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KIT contribution to SG-47: progress since June 2019

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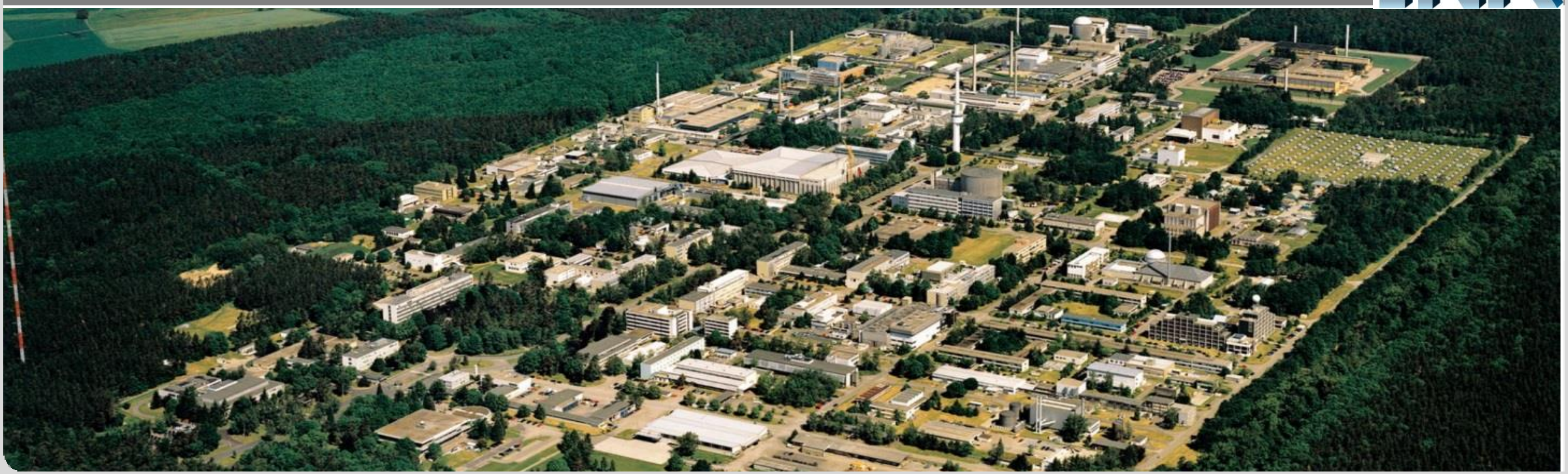


Content

from Summary records of 1st Meeting of WPEC SG47, 24 June 2019 NEA/NSC/WPEC/DOC(2019)8 :

Action 3. (S. Simakov, KIT):
Provide KFK-1977 gamma measurement data for potential SINBAD evaluation

- **done; *see next slides 3 - 7***

Action 4. (S. Simakov, KIT):
Contribute models for Oxygen ORNL broomstick benchmark and 91.44 cm liquid O data if of interest (sufficient quality) for SINBAD

- **model is created, analysis in progress; *see next slides 8 - 17***

Action 5. (Simakov, Kodeli, Milocco):
Resolve the issue of dividing by cosine for FNS-O.

- **pending (*no feedback from others - no action from my side*)**

Action 3:

“Provide KFK-1977 gamma measurement data for potential SINBAD evaluation”

To remind: Status of Fe shells with ^{252}Cf *(EFFDOC-1373, Nov 2018)*

Lab: Years	n-source Energy	Assembly, sizes cm	Method	Detector, Energy Range	Main References and Numerical Data
KFK: 1975	^{252}Cf(s.f.) 7E+7 n/s E ≈ 2.1 MeV	6 spheres: dia. = 15, 20, 25, 30, 35 and 40 cm	Pulse Height + Unfold	***Neutrons:*** 2 proton recoil (1.08 m): E = 0.06 – 0.86 MeV, E = 0.31 – 2.35 MeV 1 proton recoil (1.53 m): E = 0.92 – 5.24 MeV 1 ^{3}He/Si sandwich (surf): E = 0.10 – 7.85 MeV	H. Werle, H. Bluhm et al. - KFK-2219 (1975) - NEACRP-U-73 (1976)8 SINBAD: *NEA-1553/43*
KFK: 1977	^{252}Cf(s.f.) 5.5E+7 n/s (± 5%) (also ^{232}Th)	3 spheres: dia. = 25, 30, 35 cm (also Iron pile: 100*100*87cm)	Pulse Height + Unfold (± 10%)	***Gammas:*** Si(Li) compton spectr. - at 1.02m (bare source) - on surface (spheres) Energy range E = 0.34 – 3.11 MeV	S.-H. Jiang, H. Werle - KFK-2444 (1977) = PhD - NEACRP-L-196(1977) - NSE 66(1978)354 Data are presented only in Plots - we digitized
NIST: 2000	^{252}Cf(s.f.) 5.5E+7 n/s (± 5%)	1 sphere: dia. = 50 cm	Pulse Height +Unfold	***Neutrons:*** 2 proton recoil (1.00 m): E = 0.06 – 0.86 MeV, E = 0.31 – 2.35 MeV	B. Stanka et al. - NSE 134(200)68 not in SINBAD yet
IPPE: 1985	^{252}Cf: ≈ 2.1 MeV	6 spheres: dia. = 10, 20, 40, 50, 60, 70 cm	Pulse Height (PH)	***Neutrons:*** H-prop. 5 – 700 keV Stilben 0.2 - 17 MeV ***Gammas:*** Stilben 0.4 - 10 MeV	*ICSBEP/DICE*: *ALARM-CF_FE-SHIELD-001*

KFK gamma-ray leakage spectra for Fe spheres with ^{252}Cf(s.f.) (and ^{228}Th(α)^{224}Ra) sources

were measured at KFK in 1977 and published as:

S.H. Jiang, "Messung und Berechnung der durch 252Cf Spaltneutronen in Eisen induzierten γ-Felder", KFK-2444 (1977) = PhD

S.H. Jiang, H. Werle, "Measurement and calculation of 252Cf-fission neutron induced gamma fields in iron", NEACRP-L-196(1977)

S.H. Jiang, H. Werle, "Measurement and Calculation of Californium-252 Fission Neutron-Induced Gamma Fields in Iron", NSE 66(1978) 354

Late 2019: Prof. Shiang-Huei Jiang provided via e-mail the numerical data on measured (and calculated) gamma-ray spectra

- **from bare ^{252}Cf(s.f.) source and**
- **leaking from three Fe spheres Ø25, 30 and 35 cm with ^{252}Cf-source in center (include 2 sets of data for each sphere obtained with Compton Si detector calibrated by γ-sources located along the axial or radial directions)**

These numerical data were found to be well agree:

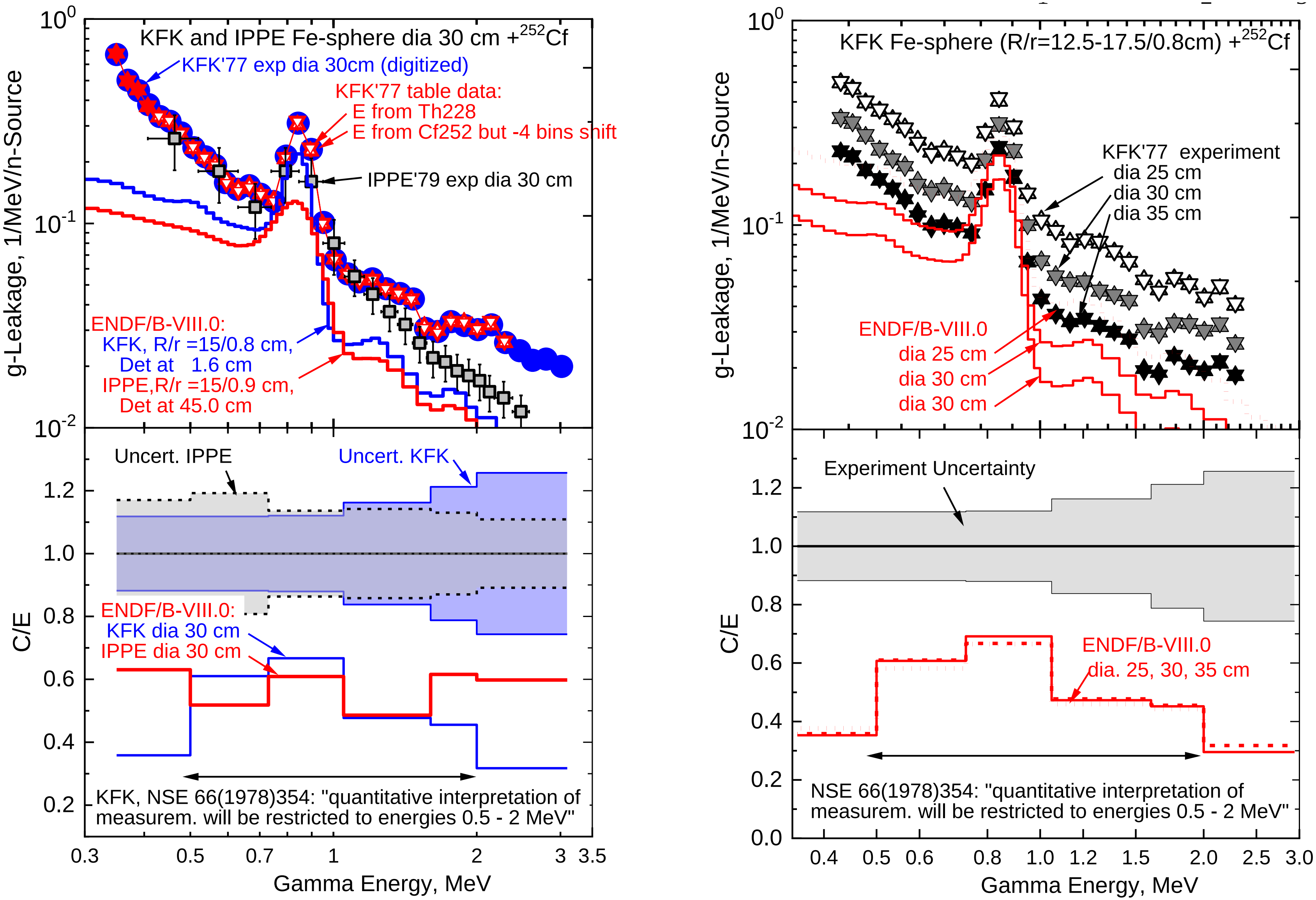
- **with those digitized from** Abb. 2.20 of KFK-2444
- **with γ-ray leakage spectra from Fe sphere of same diameter measured at IPPE**

for illustration see next slide ⇨

KFK γ-ray leakage spectra for Fe spheres with ^{252}Cf(s.f.)

Fe shell Ø30cm: KFK cp. IPPE

Fe shell Ø25-35cm: only KFK



Summary for Action 3:

“Provide KFK-1977 gamma measurement data for potential SINBAD evaluation”

- **Leaking γ-ray spectra for three Fe spheres measured in KFK in 1977 were received late 2019 from Prof. Shiang-Huei Jiang - *many thanks to him***
- **His 1977 data do confirm the γ-ray spectra measured at IPPE in 1985 for Fe spheres of similar diameters (before that the IPPE data were single available experimental numerical data set, *it is archived in ICSBEP*)**

Action 4:

"Contribute models for Oxygen ORNL broomstick benchmark and 91.44 cm liquid O data if of interest (sufficient quality) for SINBAD"

NB. The probable reason why the MCNP model was not provided for SINBAD
- authors have used the analytical expression to compute the uncollided neutron spectrum:
(from ORNL-TM-2242

$$N_c(E_j) = \sum_{E_i} N_o(E_i)\, e^{-\Sigma_t(E_i)t}\, R(E_i \rightarrow E_j)\, \Delta E_i \quad . \qquad (1)$$

*where: Source spectrum σ(tot)*Thickness Spectrometer Resolution)*

… and it works well, as it will be confirmed here by MCNP calculations

ORNL liquid Oxygen broomstick Experiments at Tower Shielding Reactor facility (TSR-II): sources of information

Publications (with many details needed to construct MCNP input):

C. Clifford et al., "Measurements of the Spectra of Uncollided Fission Neutrons Transmitted through Thick Samples of Nitrogen, Carbon, and Lead: Investigation of the Minima in Total Cross Sections ", NSE 27(1967)299
{two O broomsticks sizes (24" and 36") and 0.0429 Atoms/cm-b are given}

E. Straker, "Experimental Evaluation of Minima in the Total Neutron Cross Sections of Several Shielding Materials", ORNL-TM-2242(1968)
{one O broomstick size (60" 2 Dewars, is it 24"+36" ?) and 0.0429 Atoms/cm-b are given}

R.E. Maerker, "SDT2. Oxygen Broomstick Experiment - An Experimental Check of Neutron Total Cross Sections", ORNL-TM-3868 (revised Sep 1972)
{TSR-II spectrum and Spectrometer Energy Resolution are given}

Information available in SINBAD, NEA-1517/59:

"ST2. Oxygen Broomstick Experiment - An Experimental Check of Neutron Total Cross Sections - 1968" contains description of experiment and numerical data (TSR-II reactor and transmitted spectrum) for O broomsticks of length only 60" (152.4 cm),
no neutron transmission spectra data for 24" (60.96cm) and 36"(91.44cm),
no MCNP model.

ORNL liquid Oxygen broomstick: Experimental Set-up

information from NSE 27(1967)299, ORNL-TM-2242(1968), ORNL-TM-3868 (1972):

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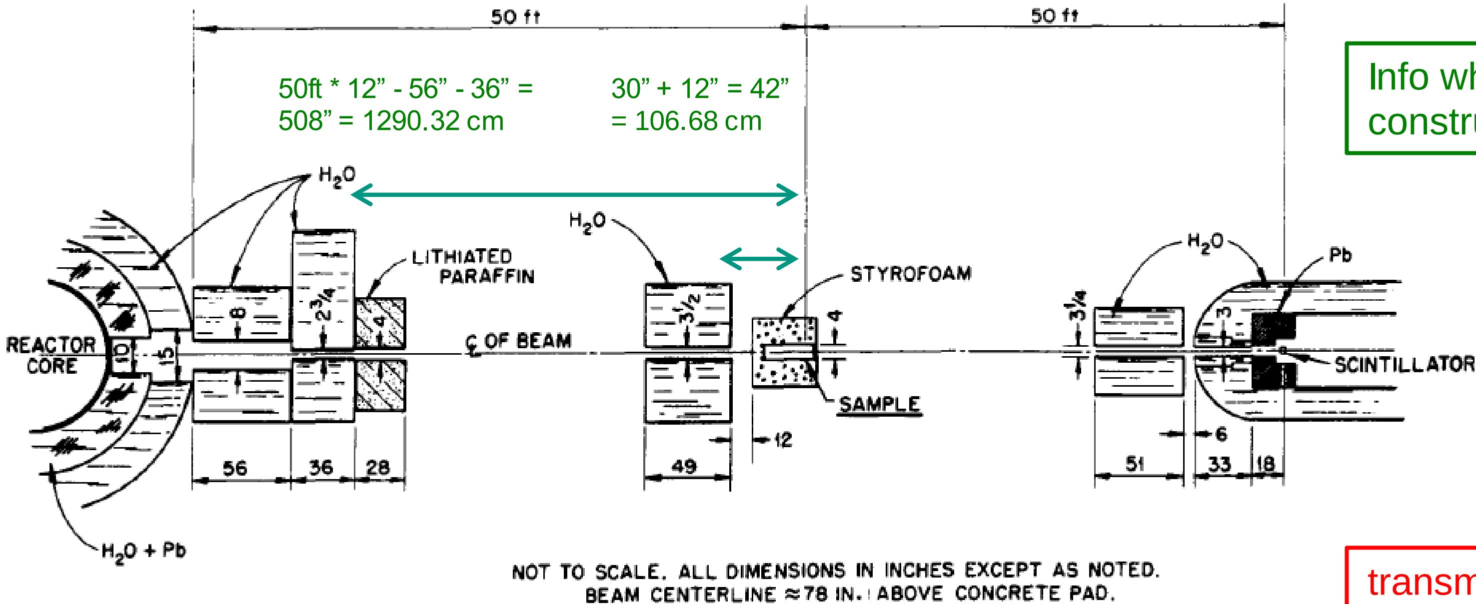


Fig. 1. Schematic diagram of experimental arrangement.

Info which was used to construct MCNP input

transmitted spectra are not available in SINBAD

Information from original publications:

- **Sample = Liquid Oxygen (99.9%), dia. 4"(10.16cm); length 24"(60.96 cm), 36"(91.44cm) and 60"(152.4 cm) contained in Dewars.**
- **To reduce air-scattering effects: the neutron beam emerging from Reactor was collimated to diameter of 3 1/2" by hydrogenous shield and detector was also collimated and shielded by lead and water**
- **Transmission spectrum was measured by 2"x2" NE-213 scintillation Detector with n-g discrimination in Energy range 1.9 to 8.6 MeV**
- **Background was measured with 28" thick H_2O in Ø4" Al can replacing sample & followed by 4" of Pb**
- **Source (reactor TSR-II) spectrum was measured by the same Detector (sample off) (there was 2" Pb filter in reactor beam, thus Source spectrum contains effect of Lead)**
- **The pulse-height distribution was converted in energy one by unfolding procedure**

ORNL O-broomstick: modelling of Energy Resol & TSR source in MCNP

TSR-II Source Geometry (ORNL-TM-4010):

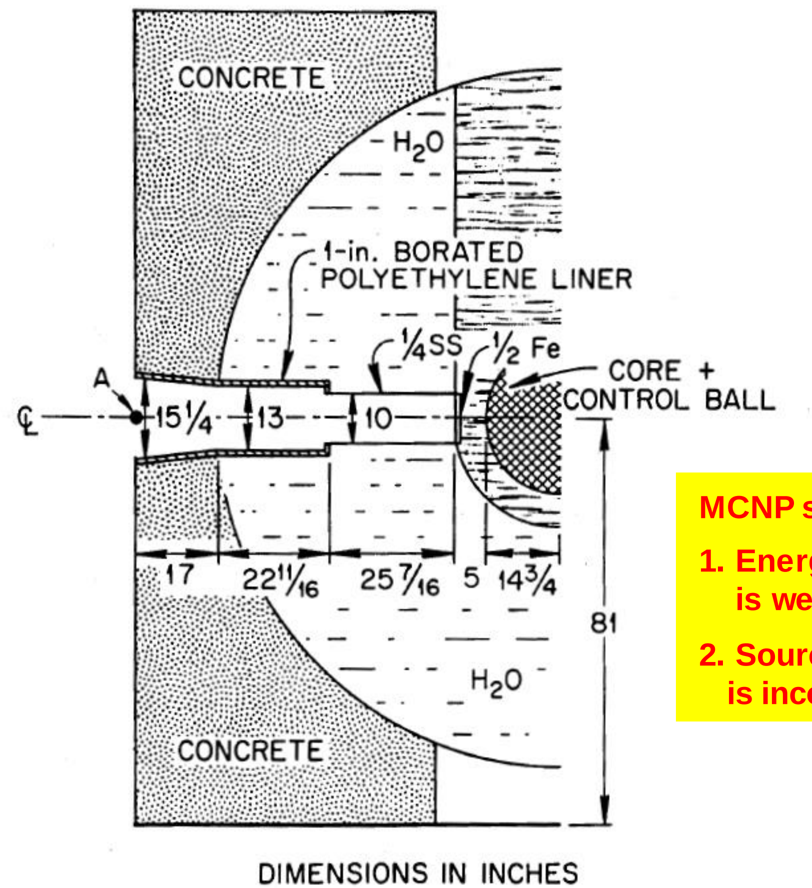
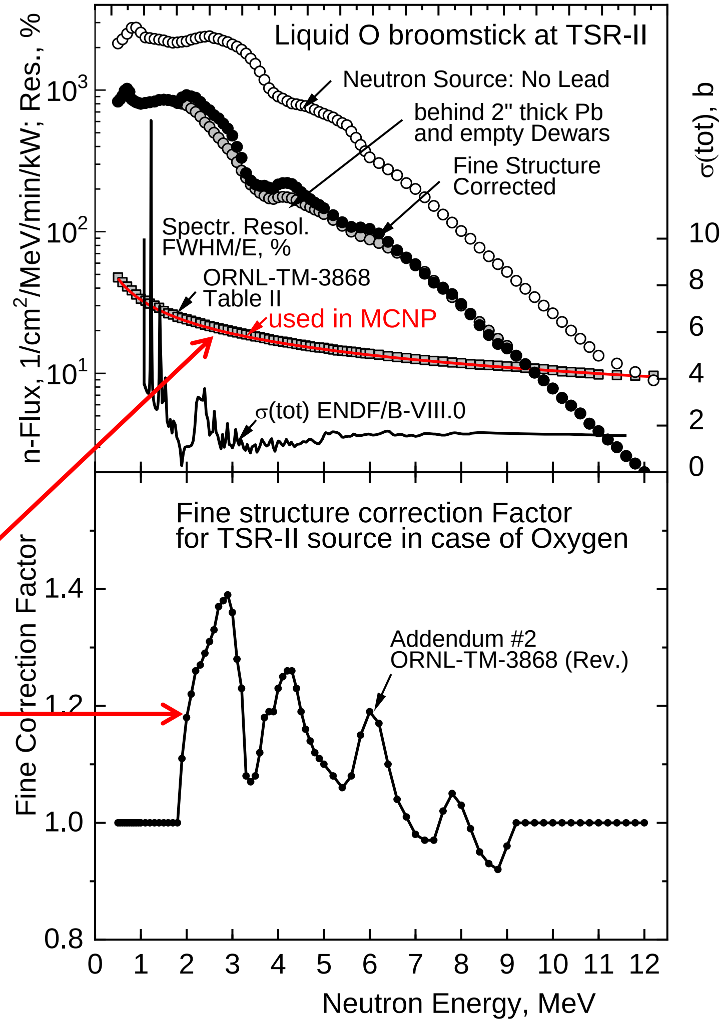


Fig. Diagram of the 15-1/4-in. Collimator Arrangement for the TSR-II Reactor at the Tower Shielding Facility.

MCNP simulation:

1. Energy resolution is well reproduced:

2. Source Fine structure is incorporated

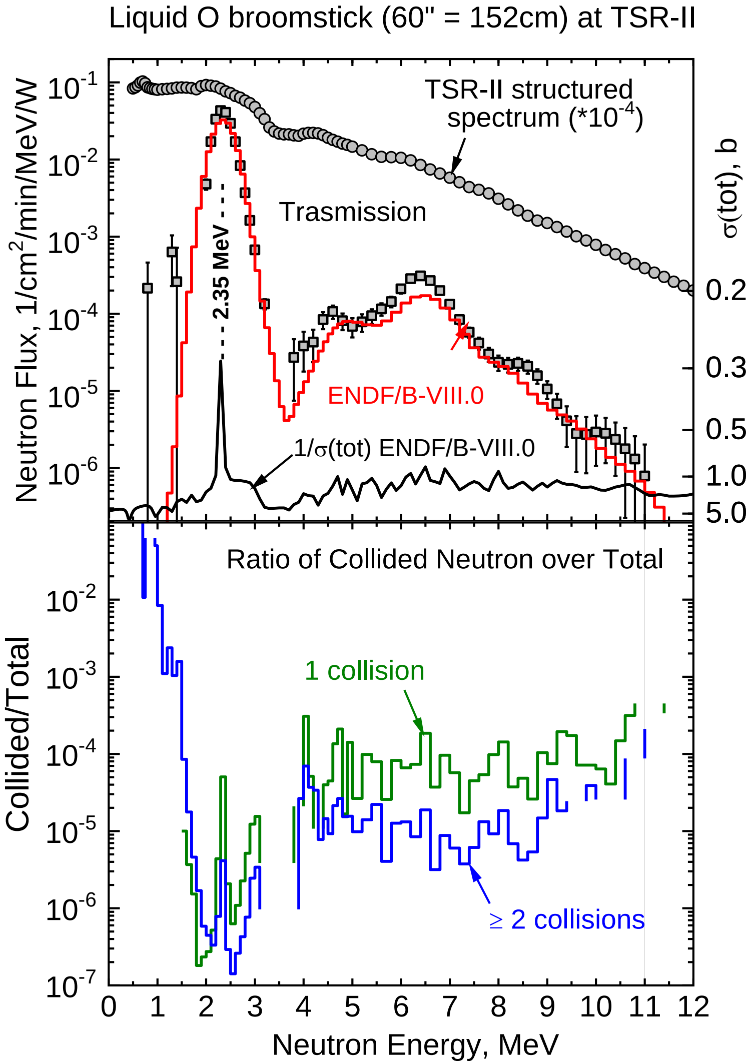


Information from original publications:

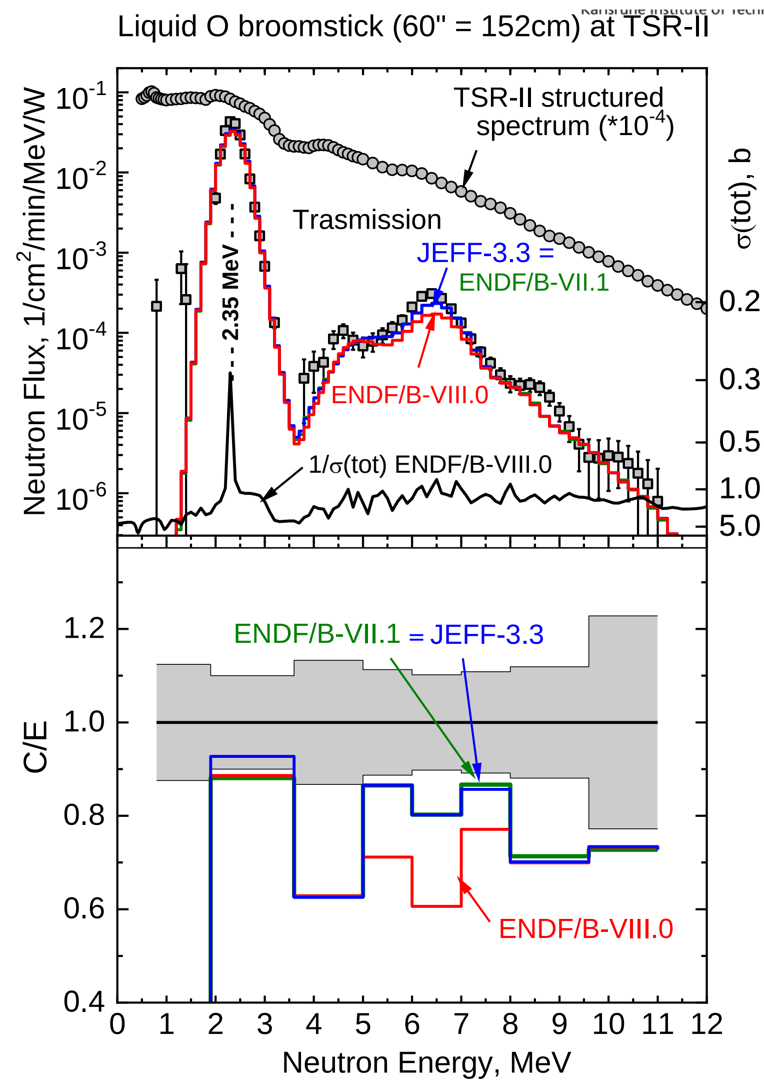
- **Materials through which the source beam had penetrated before source spectrum was measured: ≈ 2" H_2O, 3½" Al, 4" Pb, ¼" Fe and empty Dewars.**
- **Since O in H_2O, a selective fine structure in source beam can be expected to result in that the neutrons transmitted through H_2O in immediate vicinity of the O σ(n,tot) minima are somewhat greater, and off the minima somewhat less, than the poor resolution NE-213 source measurement would indicate.**

ORNL liquid O-broomstick 60”: Results of MCNP simulations

Transmitted Spectra: Contribution of Collisions



Transmitted Spectra & C/E with main Libraries

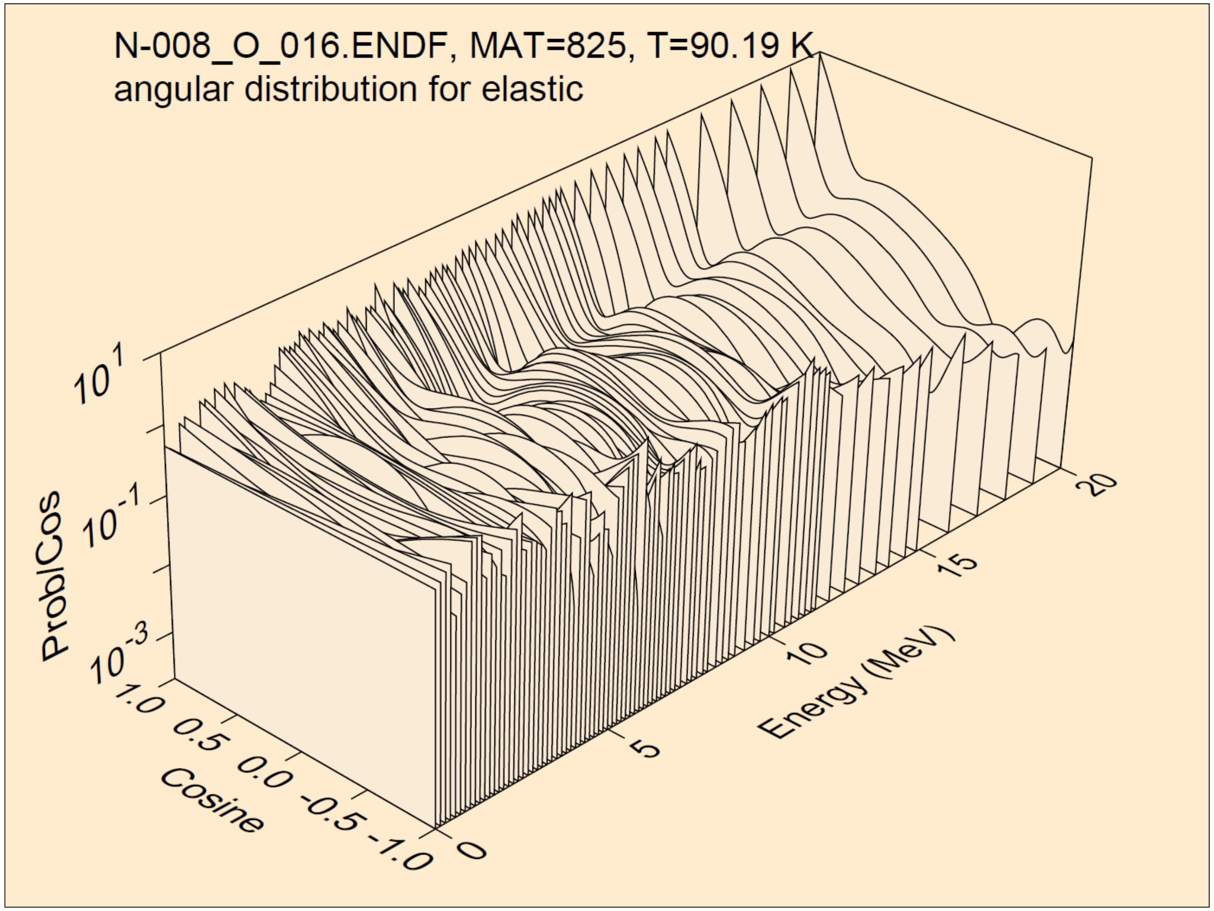


Observations:

- **Contributions of collisions: the probability of one/more collision events is ≤ 10^{-4} of uncollided ones**
- **Validation: JEFF-3.3 = ENDF/B-VII.1 are 10 - 20% better at energies 5 to 8 MeV than ENDF /B-VIII.0**

ORNL liquid O-broomstick 60”: Angular issues

Angular Distributions for $^{16}O(n,n_{el})$ in ENDF/B-VIII.0:



Angle subtended by detector which look on Ø4” O-broomstick:

*Θ = arctan (0.5 * ØSample / Distance_to_Detector)*
= arctan (2” / 50ft)
= 0.19 degree

Cosine Θ = 0.999995

Finding:
fraction of elastic neutrons within angle subtended by sample $\Theta = 0.2$ deg = $(1 - \cos\Theta) * \sigma_{el}(0^o) / (\sigma_{el}/4\pi)$ = 5E-6 * $\sigma_{el}(0^o) / (\sigma_{el}/4\pi) \approx$ E-4   => elastic collision will prevent neutrons to reach detector

ORNL liquid O-broomstick: Sensitivities Analytically & by MCNP

Sensitivities were computed by two ways:

(1) *Analytically (w/o averaging over Detector resolution):*

Transmission $T \equiv \exp(-n\,t\,\sigma_{tot})$ then:

$$Sensitivity\_n = (\Delta T/T)/(\Delta n/n) = n\,t\,\sigma_{tot}$$

$$Sensitivity\_\sigma_{tot} = (\Delta T/T)/(\Delta\sigma/\sigma) = n\,t\,\sigma_{tot} = Sensitivity\_n$$

$$Sensitivity\_\sigma_i = (\Delta T/T)/(\Delta\sigma_i/\sigma_i) = n\,t\,\sigma_{tot}\,\sigma_i/\sigma_{tot} = \sigma_i/\sigma_{tot}\,Sensitivity\_\sigma_{tot}$$

where t - thickness, n - Atom density = 0.0429 1/cm-b

NB1: Sensitivities to n and σ_{tot} are equal !

NB2: Regrettably but uncertainty of n is not given !

(guessing gives similar minimal values:

= 0.0001/0.0429 = 0.2% from last digits of n

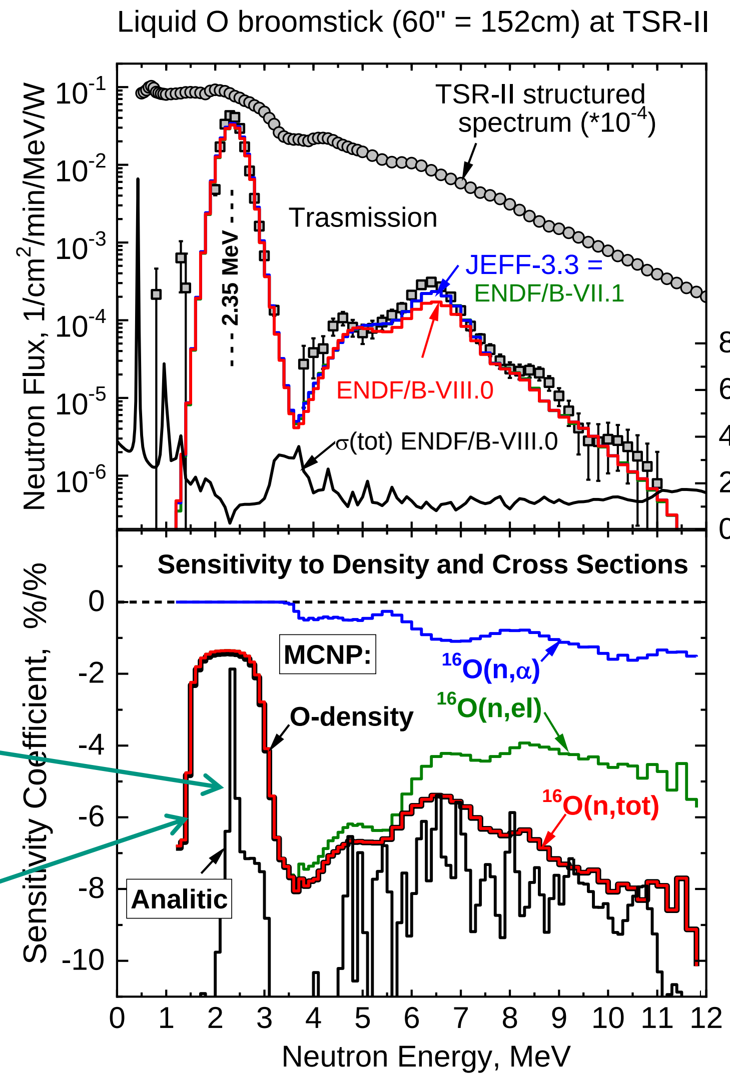
= 1%/99.9% = 0.1% from chem. composition)

thin solid curve

(2) *MCNP (pert card + averaging over Detector resolution):*

tally perturbation due to n, σ_{tot}, σ_{el}, σ_{na} variations

thick solid curves

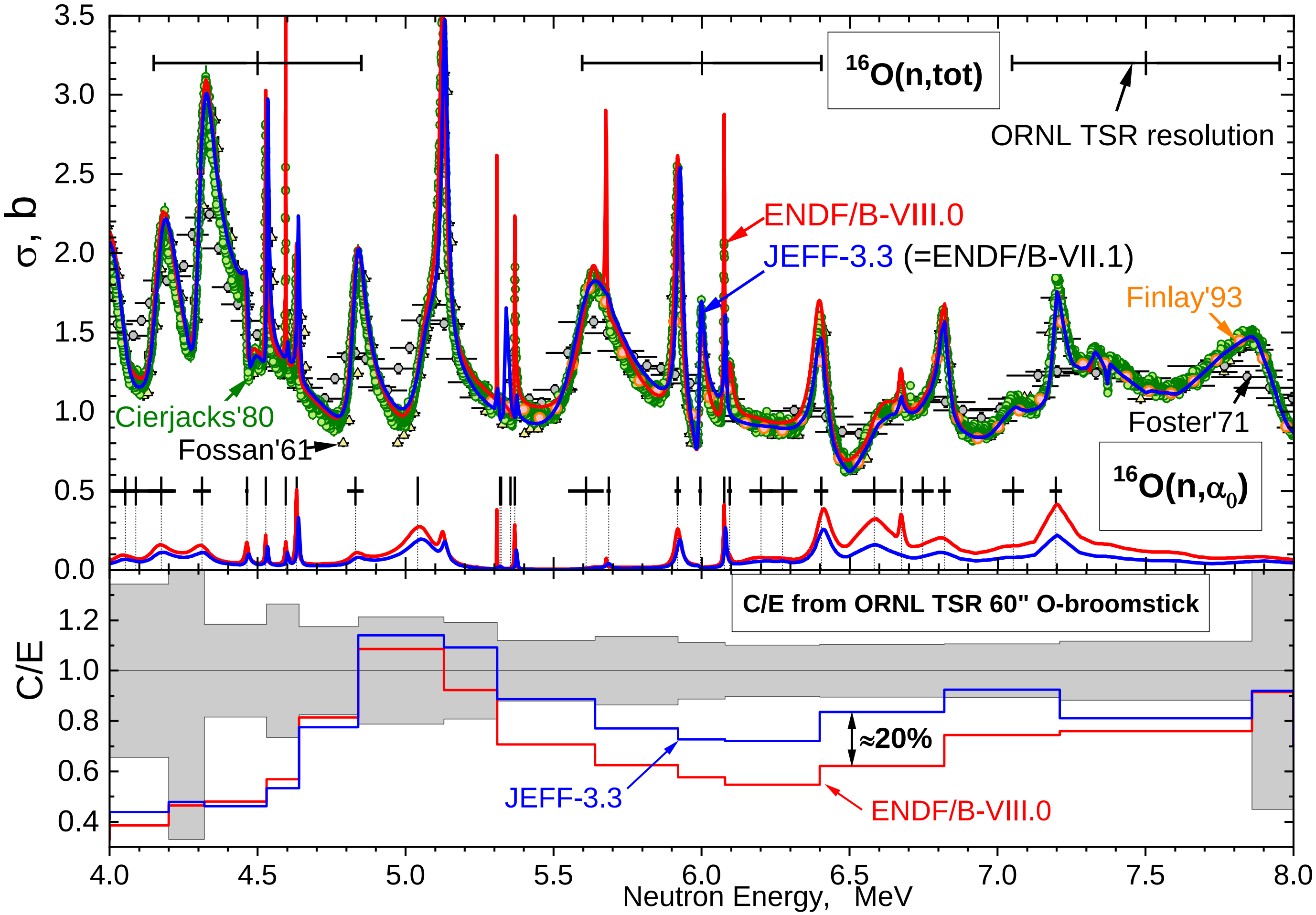


Findings for uncollided deep transmission in ORNL 60" thick O-broomstick:

- **the analytical and MCNP solvers are identical**
- **you'll never get sensitivity to cross section better than to atom density *(0.2% ? in this case)***
- **sensitivity to (n,tot) varies between -2 and -8 reaching maximum at ^{16}O(n,tot) resonance peaks *(it could be > 10 (!) at facilities with improved energy resolution)***

ORNL liquid O-broomstick 60”: validation of XS

Status of XS data for ^{16}O(n,tot) and C/E from ORNL O-broomstick:



Findings for the energy range from 4 to 8 MeV:

- recent measurements of ^{16}O(n,tot) by Y.Danon et al. (AccApp-2015, 345) are not in EXFOR yet
- Doppler 90/296°K (0.025keV) << ^{17}O Resonan. Width (2 - 150 keV) << ORNL O-stick Resolut. (≈ 750 keV)
- ORNL sensitivity to σ(n,tot) ≈ -6 => thus $\Delta\sigma(n,tot)/\sigma(n,tot) = (\Delta T/T)/(-6) \approx 20\%/(-6) = -3.3\%$ - is it due too strong/thin resonances? (likely not), then O-broomstick demands ≈ 3% down-scaling of ENDF/B-VIII.0 ?

ORNL liquid O-broomstick 60”: validation of XS (*cont.*)

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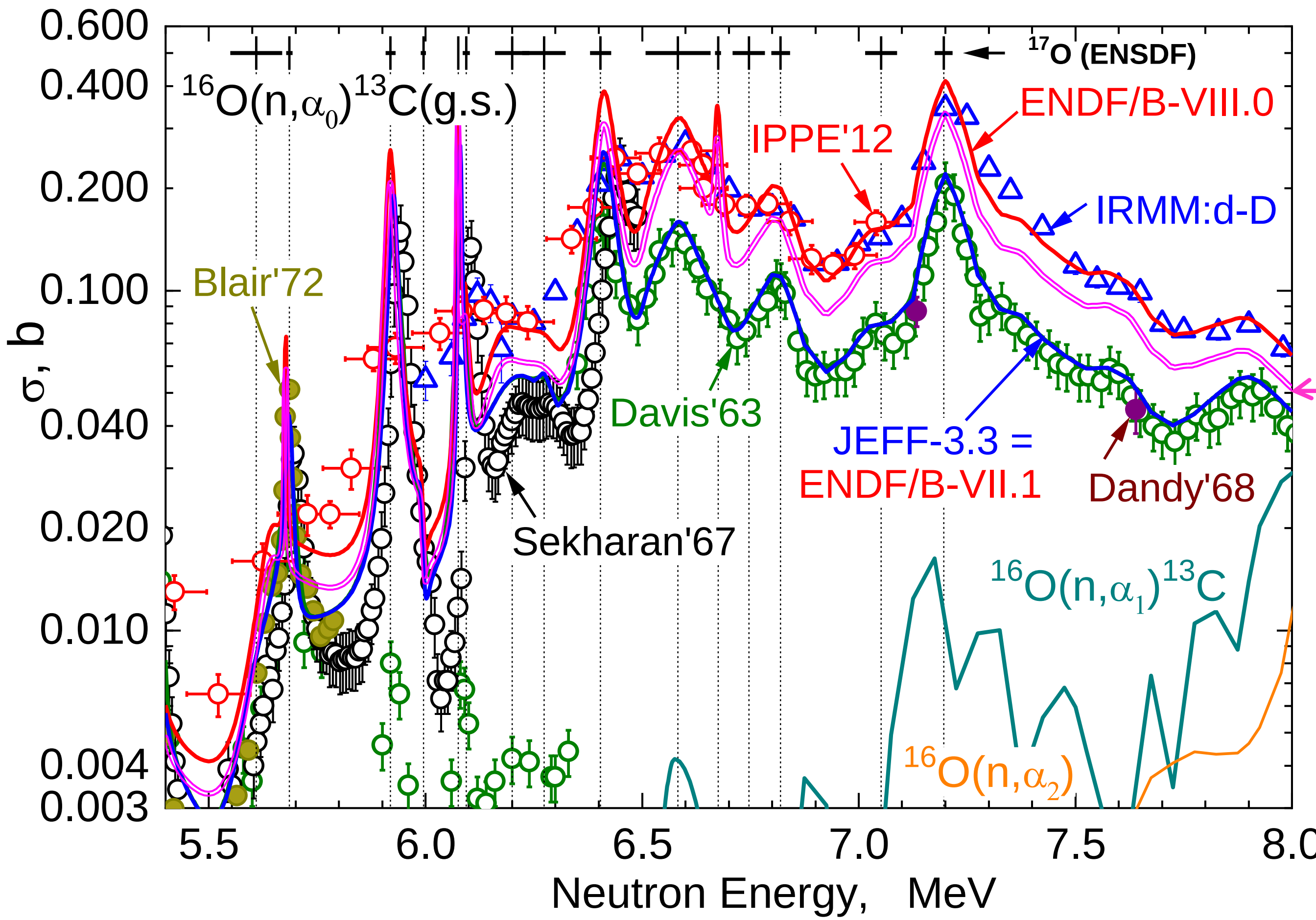
Status of measured and evaluated data for α-production $^{16}O(n,\alpha_0)$



If we apply observed 20% underestimation in interval 5 - 8 MeV to $^{16}O(n,\alpha)$:
Sensitivity to σ(n,α) ≈ -1 => thus Δσ(n,α)/σ(n,α) = (ΔT/T) /(-1) = -20% this will result to 0.8*ENDF/B-VIII.0

Summary for Action 4:
Contribute models for Oxygen ORNL broomstick benchmark and 91.44 cm liquid O data if of interest (sufficient quality) for SINBAD

- **neutron transmitted spectra for 24” and 36” thick Oxygen samples are not available in SINBAD database - can ORNL still provide them ?**

- **MCNP model was created and confirms that uncollided transmission approximation works well**

- **In comparison with Analytic approach, use of MCNP makes easier to analyse: the impact of detector resolution, contribution of collided neutrons, sensitivity estimation etc.**

- **Validation outcome: it looks like that O-broomstick shows better performance of $^{16}O(n,tot)$ XS from JEFF-3.3 (= ENDF/B-VII.1) than from ENDF/B-VIII.0**
  - ***we still would like to study this issue further …***