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SHIELDING EXPERIMENTAL BENCHMARK STORAGE, RETRIEVAL, AND DISPLAY SYSTEM

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ICRS-9, Tsukuba, Ibaraki, Japan, Oct. 17-22, 1999

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The complete description of an integral shielding benchmark experiment includes the radiation source, materials, physical geometry, and measurement data. This information is not usually contained in a single document, but must be gathered from several sources, including personal contact with the experimentalists. A comprehensive database of the experimental details is extremely useful and cost-effective in present day computations. Further, experimental data are vulnerable to being lost or destroyed as a result of facility closures, retirement of experimental personnel, and ignorance. A standard set of experiments, used globally, establishes a framework to validate and verify models in computer codes and guarantee comparative analyses between different computational systems.

SINBAD is a database that was conceived in 1992 to store, retrieve, and display the measurements from international experiments for the past 50 years in nuclear shielding. Based at Oak Ridge National Laboratory's Radiation Safety Information and Computational Center (RSICC) SINBAD has a collection of integral benchmark experiments from around the world. SINBAD is shared with the Office of Economic and Cooperative Development/Nuclear Energy Agency Data Bank, which provides contributions from Europe, Russia, and Japan.

KEYWORDS: Benchmark, Database, Archive, Shielding, Neutron Transmission, Gamma Ray Transmission, Fission, Fusion, Accelerator

I. Introduction

Accurately predicting experimental results using computational analysis involves a successful combination of several different data sets. First, the experimental data with results, including the geometric and material (chemical) compositions, and the source are assumed to be measured correctly within the reported errors. Second, the computational program used is verified and validated for use in such experimental analysis. Third, it is determined that the cross-section data libraries are accurate for the materials used; fourth, that the computational model accurately describes the experimental arrangement; and fifth, that the information for the benchmark experiment was fully and accurately reported and recorded for use in the computation. If any of these conditions are not satisfied, then the experimental results may not be predicted within the acceptable error limits. Countless hours might be spent to try to discover the missing or misrepresented data.

Shielding materials in benchmark experiments are used to validate and verify new cross-section libraries. These libraries in turn improve the performance of shielding and/or criticality predictability code systems such as SCALE (1), MCNP (2), or DOORS (3). Standards for developing recommended cross-section libraries have been created through the American National Standards Institute in conjunction with the American Nuclear Society as ANSI/ANS standard 6.1.2 (4) which requires the use of selected integral benchmarks.

In the development of a new or updated radiation transport software code, a quality assurance (QA) test of the code is needed to validate its ability to adequately compute results using models from a standard set of benchmark experiments (5).

Since computer processor speeds no longer limit the computational models to one dimension, more complex three-dimensional models have become common. The accuracies of the new computations are approaching the experimental benchmark error limits.

Published literature has been relied upon almost exclusively to house the specifics of benchmark experiments. But often error estimations, materials, source information, and data results have not been fully reported in the published document and must be discovered through experimental logbooks or other published or non-published literature and/or verbal contact with the key experimental personnel.

A thoroughly reviewed set of benchmark compilations that includes all experimental data needed for performing high-accuracy computational work is highly in demand (6).

II. Integral Benchmarks

Varied definitions exist for the term "benchmark experiments," but generally they are experiments that have been used as "stepping stones" to more complex experimental measurements. One or more "thick" materials (several radiation mean free paths) are involved in an integral benchmark experiment. Organizations that have historically developed recommended cross-sections use these benchmark experimental data repetitively, and a sense of confidence builds with time. The definition used in (4) states that an Experimental Benchmark is an "*Integral experiment for which measurements are of sufficient accuracy and for which experimental conditions are specified in sufficient detail so that conclusions may be drawn as to the accuracies of calculational models and cross section data.*" The Cross Section Evaluation Working Group (CSEWG) leads the United States in selections of appropriate benchmarks for testing of new cross-section sets (7). The Office of Economic and Cooperative Development (OECD), Nuclear Energy Agency (NEA) Nuclear Science Committee, makes similar European benchmark recommendations. All new experimental information has the potential to become a benchmark, and computational analysis often is used for its validation. The question becomes "what is good enough" when describing the differences between computation and experimental results.

Over the years, the computational predictability of these recommended benchmarks has improved significantly through the use of new transport codes, faster computers, and more accurate cross-sections. A natural trend has been to use those materials within more complex geometric and material arrangements or "mockups" of real nuclear facilities (8). This cycle increases the choices for integral benchmarks in future computations. The life cycle of the computational and experimental storage and use within the SINBAD system is shown in Figure 1.

III. Benchmark Data

What is considered benchmark information? How much information does the computational expert need? Data are anything from the experiment that could be used to improve the computational model predictions of the experimental results. The nuclear radiation source, experimental arrangement of materials, the chemical compositions of the materials, detector measurements, and the experimental error

Figure 1 SINBAD System for Benchmarks

analysis are necessary for comparison between computation and experiment. For more in-depth comparison, additional data such as background shielding, data unfolding techniques, detector resolutions, response functions, and other auxiliary functions used to generate the measured data are extremely useful.

How the computational expert uses the data must be taken into consideration when choosing what data formats are important. The computational input must be streamlined to remove external transfer or transformation errors and minimize the time to move data from the benchmark document to computational input files. Tabular data for source information and detector results are preferable. Graphically displayed data are excellent for visual comparisons with input data or computational results, but the tabular data must be available from the document to be valuable to the computation.

Graphical data showing the experimental geometry can provide extremely useful perspectives of the experimental arrangement, particularly the more complex ones. As mentioned earlier, the graphical representation of data may provide a quick analysis of source data comparisons, in which errors become obvious. The plots of data results taken from computational output can provide a quick means to compare spectral data between calculations and measurements.

IV. Benchmark Storage and Retrieval

The electronic format for storage of all forms of physical data has been proved to be useful and flexible (9). Most new benchmark publications have much of their information previously stored in word processor formats that may be easily converted to other formats. Others, especially older benchmarks

(prior to the 1980s) have to be electronically scanned and/or manually entered into the computer.

The choice for a "storage format" would be one that had the following characteristics:

1) Universally available
2) Inexpensive
3) Computer platform–independent
4) Visually friendly
5) Stable to future trends

Many different electronic storage formats exist today, but few people have access to many of them because of their expense and ever-changing upgrades. Choices for storage of the textual portions of benchmark information were reviewed against the above list of criteria and Adobe Acrobat® PDF, ASCII text, and HTML text formats were favored. Because of the volatility, the expense of updates, and the inability to transfer between other formats, other word processors were less attractive. Free updates for the Adobe Reader®, Netscape®, and Internet Explorer® browsers, and their extensive use in the World Wide Web, tend to give the PDF and HTML formats a strong advantage for long-term storage. Further, PDF and HTML documents are compatible with most popular computer systems, including UNIX, Apple, and PC systems.

Although ASCII text satisfies most of the restrictions, it does not have the versatility to integrate graphics and hyperlinks as do the PDF and HTML formats. This is a problem when data need to be visualized and when movement within large documents is necessary. ASCII format is very stable and is used for the archival storage of most raw data.

High-resolution scanners can be used to store graphical images of experimental arrangements, data results, and miscellaneous experimental information. Sometimes 20 or more graphical image files must be integrated with the benchmark text. Therefore, the graphic formats must be stored efficiently and must

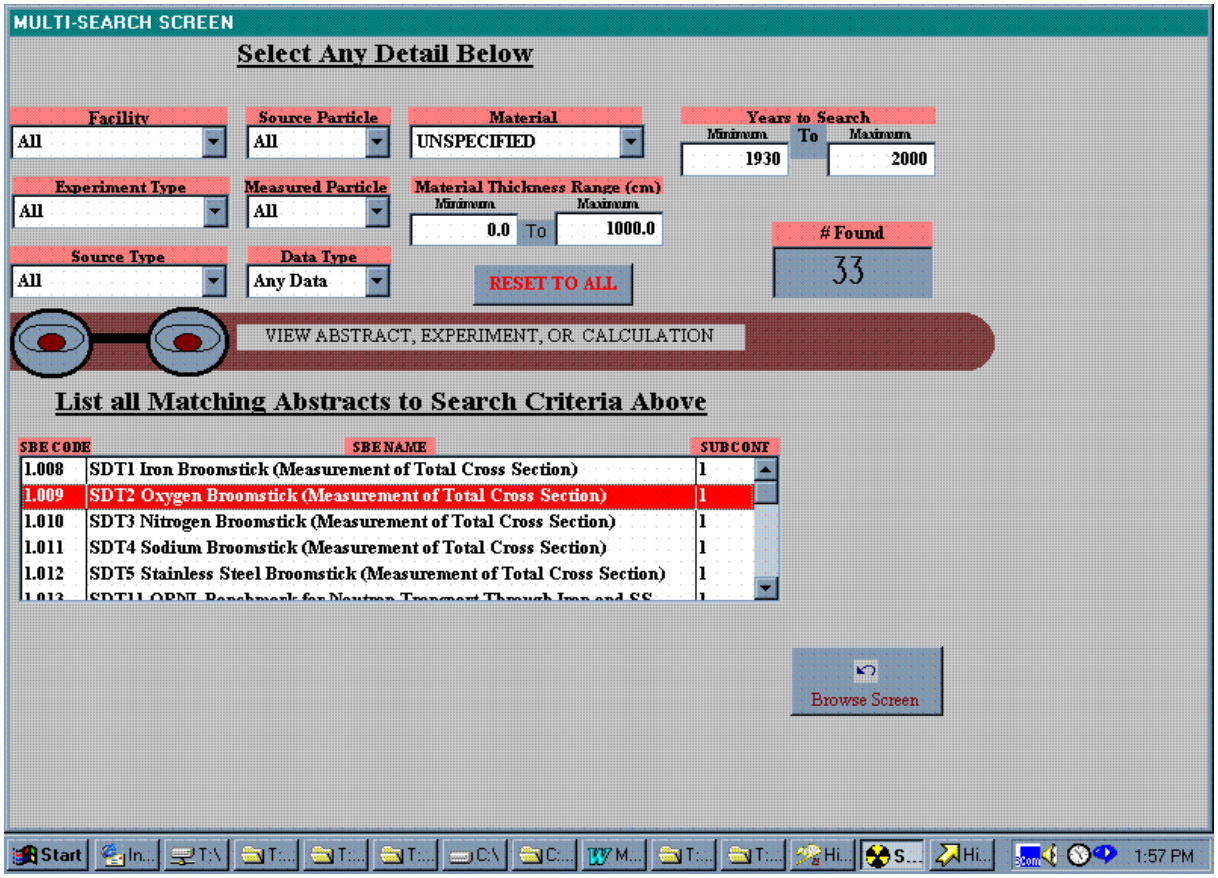

Figure 2 SINBAD Multi-Search Screen

load quickly so no significant amount of disk space is wasted and file loading delays are minimized. The graphic images must have resolutions that are high

enough to allow users to view small graphs clearly and to read minute details or dimensions in the benchmark schematics. The GIF (CompuServe®) and TIF (Tagged Image File) raster graphical formats were highly compatible with the most popular HTML browsers, which were freely available. These formats are commonly used within PDF and HTML documents today. Further, PDF formats allow the user to "zoom in" to expand the view for hard-to-read text or graphics.

Finally, the readability of a document is an important qualifier for a "user friendly" benchmark. The text and graphics must be clear and arranged with care; therefore, a review is needed to test whether a clarification is necessary. PDF and HTML documents allow embedded figures and tables, so minimal movement within those documents is necessary to see all pertinent information. Hyperlinks within the document provide a means to move quickly to other referenced areas of the document.

Since most computational experts needing new information would not be familiar with the available benchmarks, they would need to quickly and efficiently peruse the general benchmark information. An "abstract" or indexed encapsulation would be desirable for each benchmark to help with this problem.

V. SINBAD System

The SINBAD system (Shielding Integral Benchmark Archive and Database) has taken advantage of the recent computer improvements as well as the established Worldwide Web standards to store and retrieve benchmark information. The database and user interface was created with Microsoft's Visual FoxPro® 6.0 software for the PC. It has a powerful visual component composed of drop-down lists and push buttons. The user can navigate between different abstracts and associated experimental benchmarks with great ease.

The database stores specific information about the benchmarks in tables that can be indexed and displayed alphabetically or searched quickly for user input data. A useful method for finding the benchmark(s) of interest is for the user to input select characteristics to be searched against (See Figure 2). For example, if the user is interested in benchmarks with steel of a certain thickness, he/she may enter that as a search option from the SINBAD interface. Other options that may be used to isolate benchmarks are the date of experiment, experimental facility, source of radiation, types of measurements, etc. Once the database is searched, a number of "FOUND" matches is displayed and a listing of the benchmarks is provided.

The user may browse the listing of abstracts and select any of those to view. The abstracts contain useful information about each experiment and allow a quick overview of the important aspects of the data. See Table 1 below for a description of the abstract contents.

Table 1. Typical Abstract Contents for Experimental Benchmark

SINBAD ABSTRACT
SBE 1.002

1. Name of Experiment:

Measurements for the JASPER Program Axial Shield Experiment (1990-91)

2. Purpose and Phenomena Tested:

This experiment was designed to extend the studies of the effectiveness of different axial shield designs beyond the fission gas plenum and at the same time provide a comparison of the neutron attenuation characteristic of stainless steel and boron carbide as they are integrated into the designs.

3. Description of the Source and Experimental Configuration:

The neutron source was the Tower Shielding Reactor II (TSR-II) located at the Tower Shielding Facility at Oak Ridge National Laboratory. The emergent source spectrum was modified to be similar to that predicted for the LMR (liquid metal reactor) design. The spectrum modifier was composed of iron, aluminum, and boral, followed by a radial blanket comprised of natural uranium, aluminum, and sodium.

The configurations to be studied included seven hexagons containing three different internal geometrical designs. The designs consisted of (1) a central blockage type in which the coolant flowed around a central shield plug, (2) a rod bundle type in which the shield material was in the form of small rods spaced for coolant flow, and (3) an annular type in which the coolant flowed centrally through the shield assembly. These designs were used for two different shield materials, boron carbide and stainless steel. The configurations were positioned in the horizontal beam emerging from the reactor shield, preceded by the spectrum modifier. The seven assemblies were contained in an aluminum honeycomb surrounded by boron carbide and contained in a concrete slab. Changes were made by

inserting various hexagon assemblies into the aluminum honeycomb or removing them.

4. Measurement System and Uncertainties:

Four different types of detection systems were used in this experiment. A set of Bonner balls (3, 4, 5, 8, 10, and 12 inches in diameter) filled with BF3 gas was used to measure the neutron flux. In order to cover a range of neutron energies, the counter was used bare, covered with cadmium, or enclosed in various thicknesses of polyethylene shells surrounded by cadmium. A NE-213 liquid scintillator measured the neutron spectrum from about 800 keV to 15 MeV. Spherical proton-recoil counters, filled with hydrogen to pressures of 1, 3, and 10 atmospheres, covered the neutron energy range from about 50 keV to 1 MeV. The Hornyak button detector, which consisted of a lucite button interspersed with zinc sulfide mounted on a photomultiplier tube, was used to measure the absorbed energy per gram and to define the neutron streaming effect where small gaps existed in the mockup structure.

The uncertainty in the reactor power determination was assumed to be +/! 5%. The NE-213 and hydrogen counter measurements were expressed in terms of lower and upper limits that represented a 68% confidence interval. Both of the spectra for these counters have an error of about +/! 5%. The error in the Hornyak button measurements depends largely on the ability to maintain a constant temperature. The errors assigned to both the Bonner ball and Hornyak button detector measurements should lie within about +/! 10%.

5. Description of Results and Analysis:

Twelve different measurements of the neutron spectra were taken: (1) spectrum modifier, (2) B4C homogeneous hexagon, (3) SS homogeneous hexagon, (4) B4C central blockage + B4C homogeneous assemblies, (5) B4C central-blockage type assemblies, (6) SS central blockage assembly + 6 SS homogeneous-type assemblies, (7) SS central-blockage-type assemblies, (8) fission gas plenum + the 7 B4C central-blockage-type assemblies, (9) B4C rod bundle + B4C homogeneous-type assemblies, (10) SS rod bundle + SS homogeneous-type assemblies, (11) B4C central Na channel assembly + B4C homogeneous-type assemblies, and (12) SS central Na channel assembly + SS homogeneous-type assemblies.

Data from the Bonner ball measurements were predicted analytically by folding a calculated neutron spectrum with Bonner ball response functions. The NE-213 spectrometer pulse-height data were unfolded with the FERD code to yield absolute neutron energy spectra. Pulse-height data from the proton-recoil counters were unfolded with the SPEC-4 code.

The measurements for each detector were referenced to the reactor power (watts) using the data from two fission chambers positioned along the reactor centerline as a basis.

6. Special Features:

This report has recently been released by the U.S. Department of Energy.

7. Author/Organizer:

Experiment and Analysis:

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8. Availability:

Unrestricted

9. References:

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10. Data and Format:

Tables:

(1)–(14) Composition and analysis tables of different set-ups

(15)–(16) Neutron fluxes on centerline at 179.1 cm behind the radial blanket

(17)–(22) Bonner ball measurements

(23)–(24) Neutron fluxes on centerline at 32.6 cm behind axial shield

(25) Hornyak button measurements

(26)–(27) Neutron fluxes on centerline at 98.3 cm behind axial shield

(28)–(29) Neutron fluxes on centerline at 36.2 cm behind axial shield

Figures:

(1) Schematic of spectrum modifier-1

(2) Schematic of radial blanket slab

(3)–(10) SS and B4C hexagon assembly configurations

(11) Schematic of heterogeneous fission gas plenum

(12) Schematic of aluminum mesh

(13) Lithiated paraffin background shield

(14)–(15) Schematic of axial shield configurations

(16)–(21) B4C and SS radial traverses using the Hornyak button

(22) Schematic of fission gas plenum and seven B4C central leakage type mockups

(23)–(27) B4C and SS radial traverses using the Hornyak button

Document is HTML v.3.02 Format with ASCII Tables and Figures in GIF format.

SINBAD Abstract Generation Date: 08/98

SINBAD Abstract Last Update: 08/98

Within each numbered item of the abstract exists a simple, 1–2 paragraph description that helps the reader to decide whether the experiment would be of further interest. A designation appears at the top of the abstract called a "Shielding Benchmark Experiment number." In the example of Table 1, SBE 1.002 has a experimental facility number "1" and is assigned a "002" for the second experiment SINBAD has placed into the database for that facility. SINBAD contains experiments for 19 different facilities around the world. Table 2 shows the facilities and their designations.

Table 2. Facilities Providing SINBAD Benchmarks

Facility Number	*Facility Name*
1	Tower Shielding—ORNL
2	ASPIS—Winfrith
3	FNS—JAERI
4	Other—ORNL
5	ISPRA—Euracos
6	Karlsruhe—KfK
7	Oktavian—OSAKA U.
8	Proteus—Wuerlingen
9	MEPhI—Kurchatov
10	FNG—ENEA
11	INS—U. of Tokyo
12	Harmonie—Cadarache
13	Nucl. Eng.—U. of Illinois
14	AVF—Osaka U.
15	PCA—ORNL
16	YAYOI—U. of Tokyo
17	TOF ICT Accel.—LLNL
18	Nucl Eng.—Tech. U. of Dresden
19	SSC—IPPE

A total of 37 benchmarks have been added to the SINBAD database. Twenty-eight involve fast and thermal fission sources, two use accelerator-target sources, and the rest have fusion (D-T) sources.

Several benchmarks added within the past year are listed in Table 3. All have been compiled to an HTML or PDF format. Within the list are benchmarks that date from the 1960s to the 1990s, that come from facilities around the world, and that involve different types of sources, materials, and configurations. The abstracts for the SINBAD benchmarks may be viewed located at the Worldwide Web address for the Radiation Safety Information Computational Center at http://www-rsicc.ornl.gov/BENCHMARKS.html and at the Organization for Economic Cooperation and Development, Nuclear Energy Agency Data Bank sight http://www.nea.fr/html/dbprog.

Table 3. Experimental Benchmarks within SINBAD

Nuclear Fission Shielding:

Euracos—Iron Benchmark
Euracos—Sodium Benchmark
Karlsruhe KFK—Iron Benchmark
Proteus—Wuerenlingen Iron Benchmark
Harmonie—Cadarache Sodium
JANUS—Phase 1
JANUS—Phase VIII
JASPER Axial Shield
JASPER In-Vessel Fuel Storage
JASPER Radial Shield
NESDIP-2
NESDIP-3
PCA—PV

SB2—Gamma -ray
SB3—Gamma-ray
SDT1—ORNL Iron
SDT2—ORNL Oxygen
SDT3—ORNL Nitrogen
SDT4—ORNL Sodium
SDT5—ORNL SS
SDT11 ORNL Thick Iron/SS
SDT12 ORNL Thick Sodium
Winfrith ASPIS—Iron Benchmark
Winfrith ASPIS—Iron 88 Benchmark
Winfrith ASPIS—Graphite Benchmark
Winfrith ASPIS—Water Benchmark
Winfrith NESDIP-2 Benchmark
Winfrith PCA—Replica Benchmark
U of Illinois Iron Sphere

Fusion:
FNG—SS Bulk Shield
FNG—ITER Blanket
Osaka Iron Sphere
SB5—ORNL SS/BP
TUD—Dresden Iron
U of Illinois Iron Sphere

Accelerator:
INS Tokyo—Shielding Mats. I
AVF Cycl U of Osaka—Shielding Mats II

VI. Displaying SINBAD Benchmarks

The abstracts and benchmarks in SINBAD are all in PDF and HTML formats, which may be opened through the SINBAD PC search engine or as separate files in a browser software program, such as Netscape® or Microsoft Internet Explorer®, and navigated independently of the SINBAD 98 PC search engine. A user of a Unix system would be able to open each main benchmark file by an index of benchmarks alphabetized by name. A small keyword search engine has been included for Unix systems that allow users to search the HTML files for keywords and returns a listing of those with matches.

VII. Calculations Using SINBAD

The computations that use benchmark information for modeling and data input can in turn be stored within the SINBAD system. Input decks and computational results, as well as other pertinent information about cross-sections and transport code versions, would be included. This information may be used for comparisons with other types of computations and their results. SINBAD has the ability to store several computations for each benchmark experiment. A user may browse these computations when trying to set up a computational model and use the information to check against his own. The focus has been mainly on the storage of experimental results until recently, when the computational feature of SINBAD has received more attention. It is anticipated that many new computations will be placed into storage with the associated benchmarks in the near future. This enhancement will save much time during computational program setup and help in data checking of output. As computations advance in complexity and accu.16mupdciatel results will ew

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continuously updated with a greater range of test materials and geometric arrangements. Unification of the storage formats and data sets allows experienced personnel a standard for computational comparisons around the world. This is extremely important for today's strong reliance on computational predictions in nuclear shielding.

VIII. Work in Progress

JASPER (Japanese-American Shielding Program for Experimental Research) had several major advanced reactor mockup measurements performed in the late 1980s and early 1990s. Of the eight experiments performed, three have been compiled into SINBAD format, namely, Radial Shield, Axial Shield, and Intermediate Heat Exchanger. Work will continue on the last five experiments as time permits.

The Lawrence Livermore Pulsed Sphere program, initiated in the 1960s, is being reevaluated by Los Alamos National Laboratory and will be finished in the summer of 1999. More than 20 types of materials were studied using a D-T source of neutrons. It is hoped they will be ready to be added to the database this next year.

Shielding logbooks that contain vital information have been indexed and sent to a depository in the ORNL complex for permanent storage/retrieval. The index will be available for searching on the Worldwide Web. Two facilities have been archived to date, the Tower Shielding and DOSAR (Health Physics Research Reactor).

An expansion of the criticality safety benchmark work of the Idaho National Engineering Laboratory and the OECD NEA (10) to the criticality alarm area would make use of SINBAD shielding configurations and materials that were common in the criticality alarm area. These new computations would determine and verify the proper detector locations and sensitivities. During movements of storage containers, it is possible that many different materials could interfere with the criticality alarm system operation.

Other SINBAD work foreseen involves cask shielding for shipment of spent fuels, radiochemical shielding, radioisotopic storage and shielding for medical facilities, and astronomical shielding for long-term space inhabitation.

Acknowledgements

The authors wish to thank those who have helped contribute to the SINBAD database content. Without their help, SINBAD would not be possible. Many thanks to the OECD NEA and ORNL RSICC personnel and summer interns who have worked through many benchmarks. Additional thanks go to D. T. Ingersoll and R. W. Roussin, who had the foresight to push this project into existence and keep it going, and to C. O. Slater, who has provided insight as a computational expert.

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