Current status of accelerator benchmarks in OECD/NEA radiation shielding experiments database SINBAD

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Abstract

In order to preserve and make available the information on the performed radiation shielding benchmarks the Data Bank of the OECD Nuclear Energy Agency (OECD/NEADB) and the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (ORNL) started the Shielding Integral Benchmark Archive and Database (SINBAD) Project in the early 1990s. The SINBAD database now comprises 100 shielding benchmarks, also covering accelerator shielding benchmarks in addition to fission reactor shielding and fusion blanket neutronics. Recently, a thorough revision of six of the 23 accelerator benchmark experiments was completed in order to provide detailed verification of the completeness and consistency of the benchmark information, in particular concerning the evaluation of the experimental sources of uncertainty. This review process is expected to provide users with an easier choice and help them make better use of the experimental information and is planned to be extended to other available benchmarks.

The OECD NEA Working Party on Scientific Issues of Reactor Systems (WPRS) Expert Group on Radiation Transport and Shielding (EGRTS) was created in 2011 and its mandate is to monitor, steer and support the continued development of the SINBAD database. Co-ordination of the SATIF-11 Workshop is part of the mandate of EGRTS and the development of the accelerator benchmark database is done in a close co-operation with the SATIF expert group. Proposals and assistance in new benchmark compilations are welcome.

SINBAD is available at no charge from RSICC and from the NEA Data Bank. Since its beginnings SINBAD has been used by nuclear data evaluators, computer code developers, experiment designers and university students.

Introduction

The SINBAD project started in the early 1990s as a collaboration between the OECD NEA Data Bank (OECD/NEADB) and the Radiation Safety Information Computational Center (RSICC) at the Oak Ridge National Laboratory (ORNL) with the goal of preserving the information on the performed radiation shielding benchmarks and making them available in a standardised form to the international community. The SINBAD database now comprises 100 shielding benchmarks, divided into three categories, covering both low-and intermediate-energy particles applications: fission reactor shielding (46 benchmarks), fusion blanket neutronics (31), and accelerator shielding (23) benchmarks. In addition to the characterisation of the radiation source, description of shielding set-up, instrumentation and the relevant detectors, most sets in SINBAD contain also the deterministic or probabilistic (Monte Carlo) radiation transport 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. Table 1 lists the accelerator shielding experiments presently included in SINBAD.

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The database is intended for different users, including nuclear data evaluators, computer code developers, experiment designers and university students. SINBAD is available at no charge from RSICC and from the NEA Data Bank.

Present status of the accelerator benchmarks, quality review and future plans

Since the experimental data currently available in SINBAD are of varying quality, a thorough revision and classification of the benchmark experiments according to the completeness, reliability and consistency of information was undertaken recently. A series of 34 experiments, among them 6 accelerator experiments, mostly of relevance for fusion neutronics and for accelerator shields were already, or are currently being revised and reclassified. The six of the 23 accelerator benchmark experiments which have already gone through the revision process are listed in Table 2. The review concentrated on the verification of the description of the experimental set-up, the neutron source specifications, the detector characteristics, the geometry and precise material composition of the components. The main criteria for the judgment of the quality of the experiment were the completeness and the consistency of the experimental information (on the geometry, materials, the procedure to derive data-unfolding, etc.), in particular concerning the evaluation of the experimental sources of uncertainty. New or improved inputs for computer codes such as MCNPX and PHITS were prepared and the sensitivity analyses were performed to estimate the impact of the approximations used in the computational model. The following two guidelines were pursued when preparing the computational models:

Table 1: Accelerator shielding experiments in SINBAD

Benchmark	Shielding material	Projectile	Measured quantity	Computer code input
Transmission 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 scintillator	MCNPX
Transmission of n & γ generated by 65 MeV p	Concrete, Fe, Pb,graphite (10 to 100 cm thick)	65 MeV protons on Cu target	NE213 scintillator	No
Transmission of medium energy neutrons through concrete shields (1991)	Concrete	a 75-MeV proton beam incident on a stopping-range Cu assembly	7.6-cm-diameter x 7.6-cm-long NE-213 scintillator	Yes, MCNPX
Neutron production from thick targets of C, Fe, Cu and Pb by 30- and 52-MeV protons(1982)	Stainless steel 316	30- and 52-MeV protons incident on C, Fe, Cu, and Pb targets	NE 213 scintillator	Yes, MCNPX
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 Li-7 target	BC501A, Bonner ball, fission counters, TLD, SSNTD	MORSE-CG, HETC-KFA2, DORT,MCNP4B, LAHET HMCNP
Radioactivity induced by GeV-protons & spallation neutrons (2001)	B, C, Al, Fe, Cu, Nb, HgO, Pb, Pb, acrylic resin, SS-316, Inconel	2.83 and 24 GeV protons on mercury target	HPGe	No
Intermediate-and high-energy accelerator shielding benchmarks	C, Al, and Fe	113 and 800 MeV protons	BC-418 plastic scintillators	No
ROESTI I, II and III	Fe and Pb (100 cm thick)	200 GeV/c hadrons (2/3 p^+,1/3 π^+) (Roesti I&III), 24 GeV/c p^+ (Roesti II)	In, S, Al, C foils, RPL	Yes, FLUKA92
CERF bonner sphere response to charged hadrons	Polyethylene/Cd/Pb	120 GeV/c positive hadrons(1/3 p and 2/3 π)	Bonner sphere - a spherical centronics SP9 3He counter	Yes, FLUKA
CERF Radionuclide production (~2003)	steel, Cu, Ti, concrete, light materials such as C composites and B- nitride	120 GeV/c mixed hadrons (1/3 p, 2/3 π^+)	High-purity germanium (HPGe) for gammas	Yes, FLUKA
CERF residual dose rates (2003)	Al, Cu, Fe, Ti, concrete	120 GeV/c mixed hadrons (1/3 p , 2/3 π^+)	NaI crystal	Yes, FLUKA
CERF shielding experiment at CERN (2004)	cylindrical Cu target	120 GeV/c mixed hadron (1/3 p, 2/3 π^+)	NE213 organic liquid scintillator	Yes, MARS15
CERN 200 and 400 GeV/c protons activation experiments (1983)	Cu targets	200 GeV/c and 400 GeV/c extracted protons	Thermo-, photo-luminescent and optical absorption glass dosimeters, Al, Au, S, Cu foils & plastic scintill.	No
RIKEN quasi-monoenergetic neutron field (70-210 MeV)	Air	70 – 210 MeV protons on ^{7}Li	NE213 scintillator (TOF)	No
KENS p-500 MeV shielding experiment at KEK	Concrete	500MeV protons on thick W target	Activation of Bi, Al, In and Au foils	Yes, MARS14
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, MCNPX
HIMAC/NIRS high-energy neutron (up to 800 MeV)	Fe (up to 100 cm)	400 MeV/nucleon C ions on Cu target	Neutron spectra by self-TOF, NE213	Yes, PHITS
HIMAC/NIRS high-energy neutrons (< 800 MeV)	Concrete (up to 250 cm)	400 MeV/nucleon C ions on Cu target	Self-TOF, NE213, Bi and C foils	Yes, PHITS
BEVALAC experiment - 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 155 MeV/nucleon He & C ions on Al target	Al (13.34 cm)	155 MeV/nucleon He and C ions	BC-501, NE213 (TOF)	Yes, MCNPX
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 dosimeters	MCNPXe
TEPC-FLUKA comparison for aircraft dose	Air	Co60 (γ), 0.5 MeV n source, AmBe source, CERN/CERF (120 GeV p & π on Cu)	TEPC	No

Table 2: SINBAD accelerator benchmarks with quality review completed

Benchmark	Summary of quality assessment
MSU 155 MeV/nucleon He & C ions on Al targets	MCNPX model prepared, experiments are adequate for benchmarking of calculation models and codes
Transmission of n & γ generated by 52 MeV p	MCNPX model prepared, experimental information should be recovered; experimental uncertainty needed on: proton energy, density, H content in concrete, unfolding process
ISIS deep penetration of neutrons through concrete & Fe	MCNPX model prepared, experiment is adequate for benchmarking purposes
HIMAC/NIRS high-energy neutrons (< 800 MeV)	PHITS model prepared, experimental information needed, reduction in unfolding uncertainty, estimation of experimental uncertainty should be obtained before these experiments could be used for benchmarking processes
HIMAC/NIRS high-energy neutron (up to 800 MeV)	PHITS model prepared, large measurement uncertainties, unfolding uncertainty and parameter uncertainties needed, experiment is not adequate for benchmarking purposes
HIMAC He, C, Ne, Ar, Fe, Xe and Si ions on C, Al, Cu and Pb targets	MCNPX model prepared, experiments are adequate for benchmarking purposes

- Calculation should be able to reproduce the experiment as exactly as reasonably possible, avoiding unnecessary approximations.
- As much as possible the calculations should be compared to pure measured data. Often "processed" measured data are referred to as "measured" (e.g. time-of-flight experiments). In this case the involved computational approximations and uncertainties should be carefully evaluated.

This review process is expected to provide the users with an easier choice and help them make better use of the experimental information.

Conclusions

The SINBAD database currently contains compilations and evaluations of 100 benchmark experiments, among them 23 cover accelerator shielding cases. Several new experiments have been compiled and need final review.

Since the experimental data currently available in SINBAD are of varying quality, a revision and classification of the benchmark experiments according to the completeness and reliability of information is being undertaken in order to provide users with easier choices and help them make better use of the experimental information. A series of 34 experiments, among them 6 accelerator experiments, mostly of relevance for fusion neutronics and for accelerator shields were already, or are currently being revised and reclassified.

The SINBAD database is now widely used for code and data validation. Materials covered include: Air, N. O, H_2O, Al, Be, Cu, graphite, concrete, Fe, Pb, Li, Ni, Nb, SiC, Na, SS, W, V and mixtures thereof. Over 40 organisations from 14 countries and 2 international organisations have contributed data and work in support of SINBAD.

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