SINBAD Benchmark Database and FNS/JAEA Liquid Oxygen TOF Experiment Analysis

I. Kodeli
Jožef Stefan Institute
Ljubljana, Slovenia

SG39 Meeting, Nov. 2014

SINBAD - Radiation Shielding Experiments Scope and Objectives

- Compilation of high quality experiments for validation and benchmarking of computer codes and nuclear data used for radiation transport and shielding problems encompassing:
  - reactor shielding, PV dosimetry **(46)**
  - fusion blanket neutronics **(31)**
  - accelerator shielding **(23)**
- Low and inter-mediate

  energy particles applications.
- **Contains 100 experiments**

SINBAD – completed quality evaluations, not yet in SINBAD (2012-2014)

REACTOR

- Ispra Iron Benchmark (EURACOS) [**]
- Ispra Sodium Benchmark (EURACOS) [**]
- Cadarache Sodium (HARMONIE) [*]
- JANUS Phase I (Neut.Transport Through Mild&Stainless Steel) [***]
- JANUS Phase VIII (Neutron Transport Through Sodium & Mild Steel) [***]
- NESDIP-2 Benchmark (ASPIS) [*/**]
- NESDIP-3 Benchmark (ASPIS) [***]
- Winfrith Iron Benchmark (ASPIS)
- Winfrith Iron 88 Benchmark (ASPIS)
- Winfrith Graphite Benchmark (ASPIS)
- Winfrith Water/Iron Benchmark (ASPIS-PCA REPLICA)
- Winfrith Water Benchmark
- Winfrith Neutron-Gamma Ray Transport through Water/Steel Arrays (ASPIS)

ACCELERATOR

- TIARA 43 & 68 MeV PROTONS [***]
- BEVALAC [***]
- AVF 75MeV [*/**]
- PSI-590MeV [*/**]

Proposed classification

♦♦♦	valid for nuclear data and code benchmarking
♦♦	suitable for education & training
♦	benchmarks of historical interest

SINBAD: FISSION NEUTRONICS

Benchmark / quality	Additional information needed on
ASPIS Iron ~ ♦♦	n source description, positioning / dimension uncertainty, some specifications inconsistent or not complete
ASPIS Iron-88 ~ ♦♦♦	New MCNP model. Additional information needed: - detectors arrangement (e.g. stacking) - gaps between the slabs - absolute calibration of neutron source & dilution factor - effect of the cave walls
ASPIS Graphite ♦♦♦	New MCNP model. Additional information needed: - detectors arrangement in the slots (dimensions are inconsistent)
ASPIS Water ♦♦♦	New MCNP model. Supplementary information needed on: - NE-213 spectrometer - water tank (container, bowing effects) - experimental room
ASPIS n/γ water/steel arrays ~ ♦♦♦	Supplementary information needed on: - detectors arrangement - bowing of the water tanks - background subtraction - cave walls

SINBAD: FISSION NEUTRONICS

Benchmark / quality	Additional information needed on
ASPIS PCA REPLICA ♦♦♦	Supplementary information needed on: - set-up of the activation foils - rear wall of the ASPIS cave
NESDIP-2 ♦ / ♦♦	New MCNP model. Supplementary information needed on: - activation foils positioning & housing - background subtraction method, calibration
NESDIP-3 ♦♦♦	- „ -
JANIS-1 ♦♦♦	- „ -
JANIS-8 ♦♦♦	- „ -
EURACOS Iron ~ ♦♦	New MCNP model, source model, uncertainty. Supplementary information needed on: source (spectrum, spatial distribution), energy structure of the proton recoil spectra, neutron spectrometers response functions, additional details on the geometry (room return), on geometry and material composition uncertainties. Limited applicability – fast neutron attenuation in iron only.
EURACOS Na ~ ♦♦	- „ -
HARMONIE ♦	too simplified geometry, materials &n source description

SINBAD: FUSION NEUTRONICS

Benchmark / quality	Additional information needed on
OKTAVIAN W n/γ spec. ~ ♦♦♦	background subtraction method γ source measurements, γ detector response function
FNS W ~ ♦♦♦	unfolding technique of Ne–213 measurements activation foils positioning, uncertainty & housing
FNG W ♦♦♦	/
FNG/TUD W ~ ♦♦♦	neutron & γ flux point–wise uncertainties measured pulse-height distributions inconsistencies with FNG–W (integral) bench.results
OKTAVIAN Si 60cm ~ ♦♦♦	background subtraction method γ source measurements & detector response function
OKTAVIAN Si 40cm ♦♦	neutron flux measurements only available in graphical form
OKTAVIAN Ni ♦♦♦	/
FNS Graphite ~ ♦♦♦	experimental unfolding technique, activation foils positioning & housing
FNG SiC ♦♦♦	/
FNG/TUD SiC ~ ♦♦♦	neutron & γ flux point–wise uncertainties original pulse-height distributions inconsistencies with FNG-SiC benchmark results

SINBAD: FUSION NEUTRONICS

Benchmark / quality	Additional information needed on
FNS V ~ ♦♦♦	experimental unfolding technique activation foils positioning, uncertainty & housing
OKTAVIAN Al ~ ♦♦♦	neutron flight path parameter background subtraction method γ source measurements & γ detector response function
OKTAVIAN Fe ~ ♦♦♦ or ♦♦	very large uncertainties of the measurements
FNS Iron dogleg-duct ♦♦	neutron source spectrum neutron detector response function
TUD Iron slab ~ ♦♦♦	neutron source pulse height spectrum
FNG Stainless Steel ~ ♦♦♦	A comprehensive geometry description would be helpful
FNG ITER Dose Rate ♦♦♦	/
FNG/TUD ITER Bulk ~ ♦♦♦	neutron and gamma flux point–wise uncertainties original pulse-height distributions
FNG ITER Bulk ♦♦♦	/
FNG ITER Bulk streaming ♦♦♦	/
FNS Oxygen ♦♦♦	neutron effective flight path parameter
FNS Sky-shine ♦♦	neutron source spectrum

SINBAD: FUSION NEUTRONICS

<table>
<tr><th>Benchmark</th><th>Improvements, additional info needed</th></tr>
<tr><td>IPPE-V shells, 14 MeV n source</td><td rowspan="2">New 2D & 3D MCNP5 models prepared</td></tr>
<tr><td>IPPE-Fe shells , 14 MeV n source</td></tr>
<tr><td>IPPE-Th shell with 14 MeV & ^{252}Cf neutron source</td><td>more details on collimator and detector needed, experimental bare ^{252}Cf source spectra not available, 2D&3D MCNP5 models prepared</td></tr>
<tr><td>IPPE-Bi shells with 14 MeV & ^{252}Cf neutron source</td><td>TOF & energy spectra available, more details on collimator and detector housing needed, bare ^{252}Cf source spectra not available</td></tr>
<tr><td colspan="2">Improved MCNP5 models, including time domain calculations:
2D model: relies on measured bare source spectrum (used as response function), source and detector system are approximate
3D model: more details on collimator and detector housing needed
Good practice of including TOF spectra should be encouraged and extended to any TOF experiment in SINBAD</td></tr>
</table>

SINBAD Benchmarks using TOF technique

- ***Reactor Shielding***

  IPPE Th shell with 14 MeV and Cf-252 source neutrons

- ***Fusion Neutronics Shielding***

  Nickel Sphere (OKTAVIAN)
  Iron Sphere (OKTAVIAN)
  Aluminium Sphere (OKTAVIAN)
  Silicon Sphere (OKTAVIAN)
  Tungsten Sphere (OKTAVIAN)

  FNS Liquid Oxygen
  FNS Skyshine
  FNS Dogleg Duct Streaming
  IPPE Vanadium Shells
  IPPE Iron Shells
  IPPE Bi Sphere

- ***Accelerator Shielding***

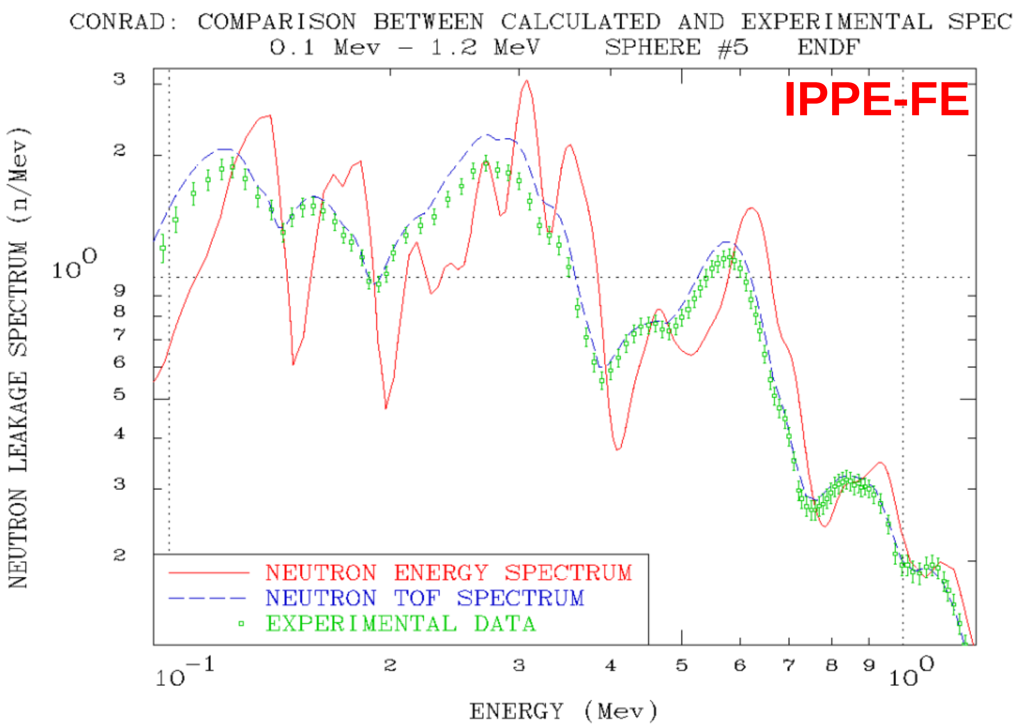
  RIKEN Quasi-monoenergetic Neutron Field in 70-210 MeV Energy Range
  HIMAC High energy Neutron (<800 MeV) Measurements in Iron
  HIMAC High energy Neutron (<800 MeV) Measurements in Concrete
  MSU experiment with He & C ions on Al target
  Neutron Spectra Generated by 590-MeV Protons on a Thick Pb Target

Different approximations were used in the neutron source and collimator-detector modelisation. Scattering in the collimator, as well as the finite detector time resolution and source pulse width were accounted for by using detector response functions (IPPE Spheres) or by using (unphysical) neutron spectra measured without the spheres as the neutron source (OKTAVIAN).

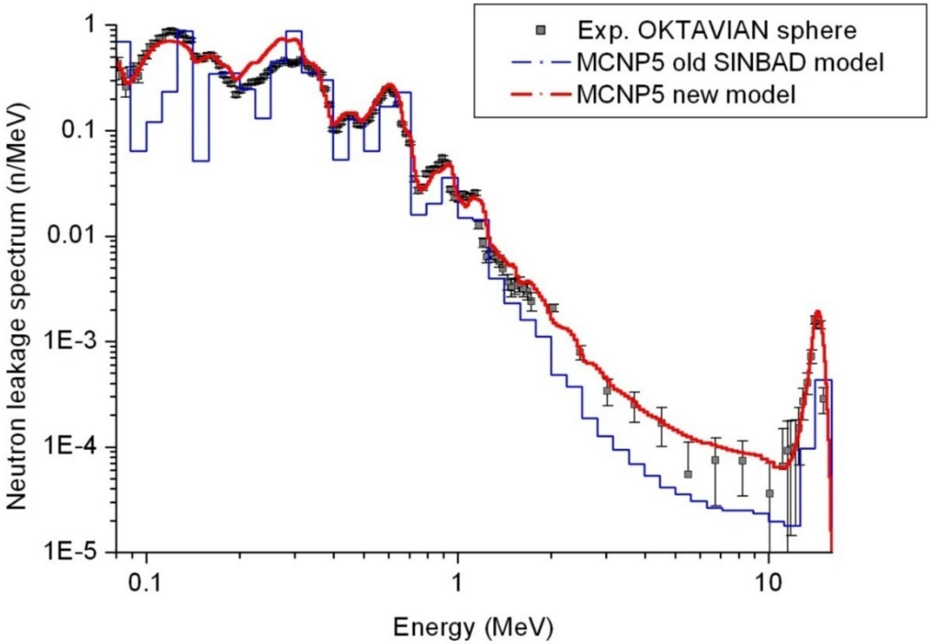
IMPROVEMENTS

- more experimental information from literature
- refinement of the D-T source model
- experimental source spectra simulations
- new MCNP5/X models for TOF analvses

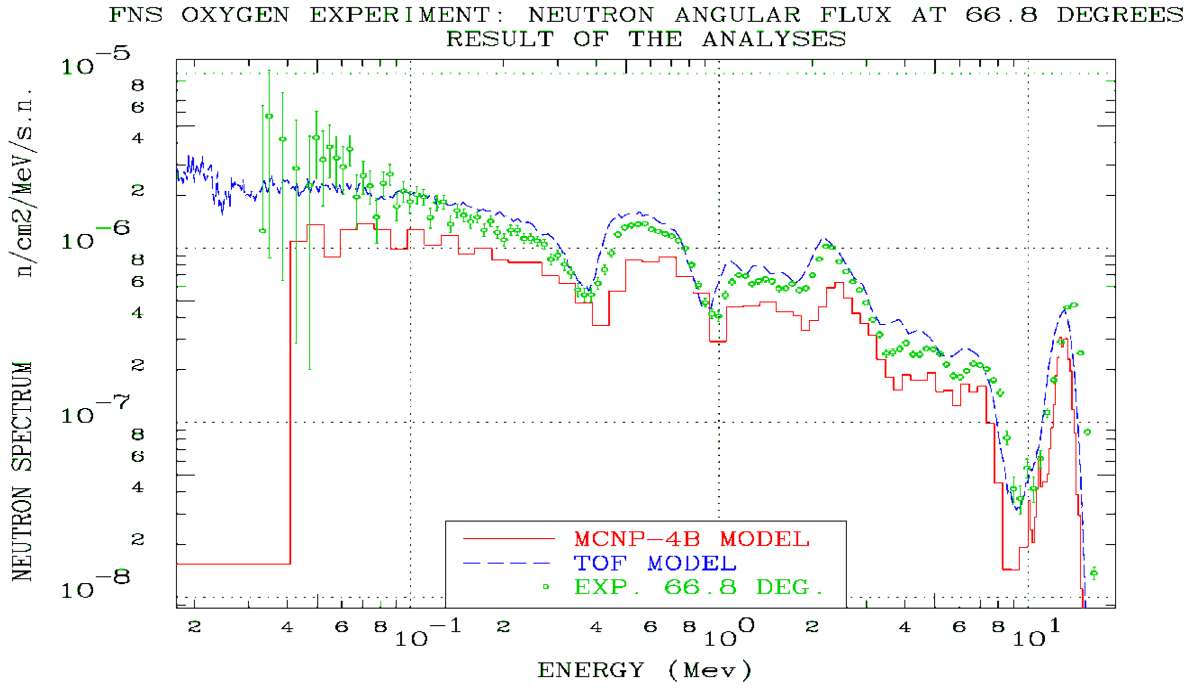
Interpretation of TOF and energy spectra (multiple scattering)



OKTAVIAN Fe sphere



FNS Oxygen



FNS-Liquid O TOF Benchmark

- 14 MeV D-T neutron facility at FNS/JAERI
- Measurement of angular neutron leaking spectra from a 20 cm slab of liquid oxygen in the 0.05 - 15 MeV energy range. Angular fluxes at 0, 12.2, 24.9, 41.8 and 66.8 degrees were measured.

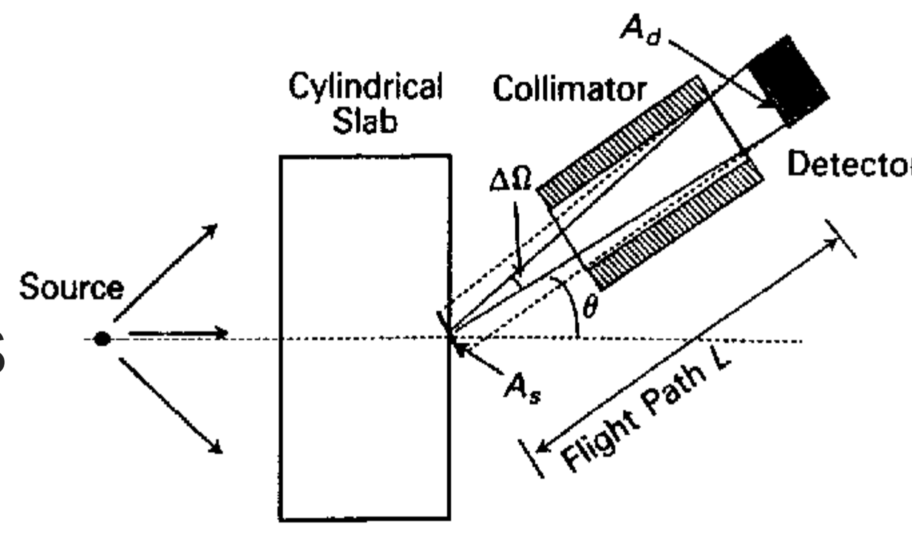
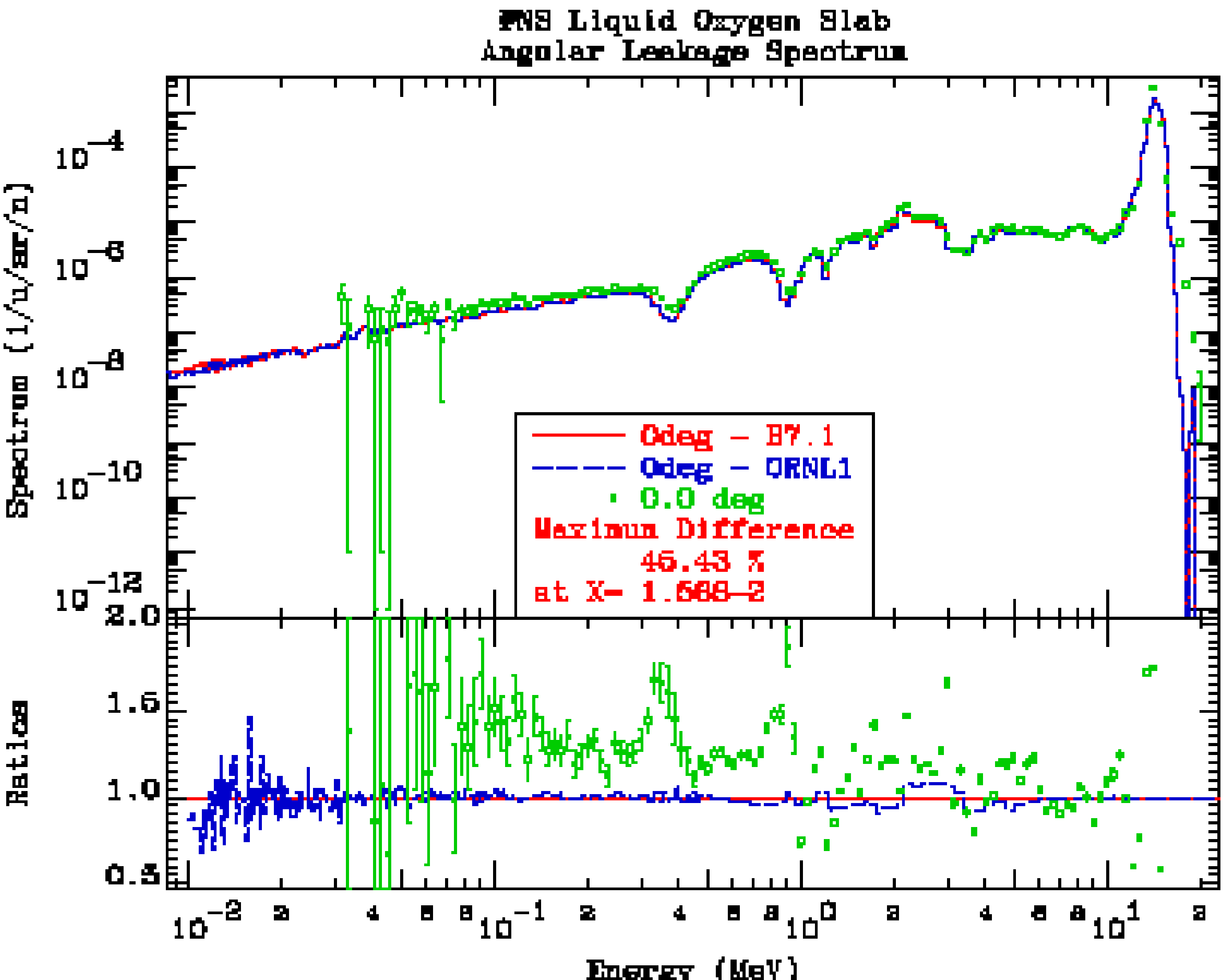


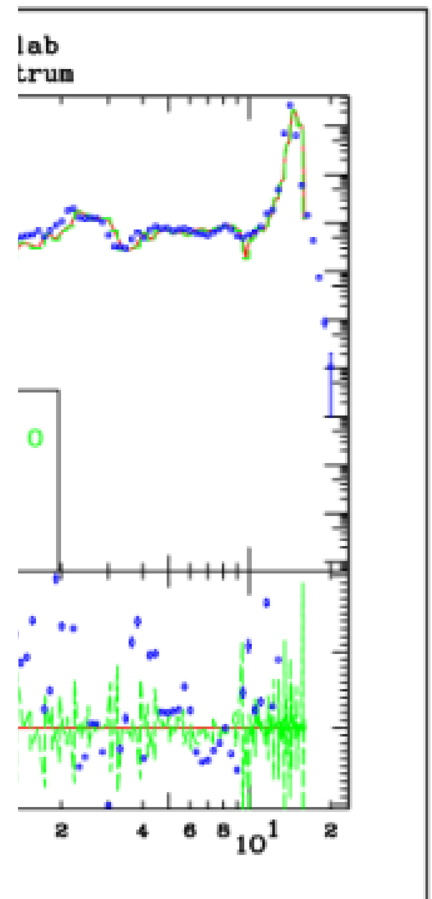
Fig. 3. Definition of the parameters used for data reduction.

FNS-Liquid O TOF Benchmark

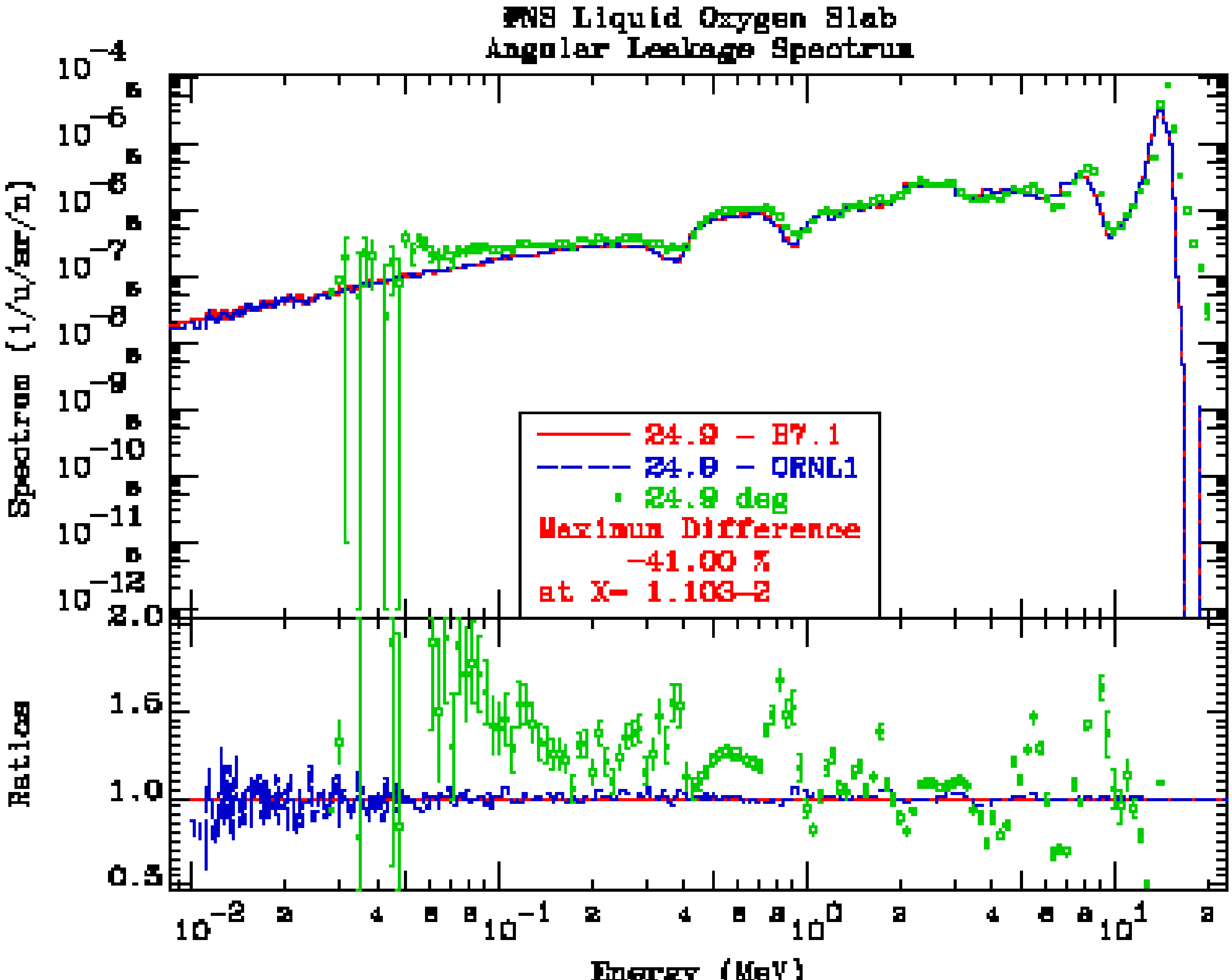
- Complete description is included in **SINBAD** and available from OECD/NEA Data Bank and RSICC. Benchmark was re-analysed and SINBAD compilation updated in 2010 (complete revision, time vs. energy domain calculation).
- **Drawback:** Uncertainty in neutron effective flight path parameter, information needed on detector efficiency function, details on conversion of experimental TOA to E spectra.
- **Analysis:**
- MCNP-6 Monte Carlo in energy and time domain (ENDF/B-VII.1, **Luiz files ORNL1** and **ORNL2**). Results of **time domain** calculations are presented here.
- In the past it was analysed using DORT with first collision source (GRTUNCL): suitable for cross-section sensitivity-uncertainty analysis.

FNS-Liquid O – MCNP results

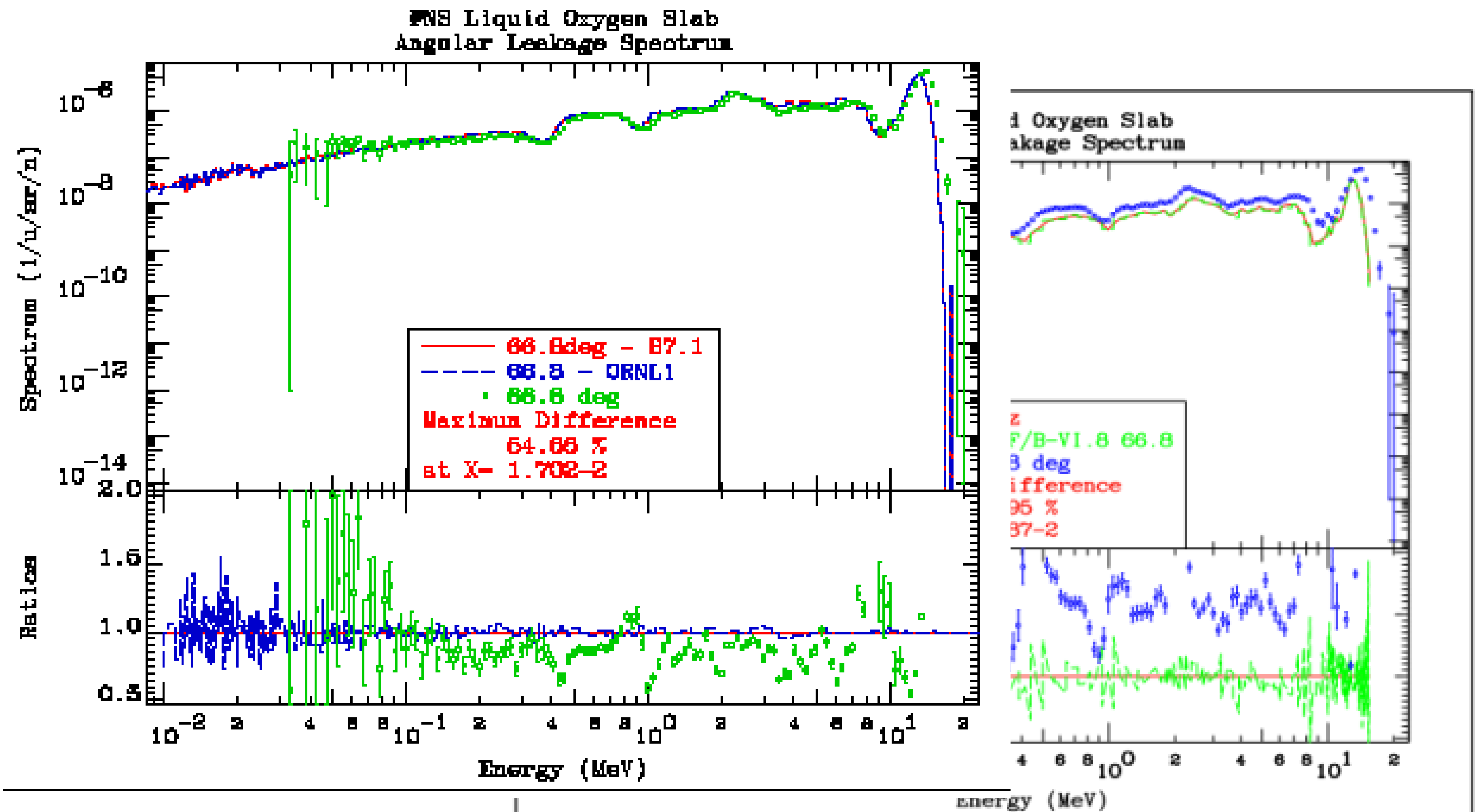




FNS-Liquid O – MCNP results



FNS-Liquid O – MCNP results



FNS-Liquid O - Conclusions

- FNS Liquid Oxygen benchmark is suitable for validation of O X-sections including SAD,
- Good C/E agreement for Luiz file and ENDF/B-VII.1. Little difference between spectra calculated using MCNP6 with ENDF/B-VII.1 and Luiz files.

To-be-done in future

- Validation of Gerry file could be done as soon as the file is completed (now only MF3 & 4 for MT=1, 4 & 800 for E<6.20 MeV). This is also true for critical benchmarks,
- Cross-section sensitivity & uncertainty calculations can be done using deterministic methods to determine the most sensitive reactions for the FNS-O benchmark (including SAD sensitivities).

SINBAD – recent references

- I. Kodeli, P. Ortego, A. Milocco, G. \v{Z}erovnik, R. E. Grove, A. Yamaji, E. Sartori, Re-evaluation and Continued Developmentof Shielding Benchmark Database SINBAD, PHYSOR 2014 – The Role of Reactor Physics Toward a Sustainable Future, Kyoto, Japan, Sept. 28 – Oct. 3, 2014
- I. Kodeli, A. Milocco, P. Ortego, E. Sartori, 20 Years of SINBAD (Shielding Integral Benchmark Archive and Database), Progress in Nuclear Science and Technology, Volume 4 (2014) pp. 308-311.
- B. L. Kirk, R. E. Grove, I. Kodeli, J. Gulliford, E. Sartori, Shielding Integral Benchmark Archive and Database (SINBAD), 14^{th} Int. Symp. on Reactor Dosimetry (ISRD- 2011)
- I. Kodeli, E. Sartori, B. Kirk, "Recent Accelerator Experiments Updates in Shielding INtegral Benchmark Archive Database (SINBAD)", Nuclear Instruments and Methods in Physics Research A 562 (2006) 725-728

Benchmark quality review reports:

- I. Kodeli, A. Milocco, A. Trkov, Lessons Learned From The TOF-Benchmark Intercomparison Exercise Within EU Conrad Project (How Not to Misinterpret a TOF-Benchmark), *Nuclear Technology*, Vol. **168** (Dec. 2009) 965-969
- A. Milocco, A. Trkov, I. Kodeli, The OKTAVIAN TOF experiments in SINBAD: Evaluation of the experimental uncertainties, *Annals of Nuclear Energy* **37** (2010) 443–449
- A. Milocco, I. Kodeli, A. Trkov, The 2010 Compilation of SINBAD: Quality Assessment of the Fusion Shielding Benchmarks, Proc. NEMEA-6 Scientific Workshop on Nuclear Measurements, Evaluations & Application, Krakow, Poland, 25-28 Oct. 2010.

FNS-Liquid O - references

- Y. Oyama, H. Maekawa, "IAEA Benchmark Problem Based on the Time-of-Flight Experiment on Liquid Oxygen Slabs at FNS/JAERI", IAEA, Nuclear Data Section, Benchmarks for FENDL validation (1994)
- I. Kodeli: Verification of Oxygen Cross Section Data for Oil Well Logging Applications, Int. Conf. on Nuclear Data for Science and Technology, ND2001, Tsukuba, Japan (7-12 Oct. 2001).
- A. Milocco, I. Kodeli, A. Trkov, The 2010 Compilation of SINBAD: Quality Assessment of the Fusion Shielding Benchmarks, NEMEA-6 Proceedings, OECD/NEA 2010