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SINBAD Shielding Benchmark Experiments
Status and Planned Activities

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ABSTRACT

SINBAD (Shielding Integral Benchmark Archive Database) started in 1996 as a joint project of the OECD/NEA Data Bank (Organization for Economic Cooperation and Development, Nuclear Energy Agency Data Bank) and ORNL/RSICC (Oak Ridge National Laboratory, Radiation Safety Information Computational Center). The objective was to produce a database containing an internationally established set of radiation shielding and dosimetry data relative to experiments relevant in reactor shielding, fusion blanket neutronics and accelerator shielding, offering to the international community a standardized and user-friendly tool for validation of radiation transport computer codes and nuclear data libraries. In addition to the characterization of the radiation source, the description of the geometry, the shielding materials, the instrumentation, the relevant detectors, and the experimental results, (dose, reaction rates or unfolded spectra) most sets in SINBAD contain also the computer model used for the interpretation of the experiment and, where available, results from uncertainty analysis. The set of primary documents used for the benchmark compilation and evaluation are provided in computer readable form.

BRIEF DESCRIPTION OF SINBAD

SINBAD is jointly developed and maintained by the OECD/NEA Data Bank (Organization for Economic Cooperation and Development, Nuclear Energy Agency Data Bank) and ORNL/RSICC (Oak Ridge National Laboratory, Radiation Safety Information Computational Center). Many organizations, authors, and benchmark analysts (see Table 1) contributed to the database which incorporates now 77 benchmark experiments. The database is divided into three main parts covering both low and intermediate energy particles applications:

- reactor shielding, pressure vessel dosimetry (37 experiments)
- fusion blanket neutronics (27)
- accelerator shielding (13)

SINBAD is available at no charge from RSICC and from the NEA Data Bank. Since its beginnings in 1996 there have been many different users, including US, European, and Japanese establishments, government programs, universities, and private companies. SINBAD was distributed to 67 establishments so far.

TABLE 1. Contributing institutions.

- *AEA Technology (AEAT), United Kingdom*
- *Austrian Research Centre Seibersdorf (ARCS),*
- *CERN SPS (Super Proton Synchrotron), Geneva, EC*
- *Comissariat à l'Energie Atomique (CEA), France*
- *EC Joint Research Centre (ISPRA), EC*
- *ENEA Frascati,Italy*
- *Forschungszentrum Karlsruhe (FZK), Germany*
- *Forschungszentrum Rossendorf e.V. (FZR), Germany*
- *Georgia Institute of Technology (GIT), USA*
- *High Energy Accelerator Research Organization (KEK), Japan*
- *Technical Univ. of Budapest, Hungary*
- *Institute of Physical & Chemical Research (RIKEN), Japan*
- *Institute of Physics & Power Engineering (IPPE), Obninsk, RF*
- *Interfaculty Reactor Intsitute (IRI), Delft, The Netherlands*
- *Japan Atomic Energy Institute (JAERI), Japan*
- *Jozef Stefan Institute (IJS), Slovenia*
- *Lawrence Berkeley National Laboratory (LBNL),USA*
- *Los Alamos National Laboratory (LANL) , USA*
- *Moscow Engineering-Physics Institute (MEPhI),*
- *Michigan State University (MSU), USA*
- *National Institute of Radiological Sciences (NIRS) of Japan*
- *National Institute of Standards and Technology, Gaithersburg (NIST), USA*
- *United States Nuclear Regulatory Commission (NRC),*
- *Oak Ridge National Laboratory (ORNL), USA*
- *Paul Scherrer Institute (PSI), Switzerland*
- *Rutherford Appleton Laboratory (RAL),USA*
- *Russian Federal Nuclear Center-VNIITF (RFNC),*
- *Research Centre Mol (SCK-CEN) , Belgium*
- *Scientific&Engineering Center for Nuclear and Radiation Safety (SEC NRS), RF*
- *Technische Universität Dresden (TUD), Germany*
- *Tohoku University, Japan*
- *University of Illinois, USA*
- *University of Osaka, Japan*
- *University of Pavia, Italy*
- *University of Tokyo, Japan*

and many experts who have contributed to the compilation, validation and review of the data.

Table 2: Reactor Shielding Experiments in SINBAD (in bold are recent compilations)

Title	**Shielding material**	**Measured quantity**	**Computer code input available ***
ASPIS Iron	Fe 1.2m	Au, Rh, In, S foils, NE213 scintillator	Yes
ASPIS Iron 88	steel 67 cm	Au, Rh, In, S, Al foils	Yes
ASPIS Graphite	graphite 0.7 m	Rh, In, S, Al foils	Yes
ASPIS PCA REPLICA	water/iron shield	Mn, Rh, In, S, ^{235}U foils, SP-2, NE213	Yes
ASPIS Water	water 50 cm	S foils, NE213	Yes
ASPIS n-γ Transport	Water/Steel Arrays	Rh, S, Mn foils, TLD, ionisat. chamber	No
NESDIP-2 (ASPIS)	water/stainless steel	S, In, Rh foils	No
NESDIP-3 (ASPIS)	PWR radial shield, cavity	Rh, S foils, H proportional counters, NE213	No
JANUS Phase I	mild & stainless steel	Mn, Au, Rh, S foils, H proportional counters, NE213 scintillator	Yes
JANUS Phase VIII	mild steel and Na	Mn, Au, Rh, S foils	No
Ispra Na (EURACOS)	Na 360 cm	S, Au foils, H proportional counters	Yes
Ispra Fe (EURACOS)	Fe 130 cm	S, In, Rh, Au foils, NE213, gas proportional counters	Yes
Cadarache Sodium (HARMONIE)	Na	Rh, S, Na, Mn, Au foils, SP2 proton recoil spectra (relative measurements)	Yes
Karlsruhe Iron Sphere	Fe 15-40 cm	proton recoil, He-3 spectrometers	No
Wuerenlingen Iron (PROTEUS)	Fe, s. steel 80 cm	Rh, In, S foils, SP2 proton recoil spectr.	No
Neutron Leakage from Water Spheres (NIST)	Water	fission chambers (^{235,238}U, ^{237}NP, ^{239}Pu)	Yes
Streaming Through Ducts (IRI-TUB)	Ducts (air)	Fe, Ni, In, Mn, Au, Sc foils, TLD	Yes

γ Production Cross Sections from Thermal Neutron Capture	Fe, SS, N, Na, Al, Cu, Ti, Ca, K, Cl, Si, Ni, Zn, Ba, S	NaI (Tl) crystal	No
γ Production Cross Sections from Fast Neutron Capture	Fe, O, Al, Cu, Zi, Ti, K, Ca, S, Si, Ni, Ba, S, stainless steel	NaI (Tl) crystal	No
JASPER Advanced Reactor Axial Shield	stainless steel, boron carbide	Bonner balls, NE213, proton-recoil counters, Hornyak button detector	No
JASPER Advanced Reactor Intermediate Heat Exchanger	Na	Bonner balls, NE213, proton-recoil counters	No
JASPER Advanced Reactor Radial Shield	stainless steel, graphite, boron carbide, boral, Na	Bonner balls, NE213, proton-recoil counters	No
ORNL TSF Iron Broomstick	Fe	NE213	No
ORNL TSF Oxygen Broomstick	O	NE213	No
ORNL TSF Nitrogen Broomstick	N	NE213	No
ORNL TSF Sodium Broomstick	Na	NE213	No
ORNL TSF Stainless Steel Broomstick	4-inch-diameter oxygen	NE213	No
ORNL Neutron Transport Through Fe & SS - Part I	iron and stainless steel	NE213	No
ORNL Neutron Transport in Thick Na	Na	NE213	No
Pool Critical Assembly-Pressure Vessel Facility	core-to-cavity region in an LWR	Np, U, Rh, In, Ni, Al foils	No
University of Illinois Iron Sphere (CF-252)	shell of iron	NE213	No
University of Tokyo-YAYOI Iron Slab	iron slabs, up to 20-cm-thick	NE213, spherical proportional detectors of H_2 and CH_4 gas	No
Balakovo-3 VVER-1000	VVER-1000 Ex-vessel Neutron Dosimetry	Np, U, Nb, Ni, Fe, Ti, Cu, Nb foils	Yes
VENUS-3 LWR-PVS	3 Loop Westinghouse LWR pressure vessel	Ni, In, Al foils	Yes
H.B. Robinson-2 Pressure Vessel	**3 Loop LWR in-/ex-vessel n dosimetry**	**Cu, Ti, Fe, Ni, U, Np foils**	**Yes**
RFNC Photon Leakage Spectra	**Al, Ti, Fe, Cu, Zr, Pb, ^{238}U Spheres**	**stilbene scintillation detector**	**Yes**
IPPE Th shell	**Th sphere 10 cm**	**fast ionization chamber (TOF)**	**Yes**

* users' contributions to fill in missing computer code inputs available or providing computer code models for alternative codes are welcome.

Table 3: Fusion Neutronics Shielding Experiments in SINBAD (in bold are recent compilations)

Title	Shielding material	Measured quantity	Computer code input
OKTAVIAN Ni Sphere	Ni sphere r=16 cm	NE213 scintillator (TOF)	Yes
OKTAVIAN Fe Sphere	Fe sphere r=50.32 cm	TOF: NE213, Li-6 glass scint.	Yes
OKTAVIAN Al Sphere	Al - 10 cm	NE218 scintillator (TOF), NaI crystal	Yes
OKTAVIAN Si Sphers	Si – 20 cm	NE218 scintillator (TOF), NaI crystal	Yes
OKTAVIAN W Sphere	W – 10 cm	NE218 scintillator (TOF), NaI crystal	Yes
FNS Graphite Cylindrical Assembly	graphite 31.4 cm x 61.0 cm	fission chambers (^{235}U,^{238}U,^{232}Th, ^{237}Np), fission track detectors, Al, Ni, Zr, Nb, In, Au foils, NE213, TLD	Yes
FNS Liquid Oxygen	liquid O 20 cm	NE213 scintillator (TOF)	Yes
FNS Vanadium Cube	V cube 25.4 cm x 25.4 cm x 25.4 cm	NE213, proton recoil counters (PRC), BF3 counter, Al, Nb, In, Au foils, BC537 scintillation, TLD	Yes
FNS Tungsten	W (2r=62.9 cm, h= 50.7 cm)	NE213, PRC, BF3 counter, Al, Nb, In, W, Au foils, BC537, TLD	Yes
FNS Skyshine		**rem-counters, He3, BF3, Ge det., NaI**	**Yes**
FNS Dogleg Duct Streaming	**iron slab 170 cm x 140 cm x 180 cm**	**NE213; Nb, In, Au foils,**	**Yes**
FNG-SS Shield (integral)	stainless steel 60 cm	HPGe detectors, Al, Fe, Ni, In, Mn, Au foils	Yes
FNG-ITER Blanket Bulk Shield (integral)	ITER inboard shield	Al, Fe. Ni, Nb, In, Mn, Au foils, TLD-300, SSD	Yes
FNG/TUD ITER Blanket Bulk Shield (spectra measurem.)	ITER inboard shield	NE213	Yes
FNG-ITER Neutron Streaming (integral)	ITER shielding system	Nb, Al, Ni, Au foils, TLD-300	Yes
FNG-ITER Dose Rate Experiment	stainless steel/water assembly	Ni foils, TLD-300	Yes
FNG Silicon Carbide (integral)	SiC (45.72 cm x 45.72 cm, 71.12 cm)	Au, Al, Nb foils, TLD	Yes
FNG/TUD Silicon Carbide (spectra)	SiC (45.72 cm x 45.72 cm, 71.12 cm)	NE213 scintillator	Yes
FNG Tungsten (integral)	W block 42-47 cm x 46.85 cm x 49 cm	Au, Mn, In, Ni, Fe, Al, Ni, Zr, Nb foils TLD	Yes
FNG/TUD Tungsten (spectra)	W block 42-47 cm x 46.85 cm x 49 cm	NE213 scintillator	Yes
TUD Iron Slab Experiment	iron slab 30 cm	NE213 scintillator	Yes
IPPE Vanadium Shells	V spheres r=5 & 12 cm	fast scintillator detector	Yes
IPPE Iron Shells	**Fe spheres r=4.5-30cm**	**fast scintillator detector**	**Yes**
ORNL 14-MeV Neutron SS/Borated Poly Slab	stainless steel	NE213	No
University of Illinois Iron Sphere (D-T)	Fe sphere r=38.1cm	NE213	No
KANT Spherical Beryllium Shells	Be shells 5, 10, 17 cm thick	NE213, Bonner sphere	Yes
MEPhI empty slits streaming experiment	**iron shielding models with empty slits**	**In, Zn, Al, Fe, F, ^{233}U foils, TLD, stilbene crystals**	**Yes**

Table 4: Accelerator Shielding Experiments in SINBAD (in bold are recent compilations)

Title	**Shielding material**	**Projectile**	**Measured quantity**	**Computer code input**
Transmission Through Shielding Materials of n & γ Generated by 52 MeV p	C (< 64.5 cm thick), Fe (< 57.9 cm), H_2O (< 101 cm), concrete (< 115 cm)	52 MeV protons on C target	NE213 scintillation	No
Transmission Through Shielding Materials of n & γ Generated by 65 MeV p	concrete, iron, lead and graphite (10 to 100 cm thick)	65 MeV protons on Cu target	NE213 scintillation	No
TIARA 40 and 65 MeV Neutron Transmission Through Iron, Concrete and Polyethylene	Fe (130 cm), concrete (< 200 cm), polyethylene (up to 180 cm)	43 and 68 MeV protons on Li7 target	BC501A, Bonner ball, fission counters, TLD, SSNTD	No
ROESTI I and III	Fe and Pb (100 cm thick)	200 GeV/c positive hadrons (2/3 p,1/3 π^+)	In, S, Al, C foils, RPL	Yes
ROESTI II	Fe (100 cm thick)	24 GeV/c protons	In, S, Al, C foils, RPL	Yes
RIKEN Quasi-monoenergetic Neutron Field (70-210 MeV)	air	70 – 210 MeV protons on ^{7}Li	NE213 (TOF)	No
HIMAC He, C, Ne, Ar, Fe, Xe and Si ions on C, Al, Cu and Pb targets	C, Al, Cu and Pb targets	100-800 MeV/ nuc. He, C, Ne, Ar, Fe, Xe & Si ions	NE213 & NE102A scintillators	Yes
HIMAC/NIRS High Energy Neutron (up to 800 MeV) Measurements in Iron	**Fe (up to 100 cm)**	**400 MeV/nucleon C ions on Cu target**	**Neutron spectra by Self-TOF, NE213**	**Yes**
HIMAC/NIRS High Energy Neutron (up to 800 MeV) Measurements in Concrete	**Concrete (up to 250 cm)**	**400 MeV/nucleon C ions on Cu target**	**Self-TOF, NE213, Bi and C foils**	**Yes**
BEVALAC Experiment with Nb Ions on Nb & Al Targets	Nb (0.51 and 1 cm thick) and Al (1.27 cm thick)	272 & 435 MeV/nucl. Nb ions	NE-102 scintillator	No
MSU experiment with He and C ions on Al target	Al (13.34 cm)	155 MeV/nucleon He and C ions	BC-501, NE213 (TOF)	Yes
PSI - High Energy Neutron Spectra Generated by 590-MeV Protons on Pb Target	**Pb target (60 cm)**	**590 MeV protons**	**NE213 (TOF)**	**Yes**
ISIS Deep Penetration of Neutrons through Concrete & Fe	**Concrete (120 cm) and Fe (60 cm)**	**800 MeV protons on Ta target**	**C, Bi, Al, In_2O_3 foils, n & γ dosemeters**	**No**
TEPC-FLUKA Comparison for Aircraft Dose	**Air**	**Co60 (γ), 0.5 MeV n source, AmBe mixed source, CERN/CERF (120 GeV p & π on Cu)**	**TEPC**	**No**

CONCLUSIONS

SINBAD with its 77 benchmark experiments already offers a large number of benchmark experiments which can be used for nuclear data and computer code validations. Further extensions are planned for the near future. Further contributions from users are encouraged, in particular in the form of the feedback on the use of the data, contribution of the calculational models etc. Submission of additional experimental data to increase comprehensiveness of the database is encouraged.

REFERENCES

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