"To ensure adequate coverage, neutron energies of 0.2, 0.5, 1, 1.5, 2, and 3 MeV, as a minimum, are suggested"**
  - **"Measurements below 200 keV down to thermal energies are also suggested"**

(n,d) data measurement initiatives

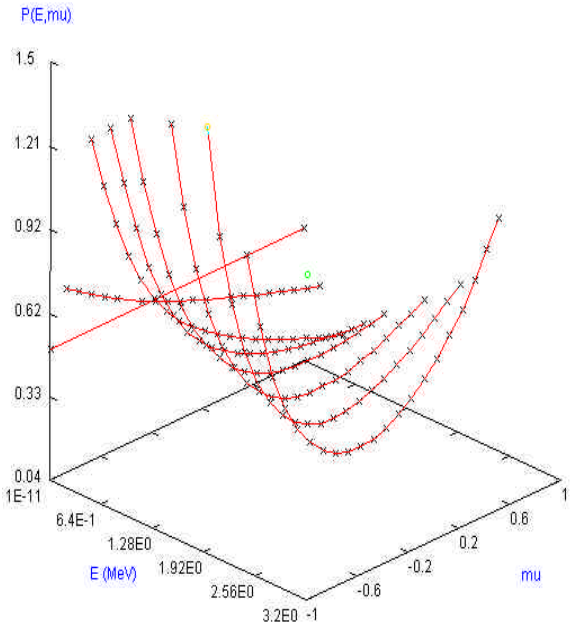
- Discussions with ORNL re: possible (n,d) scattering measurements at ORELA
  - 2006 April 07 at ORNL
  - 2006 July 25 at CRL
  - 2006 October: “Experimental Planning Task to Develop Deuterium Cross-Section Measurement Plan” received from ORNL
- Deuterium data issue raised at IAEA International Nuclear Data Committee meeting 2006 May
- (n,d) measurement request submitted to OECD-NEA High Priority Request List (HPRL) 2006 June
  - Requested accuracy: ± 5%
  - Energy range: £ 1 MeV
  - Awaiting a formal reply

(n,d) data meeting at CRL 2006 July 25

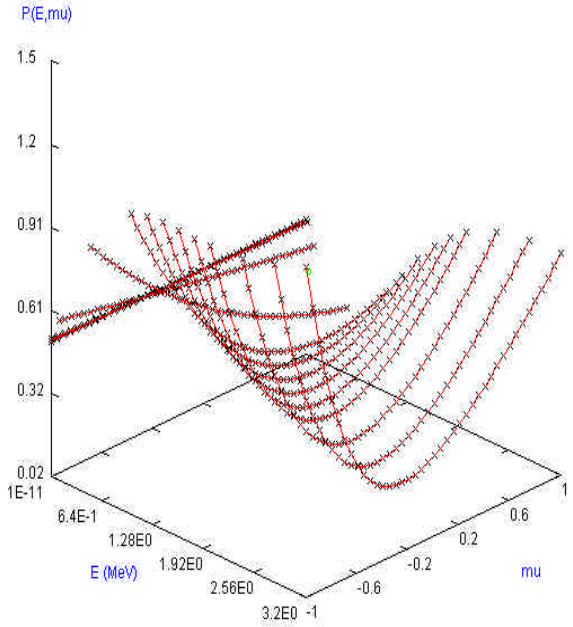
Library differences in (n,d) energy-angle elastic scattering distributions <3.2 MeV

(using LLNL's Nuclear & Atomic Data System (NADS))

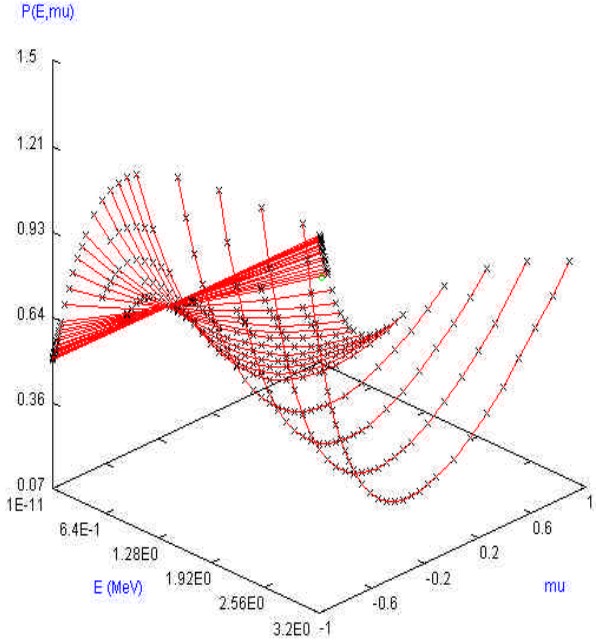
ENDF/B-V.2 (same as VI.4)



ENDF/B-VI.5 to VIIbeta2 [1997]

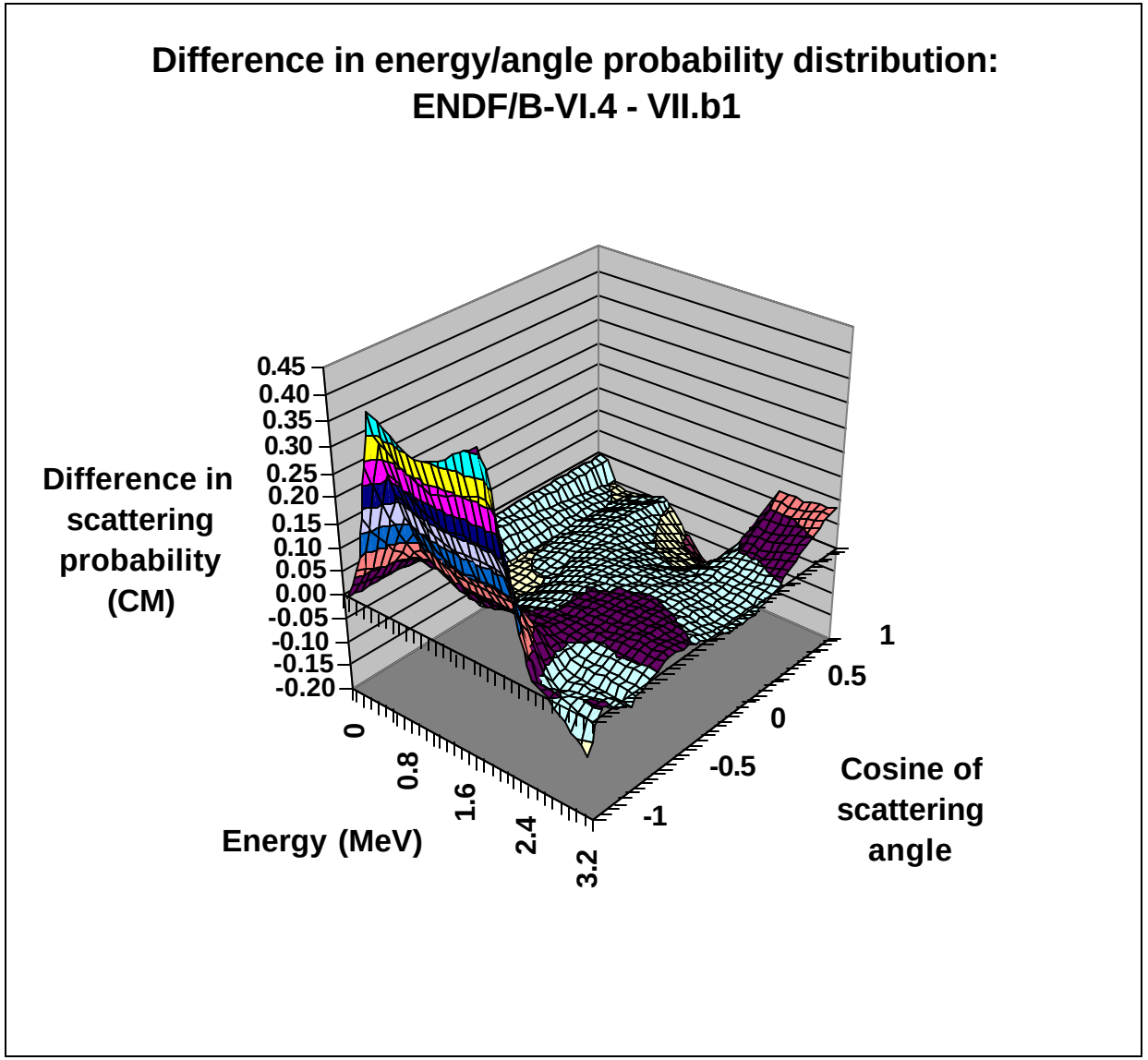


JENDL-3.3 [2001]



- ENDF/B uses coupled-channels R-matrix analysis; revised & extended to 150 MeV for VI.5 & later to address accelerator-based production of ^{3}H
- JENDL-3.3 uses Faddeev three-body nuclear model tabulated up to 20 MeV
- **ENDF/B energy tabulation seems very coarse**

Difference between interpolated CM energy-angle (n,d) elastic scattering probability distributions: ENDF/BVI.4 – B-VII.b1



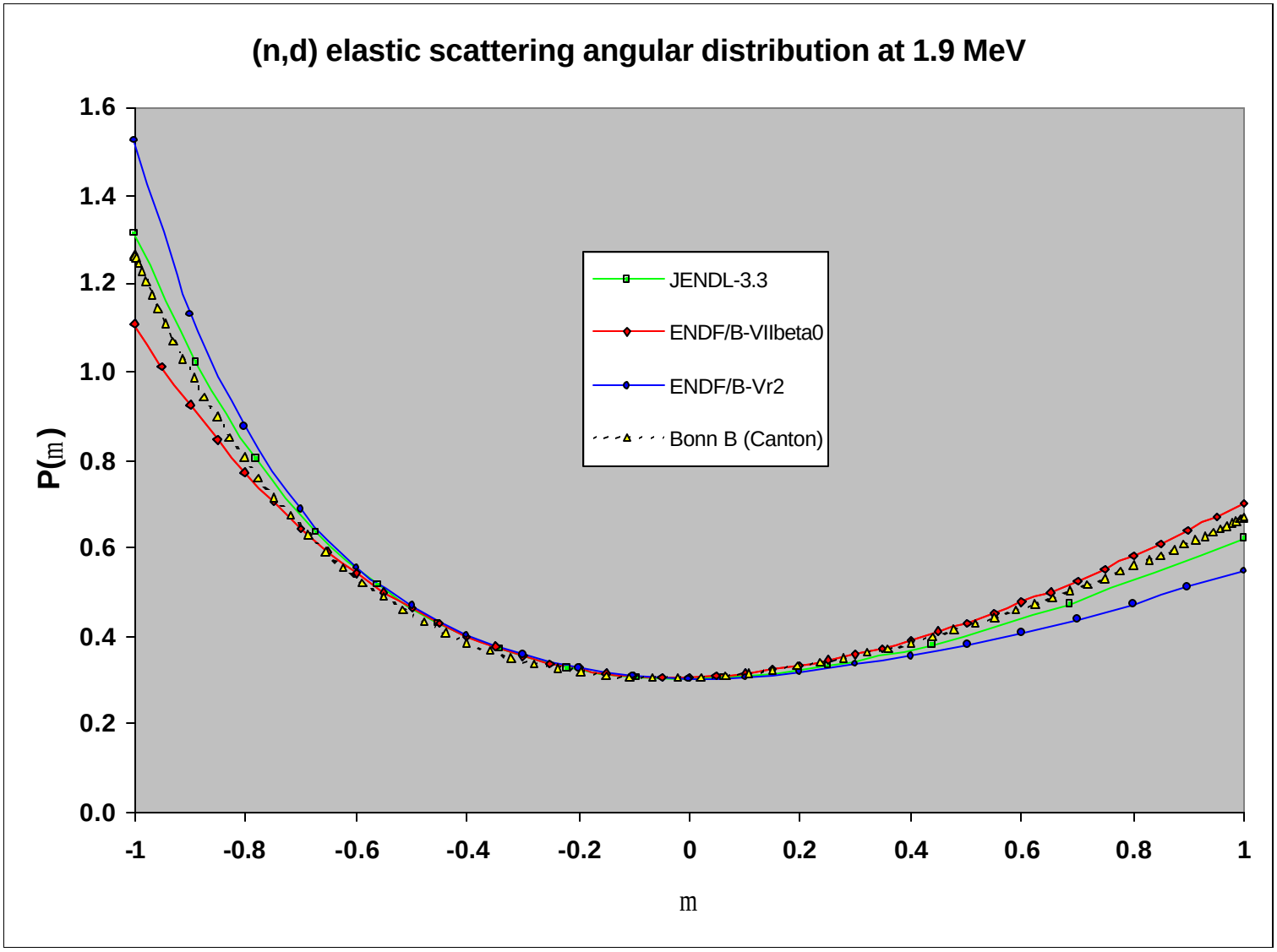
Few-nucleon theoretical models

(Juris Svenne, Senior Scholar – University of Manitoba)

- **"For the lightest nuclei (A=4), few-body methods enable *exact* solution for nuclear structure and reactions: Faddeev theory"**
- **"The Alt-Grassberger-Sandhas (AGS) equation is an alternative formulation to Faddeev, but has been proven to be equivalent**
  - **Such equations are now amenable to "exact" solution on computers, but numerical approximations must be made**
  - **Precision of the solution is limited only by the cleverness of chosen algorithms and the power of the computer(s) available"**
- **New nuclear model calculations could quickly provide a new (n,d) scattering distribution for testing & guidance for planning confirmatory (n,d) measurements**

Comparison with sample results at 1.9 MeV

- New results received from Luciano Canton, Padova University
- 'Bonn B' & 'CD Bonn' model results indistinguishable on this scale

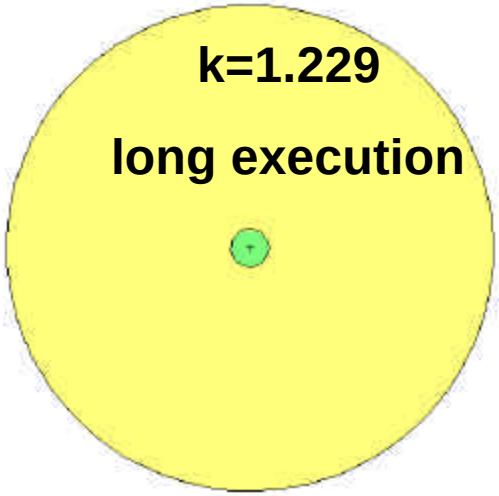


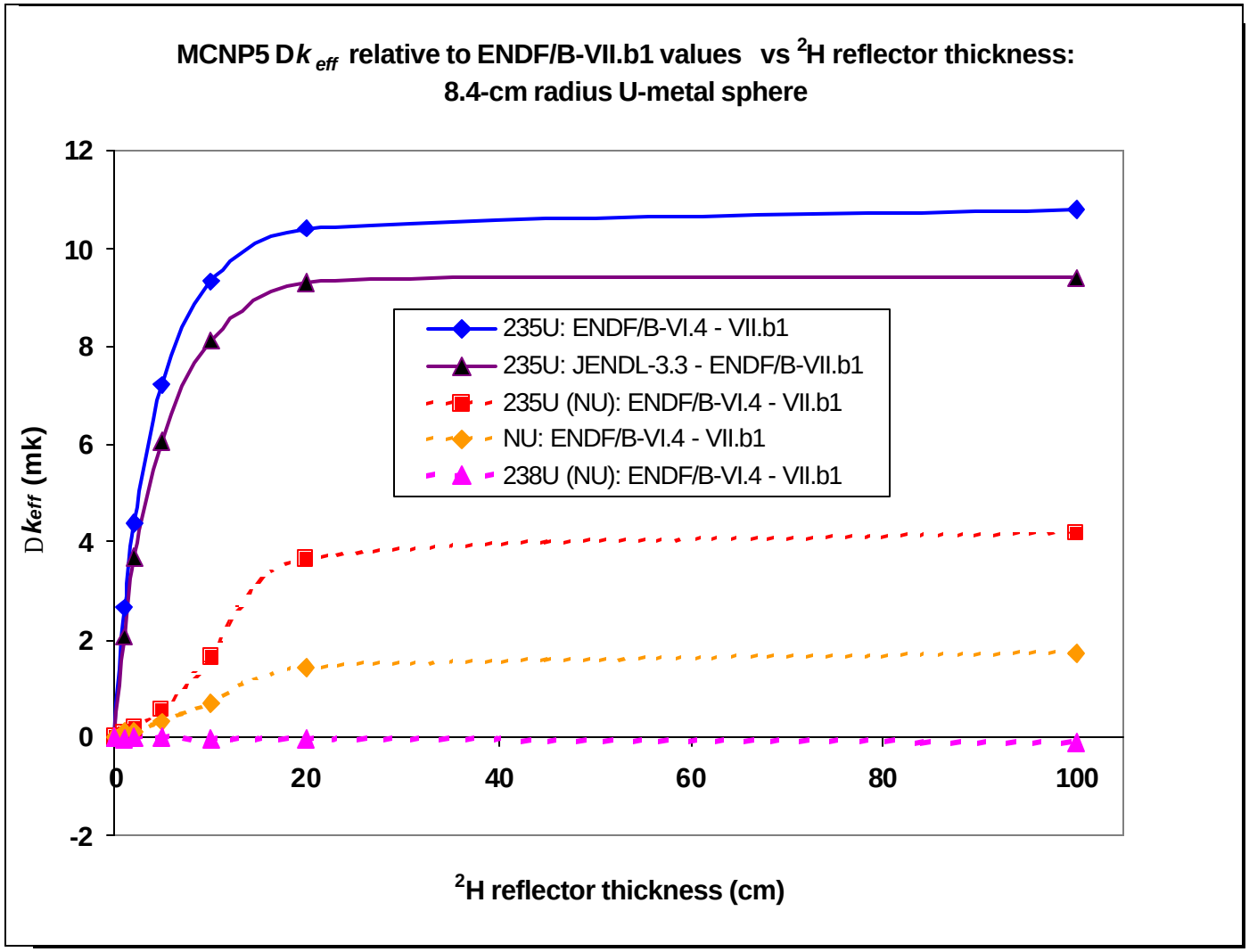
Progress on ^{2}H data sensitivity studies

- ^{2}H-(at D_2O # density) reflected 8.4-cm radius U-metal sphere;
  £ 3 nuclides; **no S(a,b)**

0 cm ^{2}H; 100% ^{235}U
k=0.997

100 cm ^{2}H; 100% ^{235}U

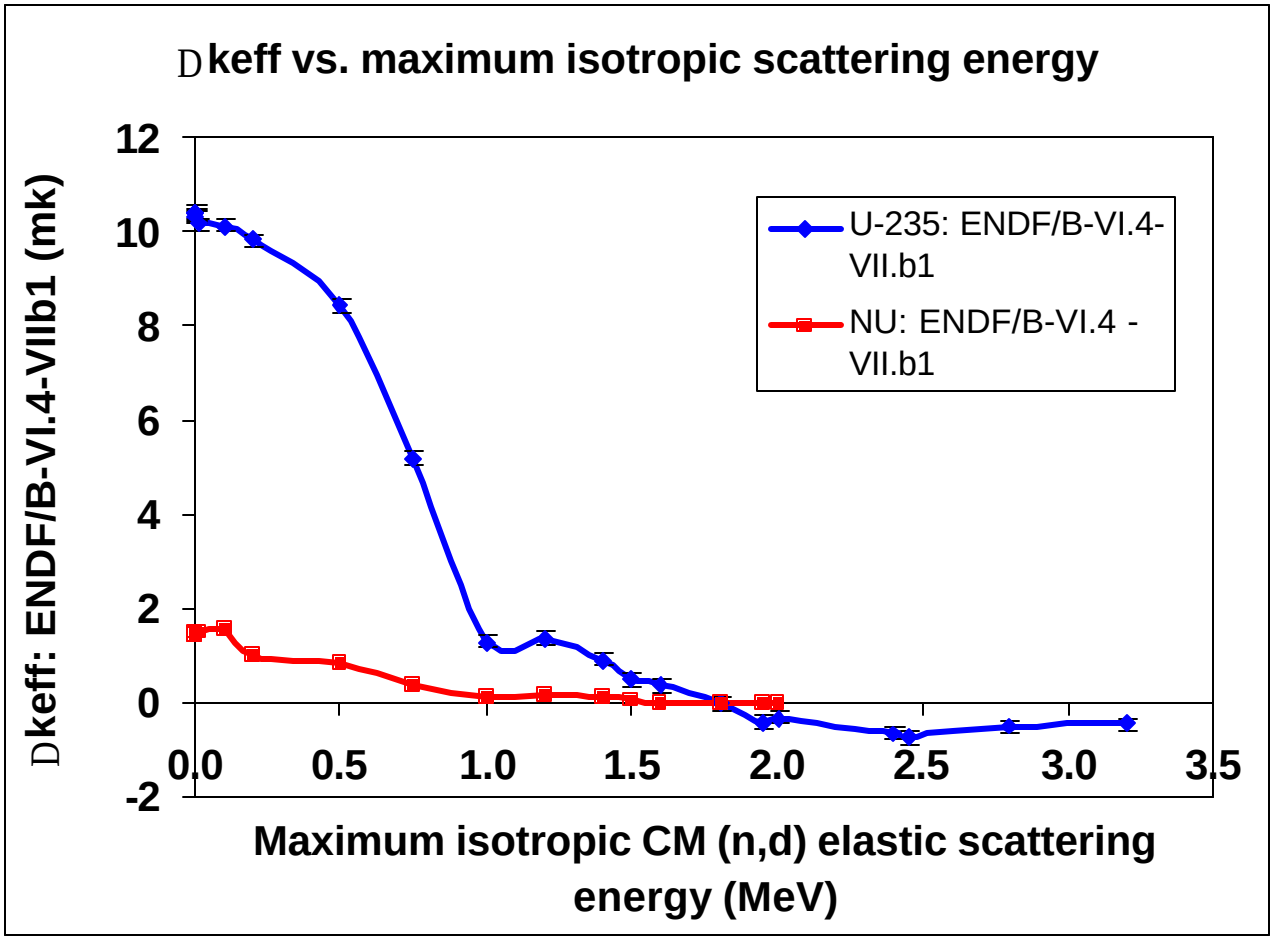




Reactivity impact of progressive artificial isotropy of CM (n,d) energy-angle distributions

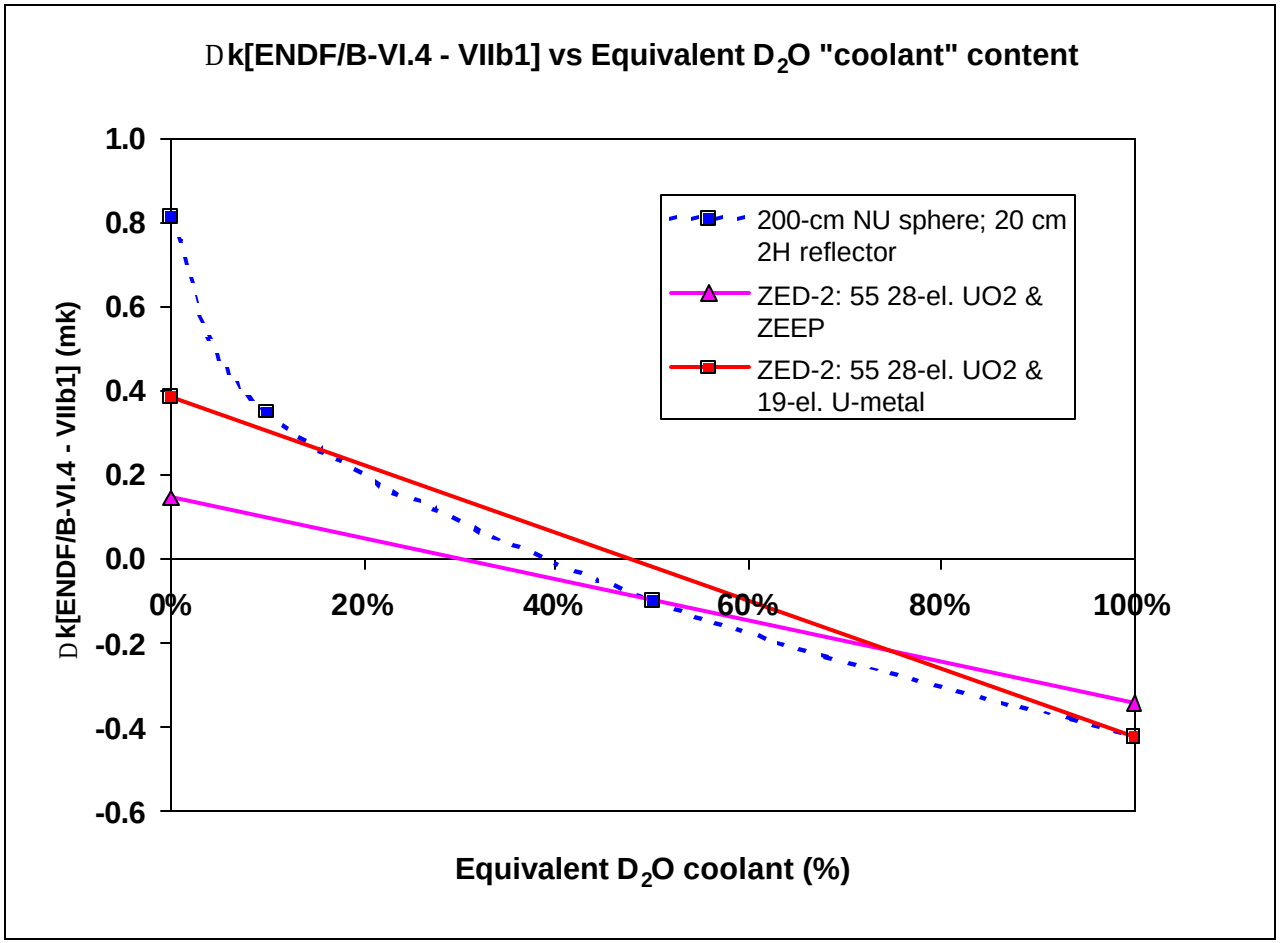
8.4-cm radius U-metal sphere 20-cm ^{2}H reflector

- **Sensitivity to nuclear data files much less for NU than pure ^{235}U**
- **Most of reactivity impact occurs at E £ 1 MeV**



New studies with simplified NU/^{2}H 'solution' model

- 200-cm radius NU-metal/^{2}H homogeneous sphere & 20-cm ^{2}H reflector [slow neutron source convergence]; low neutron leakage similar to ZED-2
- Mimics subtle reactivity sensitivity of ZED-2 D_2O CVR experiments: positive Δk for 0% D_2O (voided) & negative Δk for 100% D_2O (voided)



Status Summary

- **Improved understanding**
  - ^{235}U enrichment appears to be the main reason for the difference in reactivity sensitivity of HST & ZED-2 critical experiments
  - Key energy range = 1 MeV
- **(n,d) elastic scattering measurements:**
  - Existing data reviewed and found to be inadequate
  - Exploring the prospects for new measurements: ORNL, HPRL
- **New nuclear model calculations**
  - Sample results from Luciano Canton at 1.9 MeV
  - Eagerly awaiting more results at lower energies
- **Integral critical measurements**
  - Existing ZED-2 (& HST) data will likely provide a good test of any new ^{2}H data evaluation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