Status of SINBAD Benchmarks - Pilot study proposals

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WPEC Subgroup 47 (SG47) on
Use of Shielding Integral Benchmark Archive and Database for ND Validation

Shielding benchmarks to be considered within WPEC SG47:

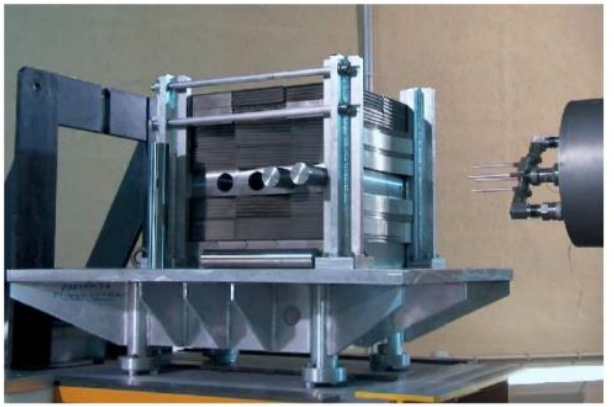
- **FNG SS, ITER Blanket, ITER Streaming, SiC, W, HCPB, (HCLL), Cu**
- **LLNL spheres**
- **ASPIS IRON88**
- **JANUS phase I to VIII (Fe, Na)**
- **TIARA (Fe, concrete)**
- **FNS**
- **OKTAVIAN**
- **Rez Iron spheres**

Drawbacks, critics:

- **evaluations and review process less complete/thorough than ICSBEP/IRPhE**
- **format (EGRTS)**
- **(MCNP) computer code inputs missing**
- **long CPU time calculations**

Benchmark Experiment on W (2002)

Validate EFF data for tungsten



Use of benchmarks to improve today's high quality cross section evaluations?

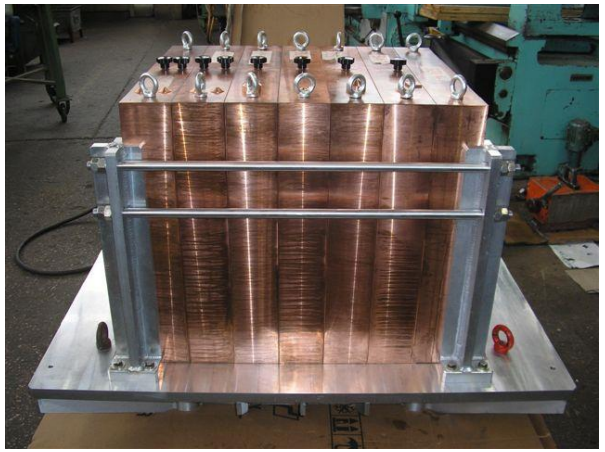
Drawbacks of older experiments:

- Include geometry and source description simplifications to allow modelisation using the codes available at the time;
- mixing of 'processed measured' and 'measured' data;
- Authors / experimentalist often not available any more, additional information and clarifications difficult to obtain.

New benchmarks should be evaluated in benchmark databases ASAP, not only published in journals !

F4E 2016-2018 SINBAD related activities: FNG-Cu & FNG-HCLL

FNG-Copper: ENEA - KIT- JSI collaboration (M. Angelone et al.); pre- and post-analysis in 2014-2015, measurements between Oct. 2014 to March 2015



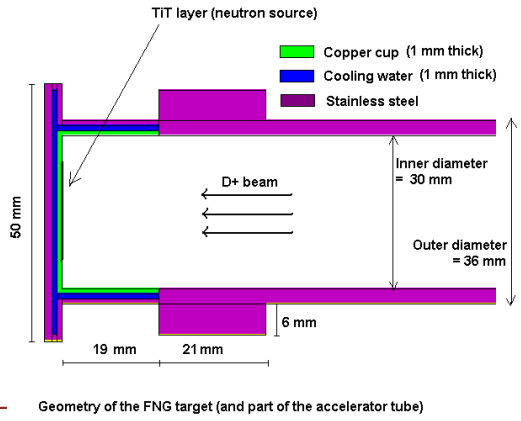
Block of Oxygen-free **Copper (99.90 wt.%) 60 x 60 x 70 cm^3** placed on Al support was irradiated at 14-MeV d-T Frascati Neutron Generator (FNG). 14 MeV FNG neutron source was located 5.3 cm in front of Cu block of the total weight of 2.2 t.

Detectors were placed at **8 locations** up to ~60 cm Cu.

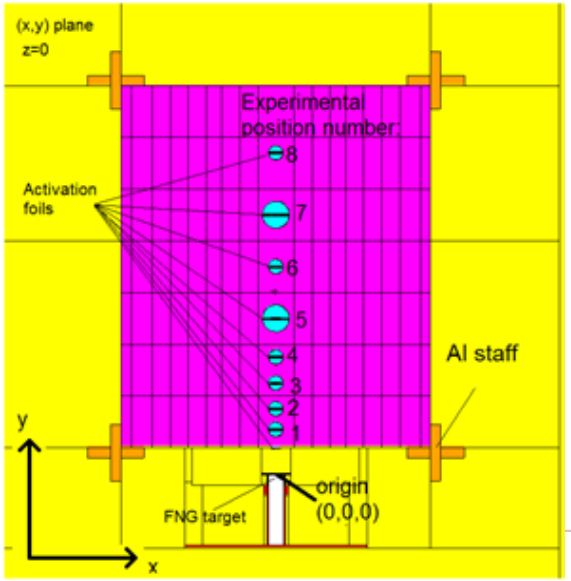
Detailed **MCNP** and simplified **DORT** models prepared

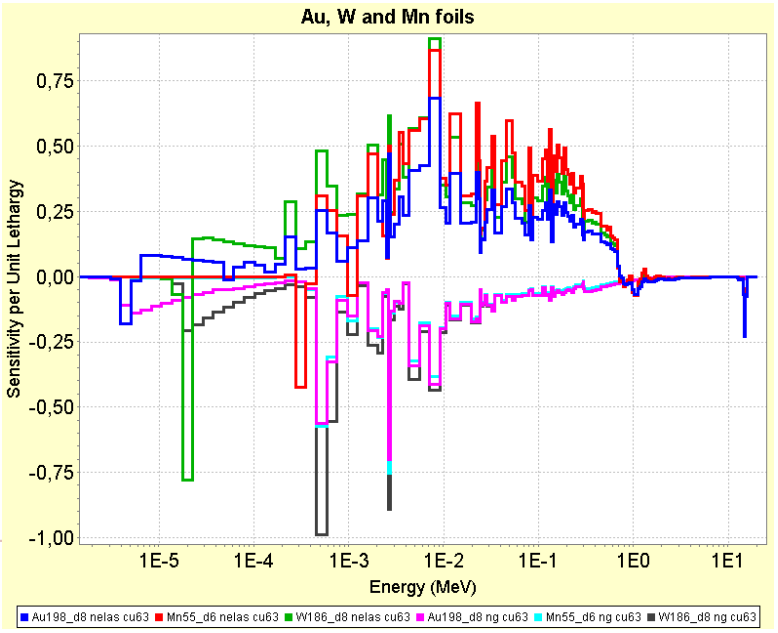
S/U pre-/post-analysis by **SUSD3D** & **MCSEN**

SINBAD evaluation in 2018

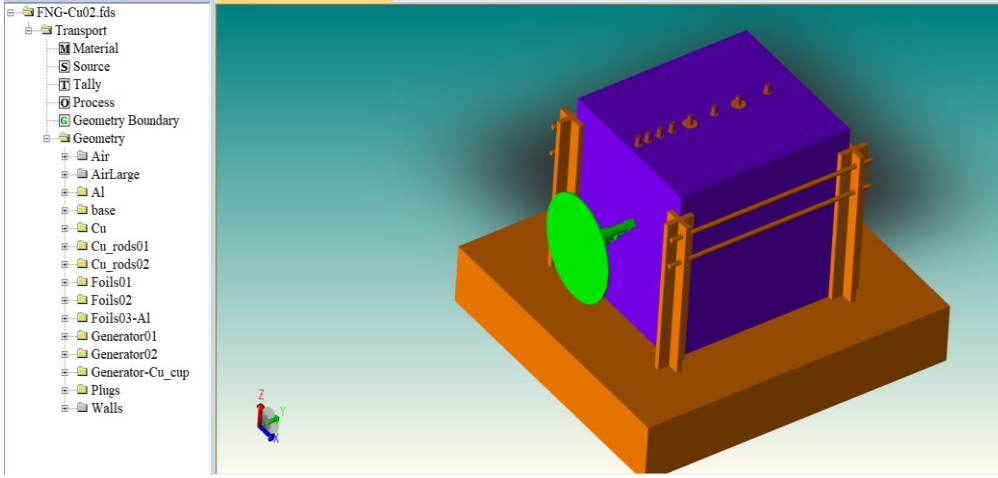


Geometry of the FNG target (and part of the accelerator tube)





FNG Cu Benchmark



SINBAD data include:

- **Abstract file** in **HTML**
- **Main benchmark description** in **PDF** **including uncertainty evaluations**
- **Computer code inputs**
- **CAD geometry**
- **Sensitivity profiles**
- **Reference documents in PDF**

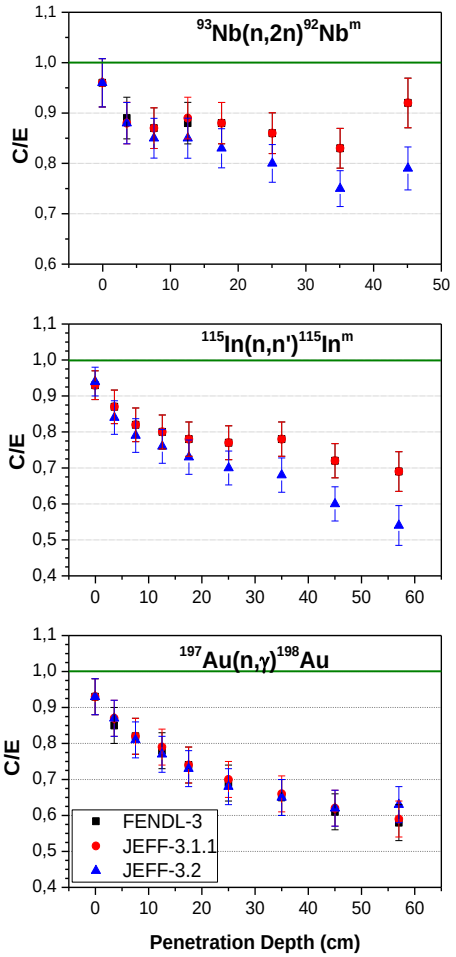
Computational models:

- **MCNP5/6**: reference detailed model; n source description:
  - D-T neutron source subroutine
  - **MCUNED -** MCNPX Extension for Using light Ion Evaluated Nuclear Data library (**NEA-1859)**;
  - **SDEF cards**
- MCNP & DORT simplified models
- Cross-section sensitivity/uncertainty analysis by **SUSD3D** & **MCSEN**

fng_cu\fngcu-a.htm

FNG-Cu: nuclear data uncertainties vs. C/E

Reaction rate / det. position	Uncertainty (%)		
	Transport cross-section		
	JEFF-3.3	ENDF/B-VI.8	TENDL-2013
^{58}Ni(n,p) -35cm	4.8	13.7	22.9
-57cm	9.1	27.2	41.9
^{115}In(n,n')-35cm	8.2	9.4	12.1
-57cm	12.7	18.7	23.5
^{27}Al(n,a) -57cm	12.5	33.2	51.9
^{93}Nb(n,2n)-57cm	13.3	34.7	53.4
^{197}Au(n,γ) -57cm	15.3	19.9	18.6
^{186}W(n,γ) -57cm	23.2	28.6	27.3
^{55}Mn(n,γ) -35cm		24.9	18.8

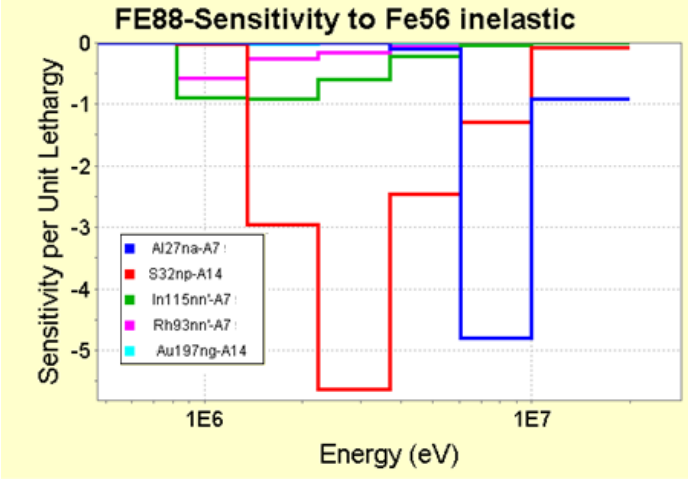


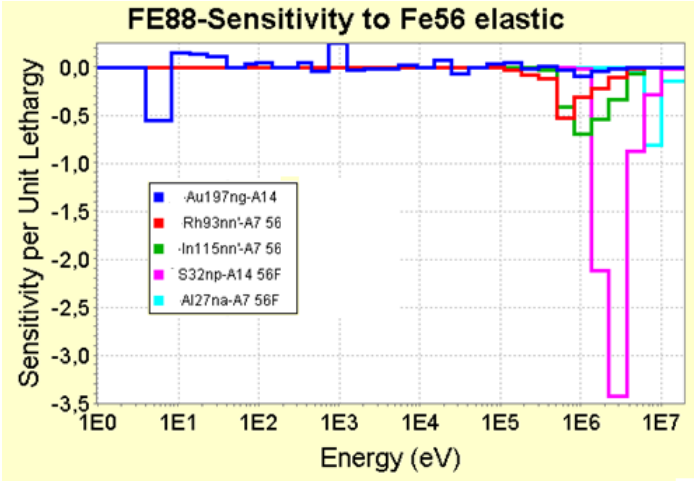
FNG HCLL: sensitivity/uncertainty results

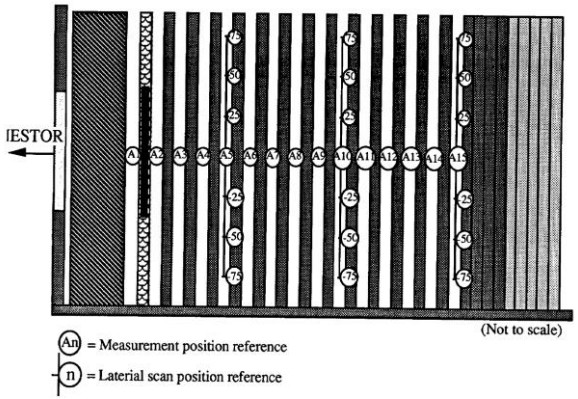
ND UNCERTAINTY	Au(n,γ) D7	Mn(n,γ) D7	Ni(n,2n) D7	In(n,n') D8	Al(n,α) D8	Nb(n,n') D8	Ni(n,p) D8
Δ_{tr}(ENDF/B6.8)	3.3%	3.3%	5.2%	3.0%	4.8%	5.3%	3.1%
Δ_{tr}(JEF3.2)	1.1%	1.0%	4.0%	1.2%	5.1%	5.2%	3.2%

ASPIS FE88

Sensitivity (SUSD3D/DORT)

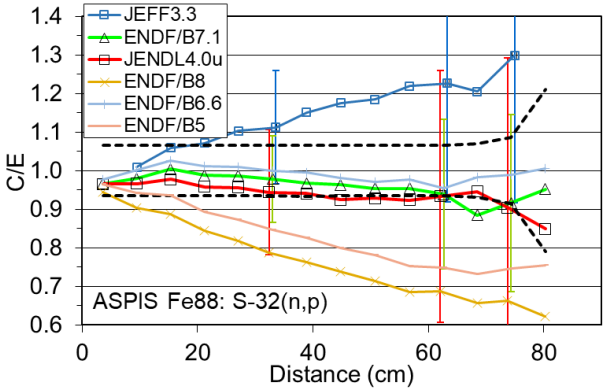


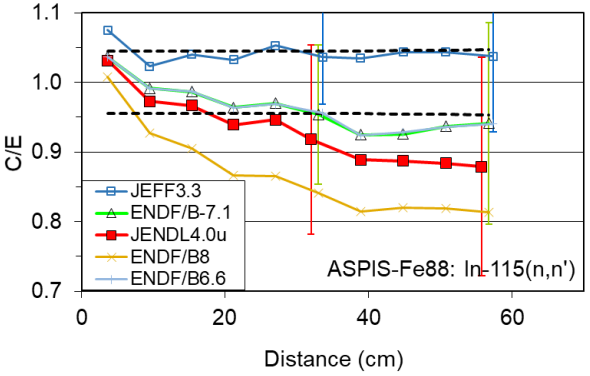




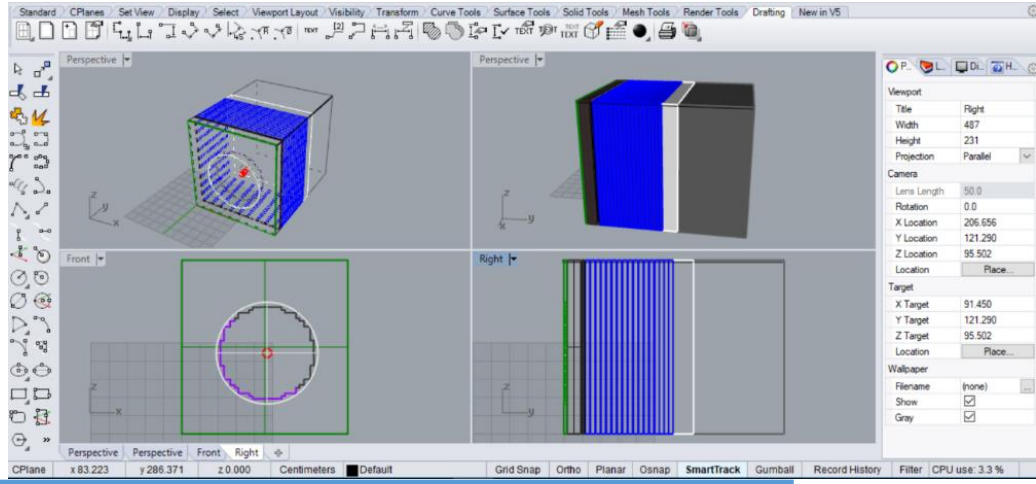
- $^{197}Au(n,\gamma)/Cd$
- $^{32}S(n,p)$
- $^{103}Rh(n,n')$
- $^{115}In(n,n')$
- $^{27}Al(n,\alpha)$

- ~1997: first SINBAD evaluation (Avery, Kodeli)
- 2014/2016 quality reevaluation (Milocco, Kodeli): **MCNP & DORT/SUSD3D** models, TORT (Pescarini)
- Neutron transport up to **67 cm in steel.**
- Fission plate (93% enriched UAl alloy) driven by thermal neutrons from NESTOR reactor.





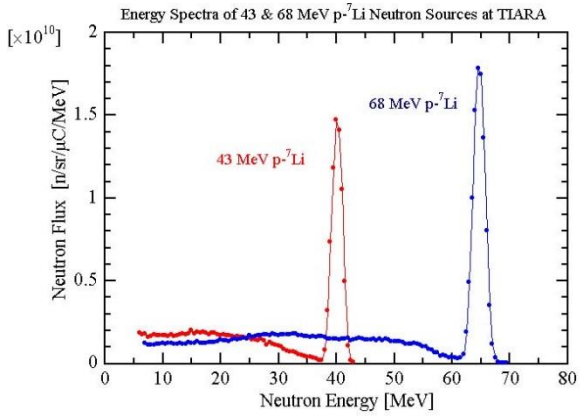
ASPIS – IRON88: Uncertainties in calculated detector reaction rates due to cross-section uncertainties compared to measurement uncertainies

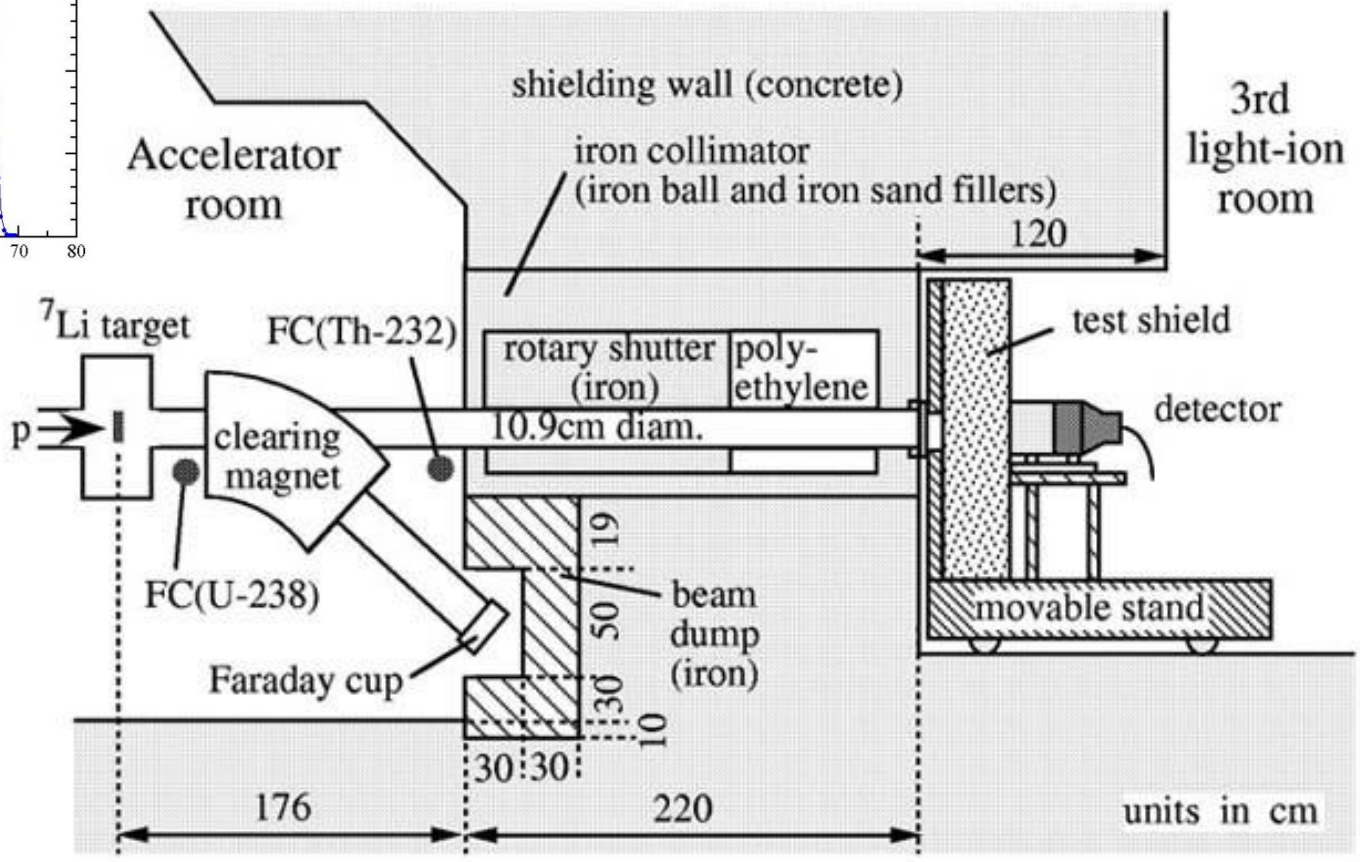


Reaction rate / det. position	Uncertainty (%)			
	ΔE	ΔC (nuclear data)		
		JEFF-3.3	ENDF/B-VII.1	JENDL-4
^{197}Au(n,g): 26cm	4.2	5.1	9.9	9.2
46cm	4.2	4.3	8.8	8.8
62cm	4.2	3.7	8.1	8.5
^{103}Rh(n,n') 26cm	5.1	6.4	7.8	8.6
62cm	5.1	**11.7**	**18.7**	**14.9**
^{115}In(n,n'): 26cm	4.5	6.6	10.5	14.8
62cm	4.7	**10.5**	**15.0**	**17.8**
^{32}S(n,p): 26cm	6.5	13.3	11.5	17.2
52cm	6.5	25.0	20.8	35.0
62cm	8.6	**29.3**	**25.1**	**42.9**
^{27}Al(n,a): 26cm	4.7	**18.8**	**31.5**	**29.5**

Bor Kos (ADVANTG): https://www-nds.iaea.org/publications/indc/indc-nds-0771.pdf

Tiara Facility





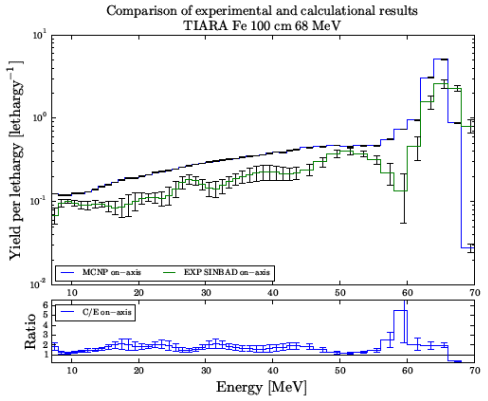
Projectile: 43 & 68 MeV protons on Li-7 target

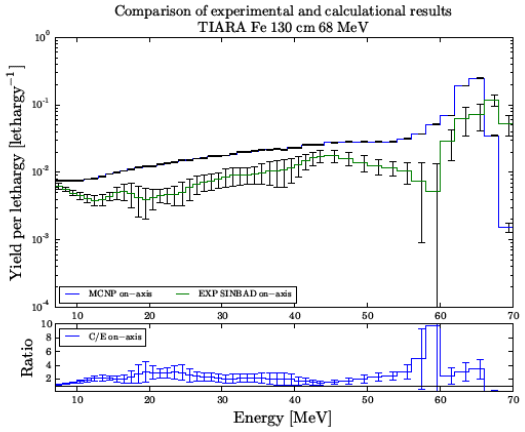
Shield: Fe (130 cm), concrete (< 200 cm), polyethylene (< 180 cm)

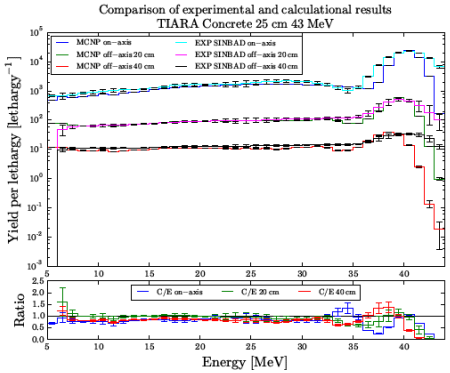
Measurement: neutron spectra and reaction rates by BC501A, Bonner sphere fission counters, TLD and SSNTD

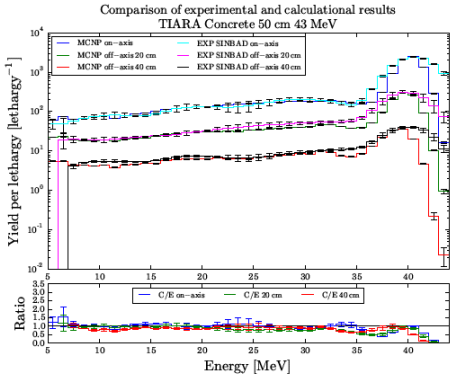
Organisation: TIARA/JAERI

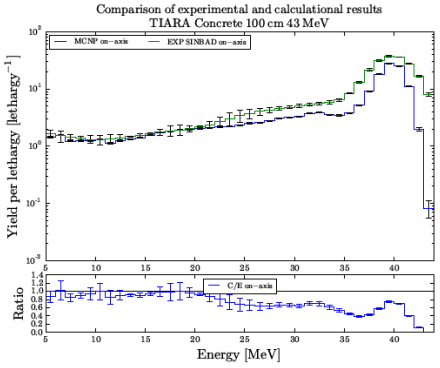
TIARA Fe & concrete/ JEFF3.3

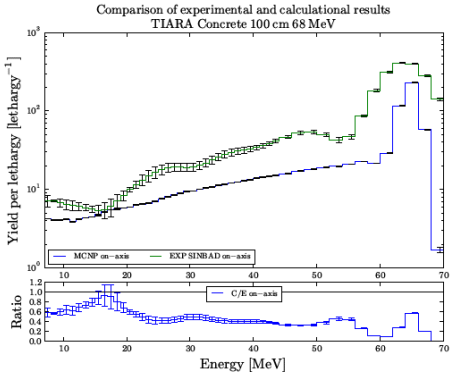


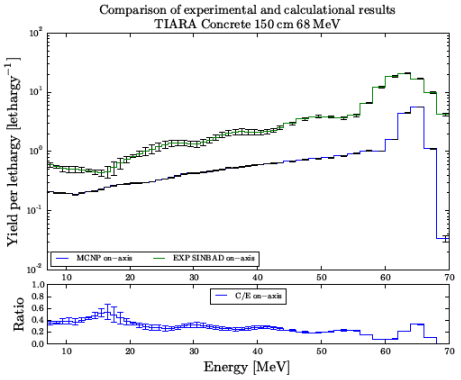


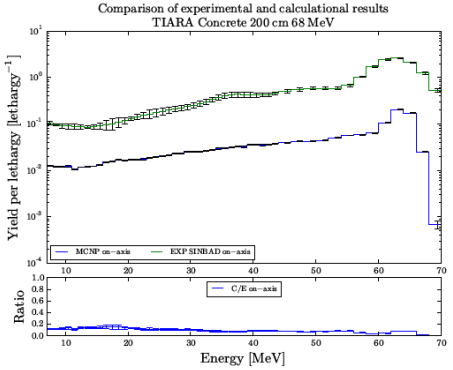






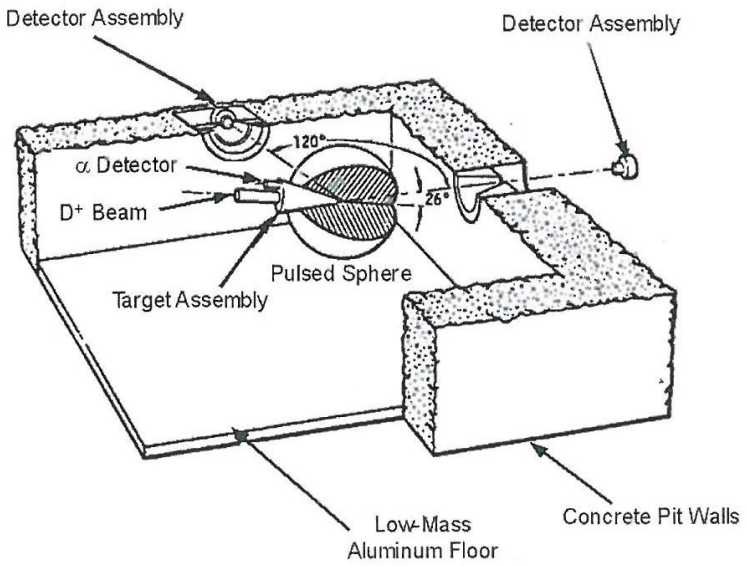


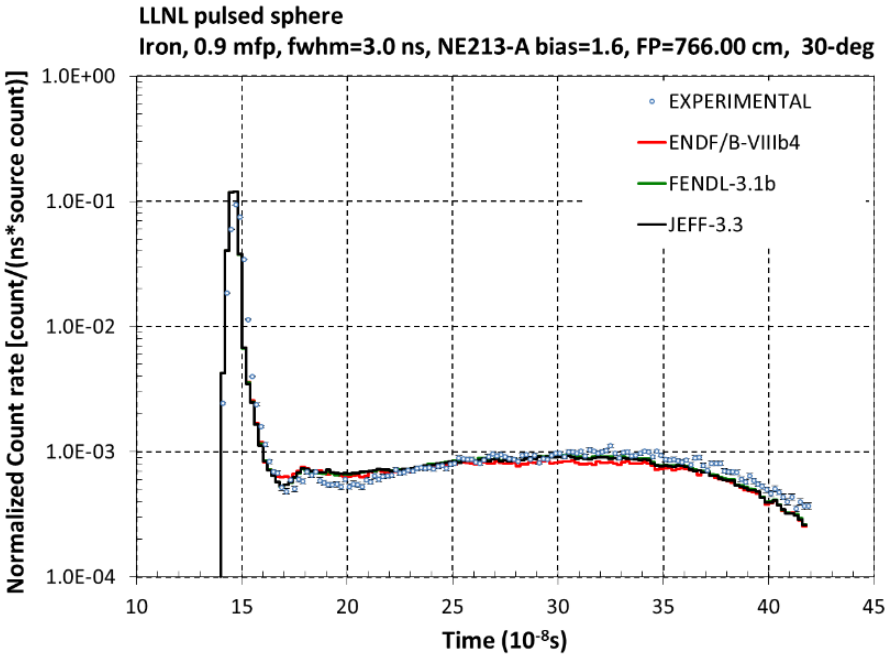




Bor Kos (ADVANTG): https://www-nds.iaea.org/publications/indc/indc-nds-0785/

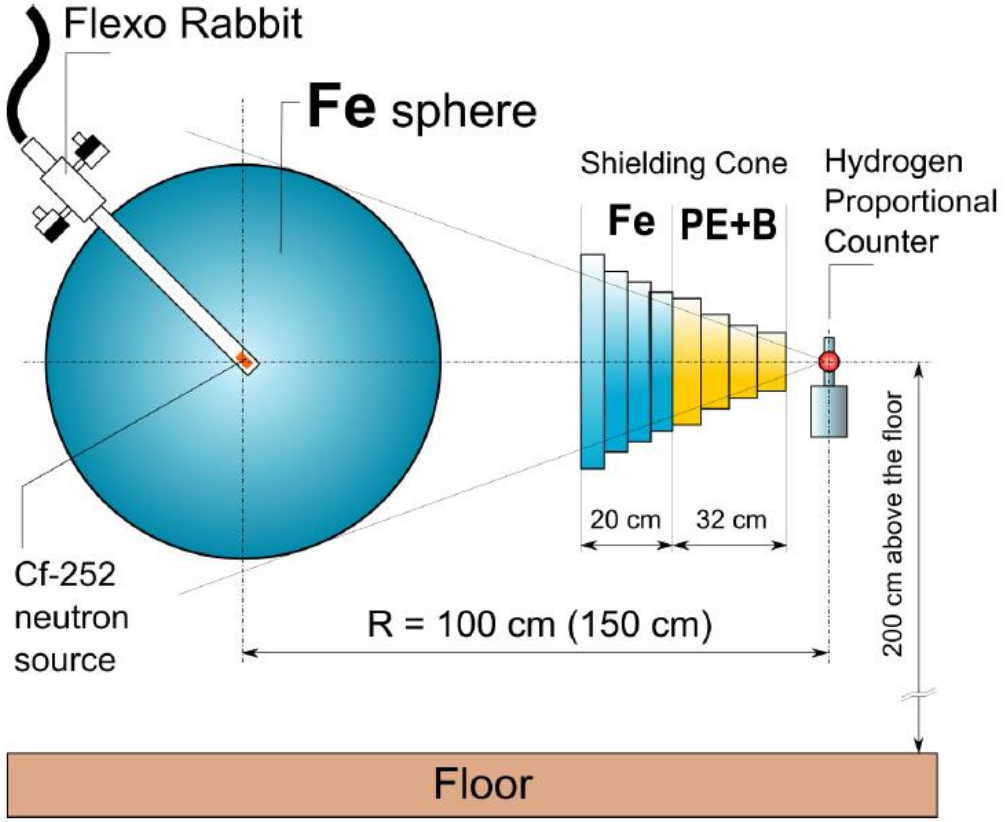
LLNL Pulsed Spheres





Projectile: 400 keV deuteron beam on titanium tritiate target
Shields: spheres of different radius & materials (H_2O, Teflon, C, N_2, Al, Si, Ti, Fe, Cu, Ta, W, Au, Pb, ^{232}Th, ^{235}U, ^{238}U, ^{239}Pu, …)
Measurement: TOF neutron/gamma spectra by NE213 detector
Organisation: LLNL

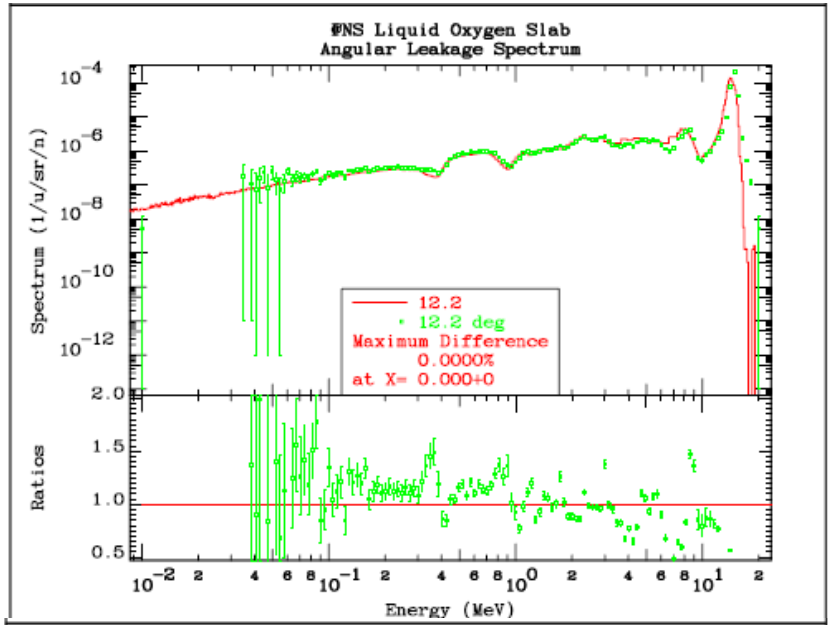
Rez spheres (Fe, H2O)



Projectile: Cf-252 neutron source
Shields: Fe, H2O, D2O spheres of diameter up to 1 m
Measurement: Proportional counter illed by H (HPD), stilbene
Organisation: Research Centre Rez, Czech Republic (B. Jansky)

Institut "Jožef Stefan" Ljubljana, Slovenija

FNS Liquid Oxygen 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 0.05 - 15 MeV energy range.
- Angular fluxes at **0, 12.2, 24.9, 41.8 and 66.8 degrees** were measured.
- **JEFF3.3T4 results**

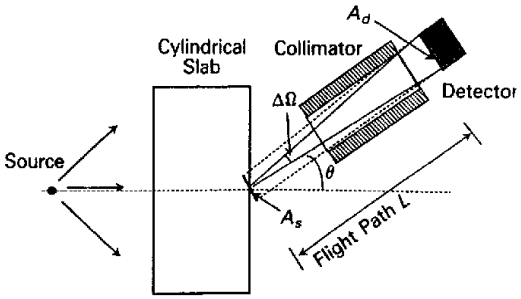
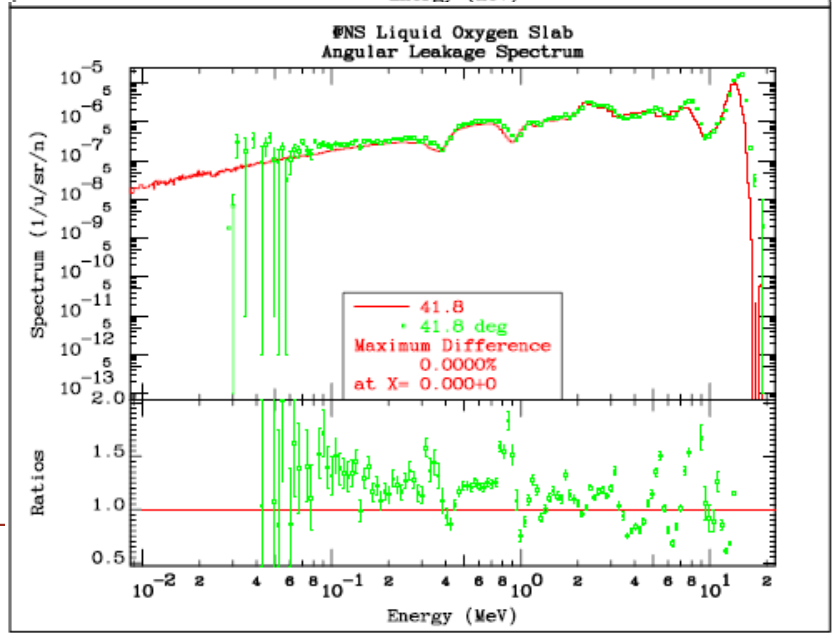
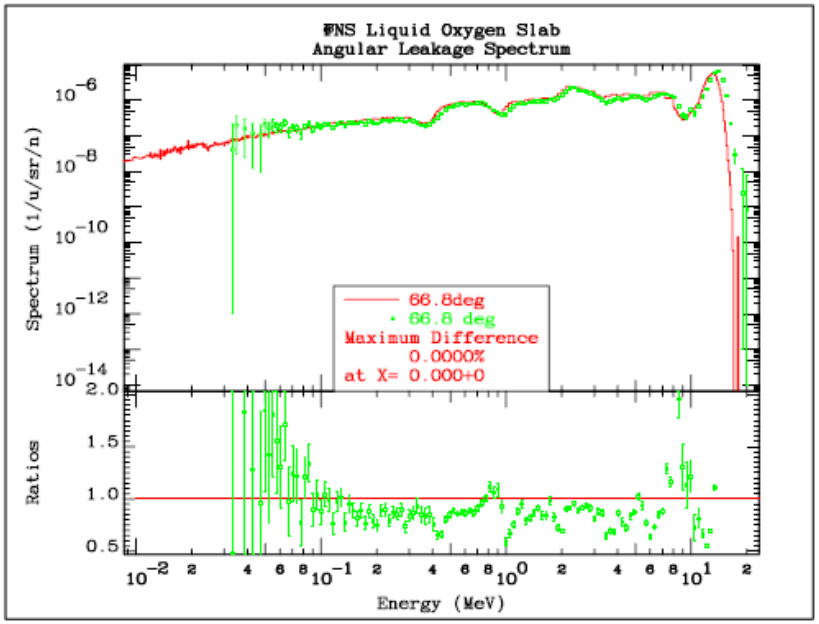


Fig. 3. Definition of the parameters used for data reduction.





Candidates for future SINBAD evaluations

- **FNG-Cu**: F4E compilation finished (2018) MCNP, DORT model, sensitivities
- **FNG-HCLL**: F4E compilation (partly) finished (2018)
- **FNS Cu**, Mo, Ti, Li_2O: copyright issues between QST and JAEA
- **OKTAVIAN**: LiF, CF_2, Ti, Cr, Co, Cu, As, Se, Zr, Nb, Mo;
- **LLNL** spheres
- **IPPE**: BTiH, U, …
- **CIAE** leakage spectra from SiC, Fe, graphite (14 MeV neutrons)
- **HINEG** benchmark experiments
- VENUS-1, VENUS-2 PV dosimetry experiment
- **JET:** SDR experiment (2012-2013), streaming, dose rate
- **KAMINI reactor** neutron attenuation in fast reactor shield materials, Indira Gandhi Centre for Atomic Research, India & Ghana Atomic Energy Commission, *Ann.Nucl.Energy* **53** (2013), Ferro Boron, Ferro-tungsten, mild steel shielding;
- Neutron Penetration through Fe & Concrete for 140-350-MeV Quasi-Monoenergetic Neutrons, RCNP, Osaka University, *Nucl. Tech.* **168** (2009) 298-303 & 304-309 (Prof. Takashi Nakamura)
- **JASMIN**: Japanese-US Study of Muon Interactions&Neutron Detection FERMILAB, Japan Fermilab-Conf-10-330-APC, Aug. 2010 (Prof. Takashi Nakamura)
- Measurements of reaction rates and induced activity in concrete exposed to secondary particles produced by intermediate energy heavy ions on Fe target HIMAC (NIRS).T.Ogawa et al, *NIM-B* **269** (2011), *NIM B* **271** (2012)

Conclusions

- SINBAD database currently contains compilations and evaluations for 102 fission, fusion and accelerator shielding problems. Few new data since 2009. Quality review done for half of the benchmarks and need to be completed.
- Selection of recent and older shielding benchmarks for pilot studies, such as: FNG-Cu, ASPIS Fe88, TIARA, LLNL, Rez spheres, FNS, OKTAVIAN, HINEG.
- **Sensitivity profiles** for new FNG-Cu and ASPIS FE88 benchmark evaluations; **geometry in CAD** format
- **Substantial acceleration of MCNP calculations using ANVANTG code reducing CPU time from weeks to only few minutes;**
- Transport code inputs prepared in the scope of WPEC could be made available through SINBAD
- Revision and classification of existing benchmark and on **new evaluations according to the SINBAD priority list.**

Web pages for SINBAD Database

- **at OECD/NEA**
  https://www.oecd-nea.org/science/wprs/shielding/sinbad/
- **at RSICC:**
  https://rsicc.ornl.gov/Benchmarks.aspx

SINBAD Index – Reactor Shielding (46)

- 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)
- **NESDIP-2 Benchmark (ASPIS)**
- **NESDIP-3 Benchmark (ASPIS)**
- **JANUS Phase I (Neutron Transport Through Mild and Stainless Steel)**
- **JANUS Phase VIII (Neutron Transport Through Sodium Mild Steel)**
- **Ispra Sodium Benchmark (EURACOS)**
- **Ispra Iron Benchmark (EURACOS)**
- **Cadarache Sodium (HARMONIE)**
- Karlsruhe Iron Sphere
- Wuerenlingen Iron Benchmark (PROTEUS)
- Neutron Leakage from Water Spheres (NIST)
- Streaming Through Ducts (IRI-TUB)
- Gamma Production X-Sections from Thermal Neutron Capture in 14 elements & SS
- Averaged Gamma Production X-Sections from Fast Neutron Capture in 14 ele. & SS
- JASPER Advanced Reactor Axial Shield Measurements
- JASPER Advanced Reactor Intermediate Heat Exchanger Measurements
- JASPER Advanced Reactor Radial Shield Measurements

Reactor Shielding (46) (Cont.)

- ORNL TSF Iron Broomstick
- ORNL TSF Oxygen Broomstick
- ORNL TSF Nitrogen Broomstick
- ORNL TSF Sodium Broomstick
- ORNL TSF Stainless Steel Broomstick
- ORNL Neutron Transport Through Iron and SS - Part I
- ORNL Neutron Transport in Thick Sodium
- Pool Critical Assembly-Pressure Vessel Facility Benchmark
- University of Illinois Iron Sphere (CF-252)
- University of Tokyo-YAYOI Iron Slab
- Pressure vessel monitoring in NRI LR-0 VVER-440 reactor
- Pressure vessel monitoring in NRI LR-0 VVER-1000 reactor
- Balakovo-3 VVER-1000 Ex-vessel Neutron Dosimetry Benchmark
- **VENUS-3 LWR-PVS Benchmark**
- H.B. Robinson-2 Pressure Vessel
- Photon Leakage Spectra from Al, Ti, Fe, Cu, Zr, Pb, U238 Spheres
- Photon Spectra from H2O, SiO2 and NaCl
- **Baikal-1 Skyshine Benchmark Experiment**
- NAÏADE 1 Graphite Benchmark (60cm)
- NAÏADE 1 Iron Benchmark (60cm)
- NAÏADE 1 Light Water Benchmark (60cm)
- **IPPE Th shell with 14 MeV and Cf-252 source neutrons**
- **IPPE neutron transmission through bismuth shell**

SINBAD Index – FUSION (31)

- Osaka Nickel Sphere (OKTAVIAN)
- Osaka Iron Sphere (OKTAVIAN)
- Osaka Aluminium Sphere (OKTAVIAN)
- Osaka Silicon Sphere (OKTAVIAN)
- Osaka Tungsten Sphere (OKTAVIAN)
- Osaka Manganese Sphere (OKTAVIAN)
- FNS Experimental data for fusion neutronics benchmark
- FNS Clean Experiment on Graphite Cylindrical Assembly
- FNS Liquid Oxygen
- FNS Vanadium Cube
- FNS Tungsten
- FNS Skyshine
- FNS Dogleg Duct Streaming
- FNG-SS Shield (integral measurements)
- FNG-ITER Blanket Bulk Shield (integral measurements)
- FNG/TUD ITER Blanket Bulk Shield (spectra)
- FNG-ITER Neutron Streaming (integral)
- FNG-ITER Dose Rate Experiment
- FNG Silicon Carbide (integral measurements)
- FNG/TUD Silicon Carbide (spectra)
- FNG Tungsten (integral measurements)
- FNG HCPB Tritium Breeder Module (integral)
- FNG/TUD Tungsten (spectra)
- TUD Iron Slab Experiment

- IPPE Vanadium Shells
- IPPE Iron Shells
- ORNL 14-MeV Neutron SS/B Poly Slab
- University of Illinois Iron Sphere (D-T)
- KANT Spherical Beryllium Shells
- MEPhI empty slits streaming exp.
- Juelich Li Metal Blanket Experiment

SINBAD Index – Accelerator Shielding (23)

- **Transmission Through Shielding Materials of n/γ Generated by 52 MeV Protons**
- Transmission Through Shielding Materials of n/γ Generated by 65 MeV Protons
- **Transmission of Medium Energy Neutrons Through Concrete Shields**
- Neutron Production from Thick Targets of C, Fe, Cu & Pb by 30- and 52-MeV Protons
- **TIARA 40 & 65 MeV Neutron Transmission Through Iron, Concrete & Polyethylene**
- Radioactivity induced by GeV-Protons and Spallation Neutrons using AGS accelerator
- Intermediate and High-Energy Accelerator Shielding Benchmarks
- ROESTI I, II and III (CERN)
- CERF Bonner Sphere Spectrometer Response to Charged Hadrons
- CERF Radionuclide Production
- CERF Residual Dose Rates
- CERF Neutron Energy Spectra behind Shielding of a 120 GeV/c Hadron Beam Facility
- CERN 200 and 400 GeV/c protons activation experiments
- RIKEN Quasi-monoenergetic Neutron Field in 70-210 MeV Energy Range
- KENS p-500 MeV shielding experiment using 4m Concrete at KEK
- **HIMAC experiments with He, C, Ne, Ar, Fe, Xe and Si ions on C, Al, Cu & Pb targets**
- **HIMAC High energy Neutron (<800 MeV) Measurements in Iron**
- **HIMAC High energy Neutron (<800 MeV) Measurements in Concrete**
- **BEVALAC Experiment with Nb Ions on Nb & Al Targets**
- **MSU experiment with He & C ions on Al target**
- **Neutron Spectra Generated by 590-MeV Protons on Thick Pb Target**
- **ISIS Deep-Penetration Neutrons through Concrete & Fe Shields using p-800 MeV**
- TEPC-FLUKA Comparison