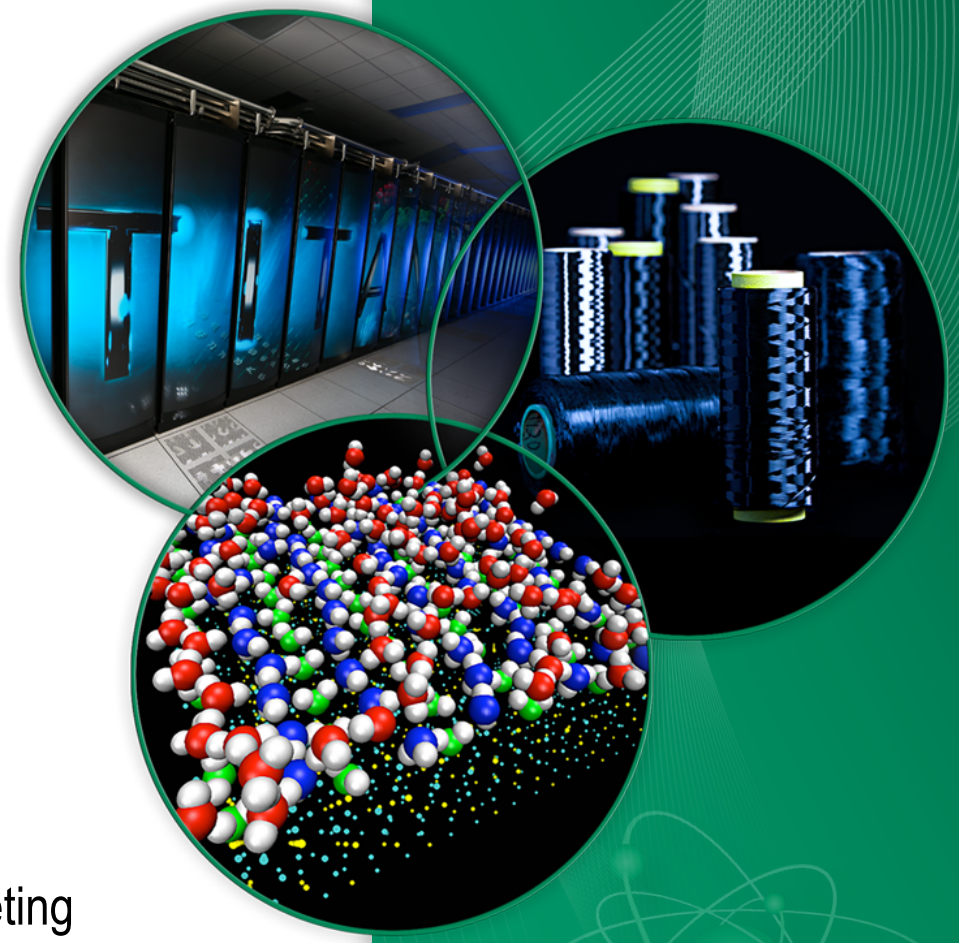
Reactor and Nuclear Systems Division (RNSD) M&S Support for Fusion Applications



Michael Dunn, Luiz Leal, Bob Grove,
and Tim Valentine

The Virtual Laboratory for Technology Meeting

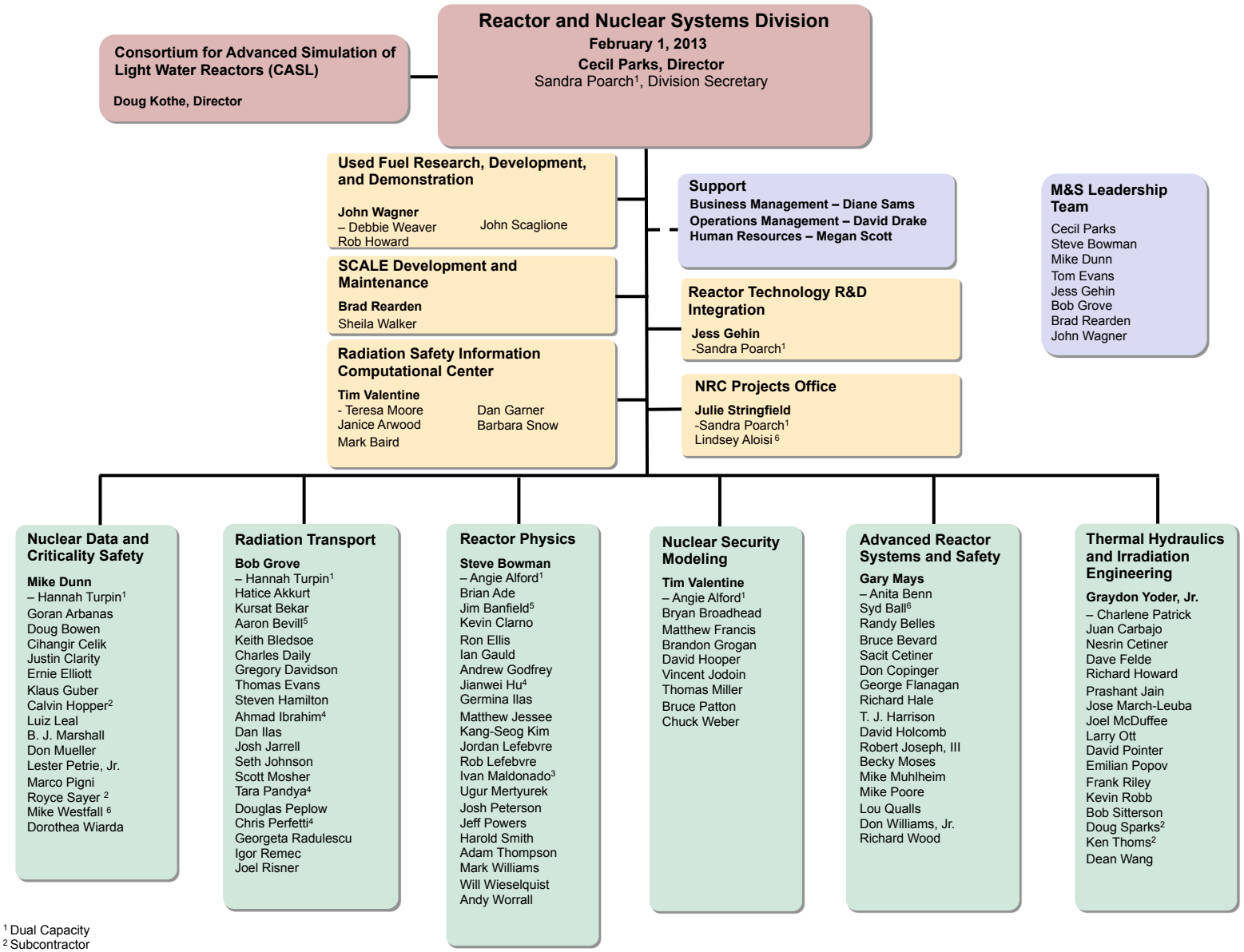
May 15, 2013

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Outline

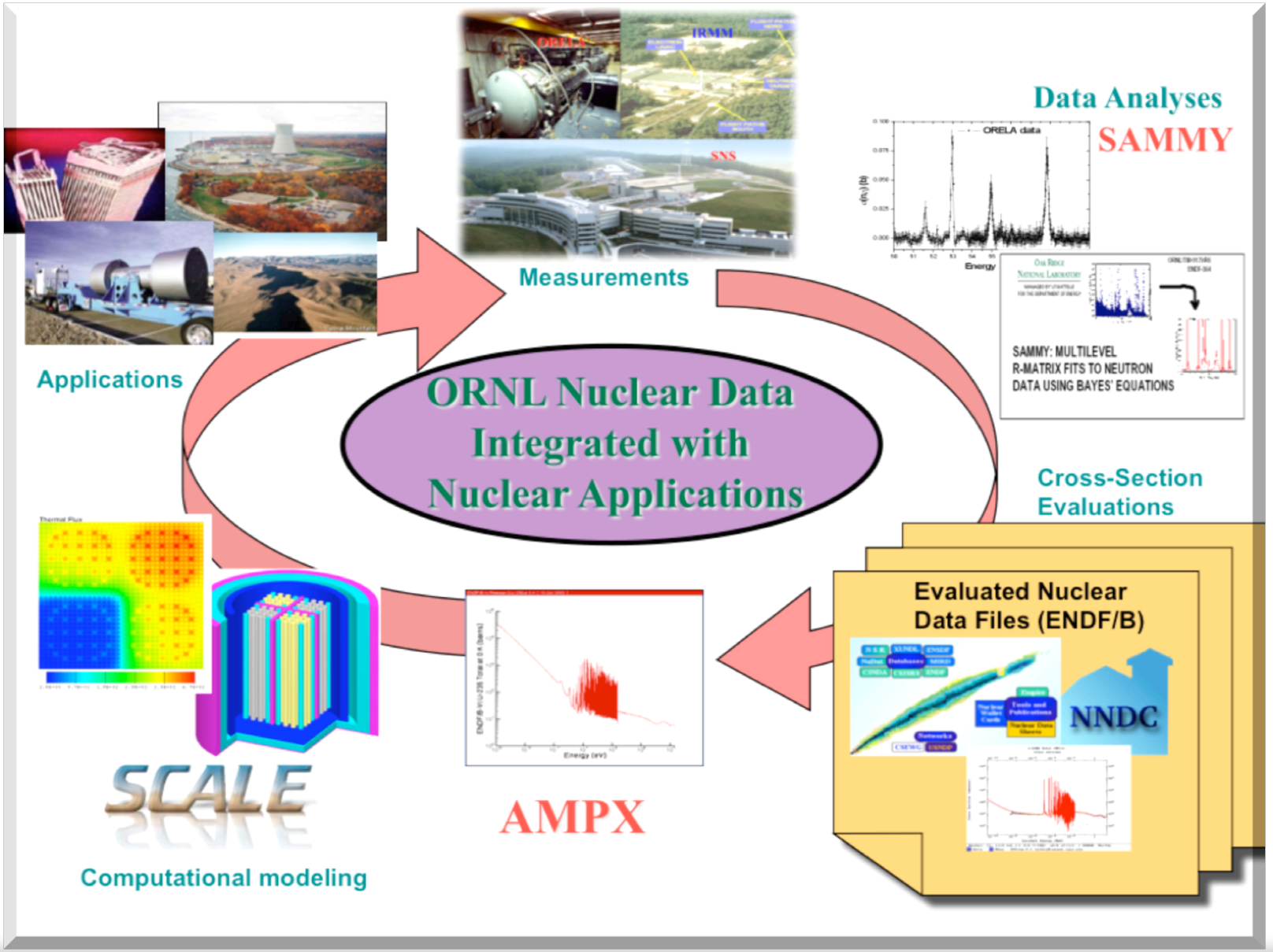
- RNSD Organization
- Nuclear Data and Fusion Evaluated Nuclear Data Library
- Modeling and Simulation Capabilities
- RSICC and SINBAD Database
- Summary



[1] Dual Capacity
[2] Subcontractor
[3] Joint Faculty
[4] Post Doc
[5] Postmasters
[6] Casual/Part-time
[7] On Assignment

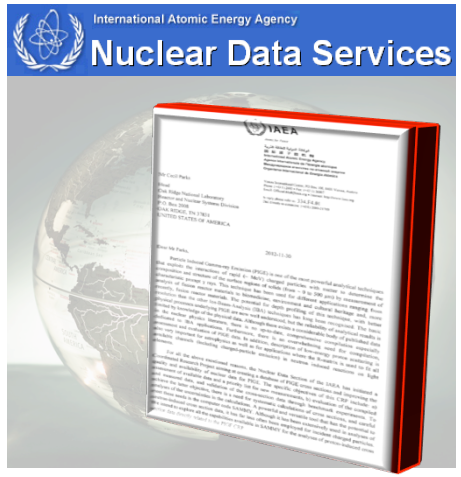
OAK RIDGE National Laboratory

Integrated Nuclear Data and M&S Capabilities



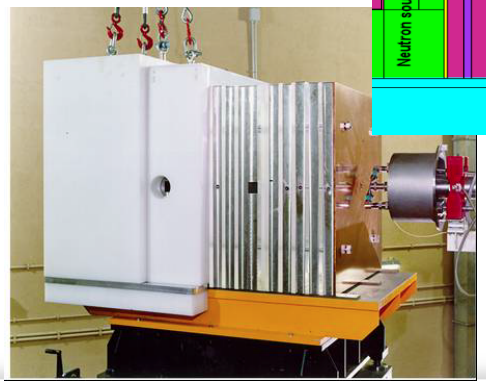
RNSD Support for Fusion Evaluated Nuclear Data Library Version 3 (FENDL-3)

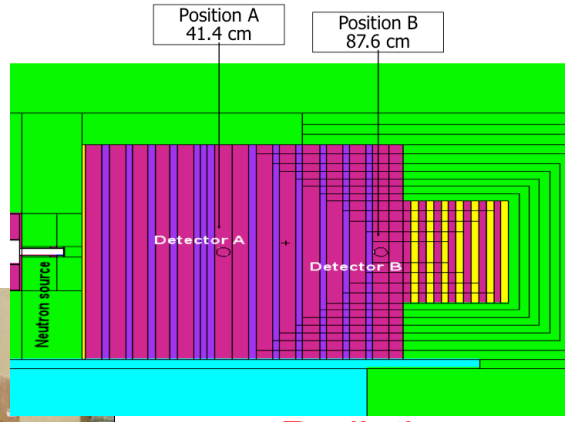
- Nuclear cross-section database project developed and maintained by the IAEA for fusion applications
  - Includes data for neutron, gammas, charged particle, nuclear heating, and gas production reactions along with limited cross-section covariance (uncertainty) data
- IAEA initiated Coordinated Research Project (CRP) in 2008 to improve nuclear cross-section data for fusion analyses including IFMIF
- FENDL-3 is latest library developed, tested, and released through CRP—Luiz Leal (RNSD) invited member of IAEA FENDL CRP



- FENDL-3 V&V calculations are in progress both in the US and internationally—M. Sawan (Univ Wisconsin) performed detailed V&V with MCNP (example results):
  - Activation analysis: FENDL-3 C/E activation foil results improved relative to FENDL-2.1 for bulk shield experiment except for tungsten data—need improved tungsten data
  - Gas production: Missing D, T, He-3 reactions for several materials—need update to FENDL-3

FNG Experimental Benchmark



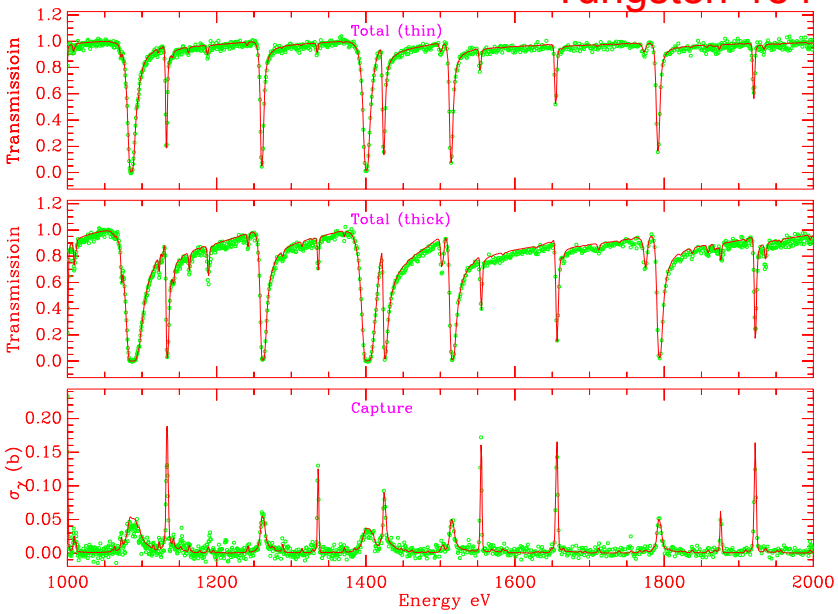


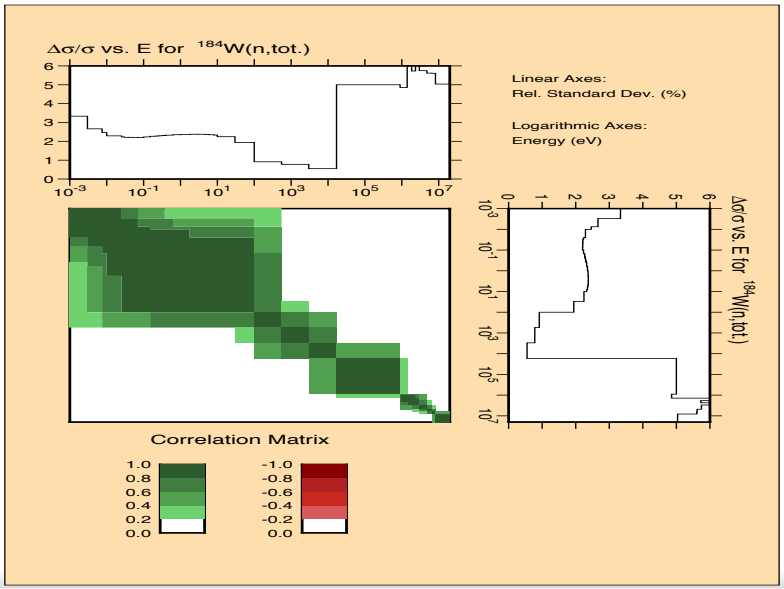
Radiation Transport Model

RNSD Support for Fusion Evaluated Nuclear Data Library Version 3 (FEND-3)

- ORNL Contributions to IAEA FENDL CRP
  - Nuclear data evaluations using ORNL-developed SAMMY R-matrix analysis software —providing neutron cross-section evaluations with covariance data
  - RNSD contributions to FENDL-3: ^{27}Al, ^{55}Mn, ^{28}Si, ^{30}Si, ^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti, ^{50}Ti, ^{50}Cr, ^{52}Cr, ^{53}Cr, ^{54}Cr
  - RNSD evaluations in progress: tungsten isotopes (^{182}W, ^{183}W, ^{184}W, ^{186}W) and ^{56}Fe
- Data assessment needs—potential collaboration with M. Sawan (Wisconsin)
  - Use of nuclear data covariance propagation tools to assess nuclear data uncertainty impacts for fusion applications (e.g., ORNL-developed SCALE sensitivity/uncertainty capabilities)
  - Verification of MCNP results with other transport codes (SCALE)

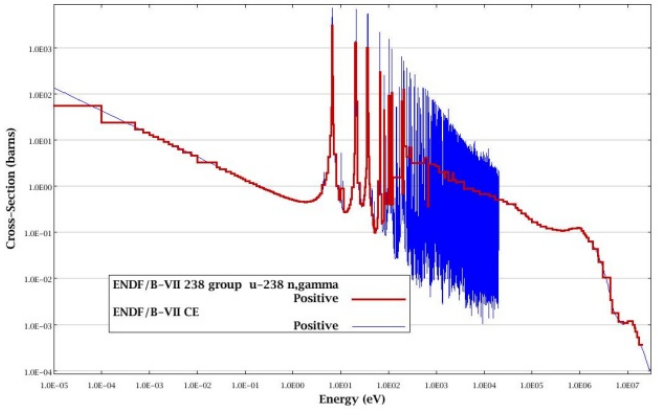
Tungsten-184



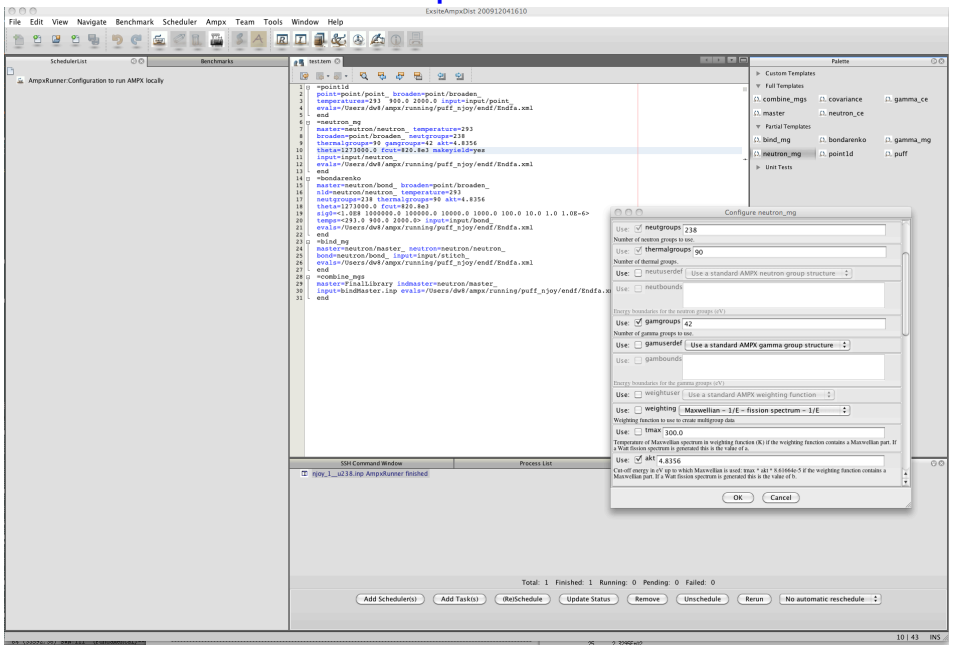


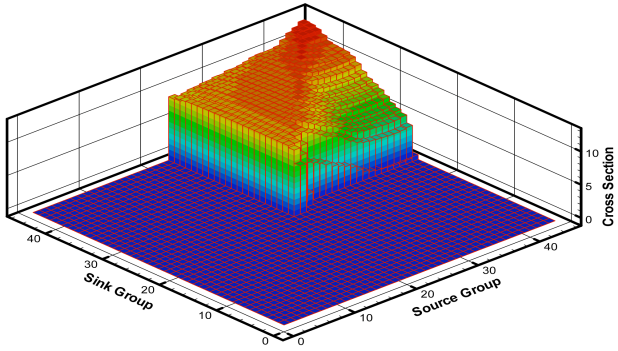
AMPX Providing Nuclear Data Libraries for M&S

- RNSD radiation transport methods and analyses rely upon nuclear data libraries produced by AMPX



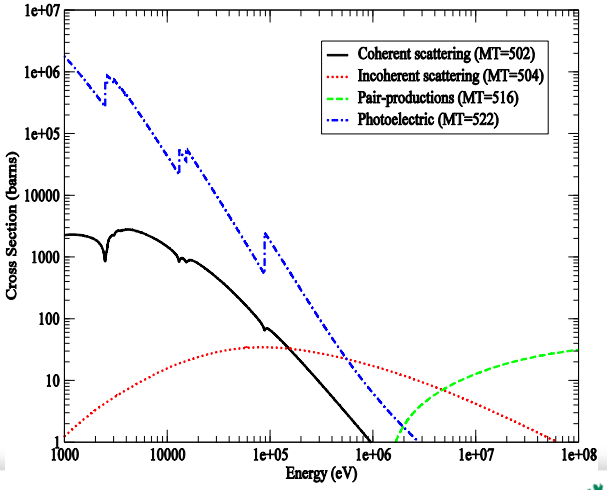
AMPX Graphical User Interface



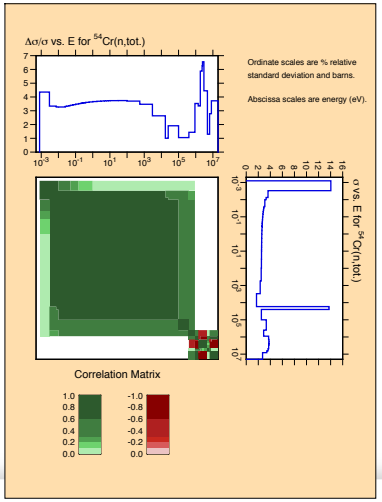


Multi-group elastic scattering for hydrogen

Cross Sections for Gamma Interactions in Lead



Covariance Data



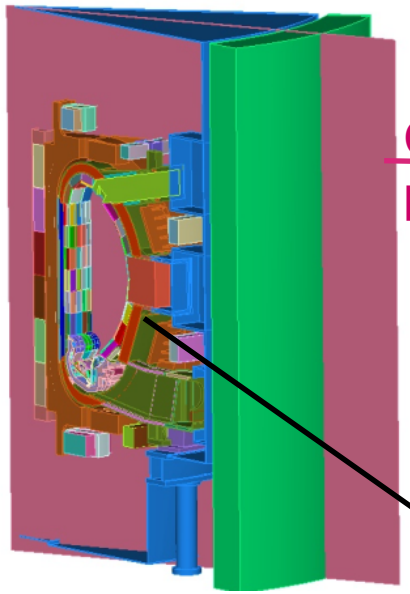
RNSD and the RNSD Radiation Transport Group – unique capabilities for fusion neutronics

- A community of experts in all aspects of radiation transport and shielding for many applications including nuclear reactors, accelerators, irradiation/activation facilities, as well as fusion neutronics
- Experts and software tools that provide all required nuclear data; sensitivity and uncertainty analyses for all types of radiation transport applications
- Access to and ongoing development of radiation transport analysis tools on US leadership-class computing facilities and on RNSD capacity computing clusters
- Extensive collaboration with US ITER fusion neutronics efforts (Univ Wisc – Madison, UCLA, PPPL) and growing contacts with the international ITER fusion neutronics community
- Of specific interest for ITER and fusion neutronics design and analyses:
  - Accurately and efficiently determining nuclear responses in complex systems (nuclear heating, damage, gas production, material and biological doses, etc.) using full-scale models and our signature analysis tools
  - Developing tools for accurately determining the complex, ITER shutdown dose rates (SDDR)
  - Providing expert assistance to others using our signature tools, expert reviews of ITER neutronics analyses, consulting services for the ITER computer server, located at ORNL

RNSD and the RNSD Radiation Transport Group – unique capabilities for fusion neutronics

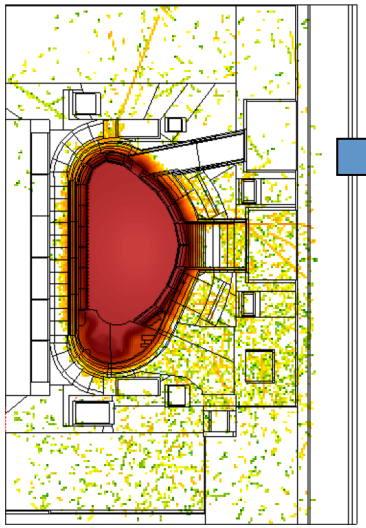
- Our signature hybrid Monte Carlo / deterministic transport methods and tools are providing solutions to previously intractable problems for ITER neutronics analyses
  - CADIS (Consistent Adjoint-Driven Importance Sampling)
    - High-fidelity (low variance) results in local regions
  - FW-CADIS (Forward Weighted CADIS)
    - High-fidelity results throughout entire problem spaces
  - MS-CADIS (Multi-Step CADIS)
    - Under development (unfunded) to address the complex multi-step problem for ITER shutdown dose rate analyses
    - Neutron transport ➔ material activation / transmutation / decay ➔ photon transport ➔ dose rates, nuclear heating, etc.
  - Implemented in our signature tools, ADVANTG (hybrid) and Denovo (deterministic transport), to provide advanced VR (variance reduction) parameters for dramatically speeding up MCNP particle simulations

Many extremely difficult ITER fusion-neutronics calculations need ADVANTG



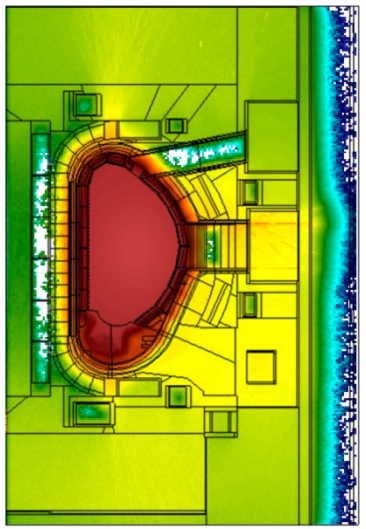
Central plane

20° plane



Prompt dose rate maps

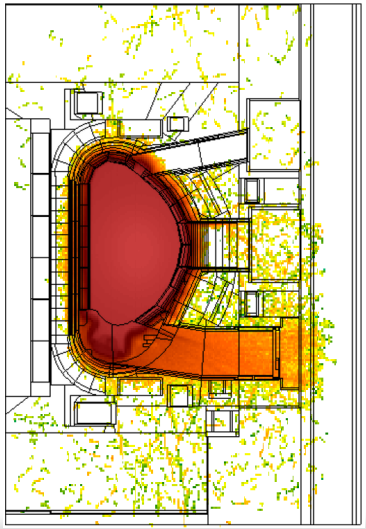
Solution in 25.8% of regions

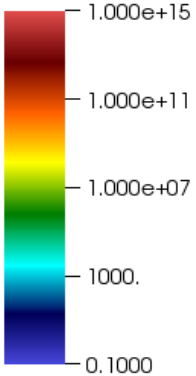


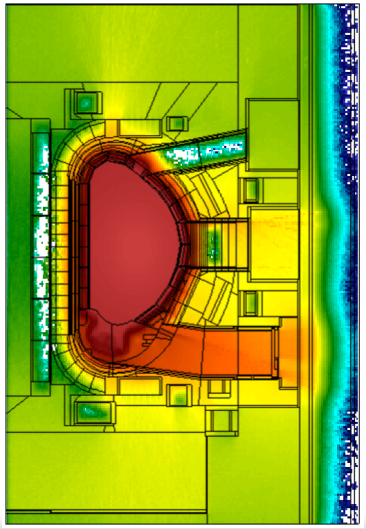
Solution in 95.6% of regions

10 days analog MCNP

10 days FW-CADIS/MCNP

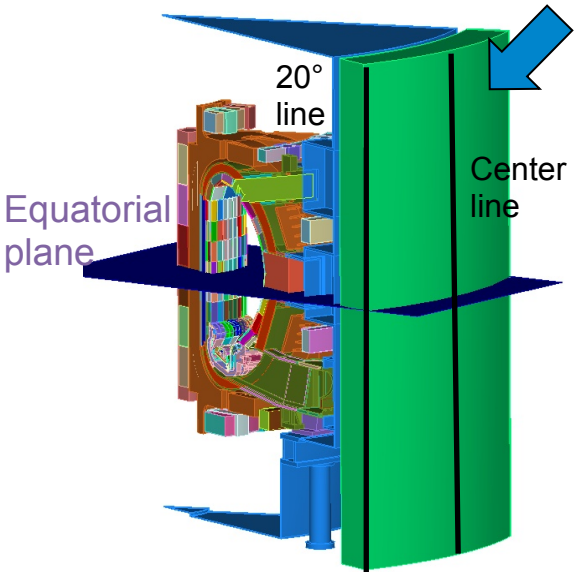


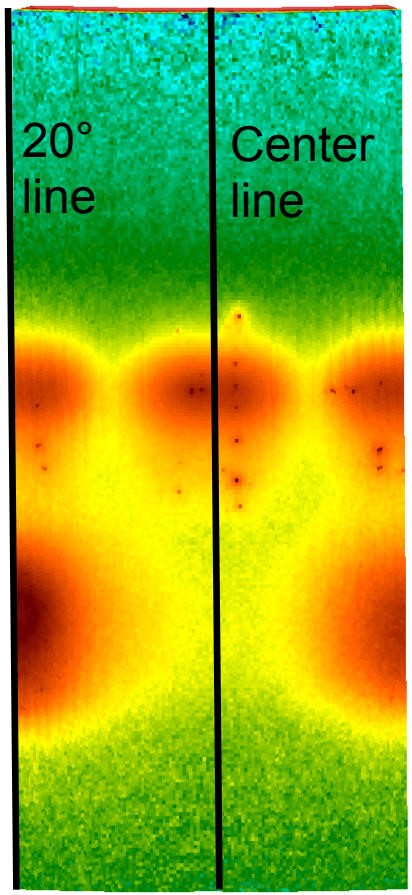


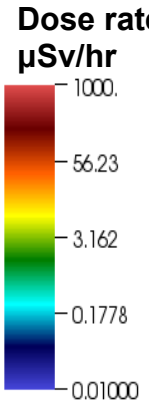


Ports plugs in vacuum vessel

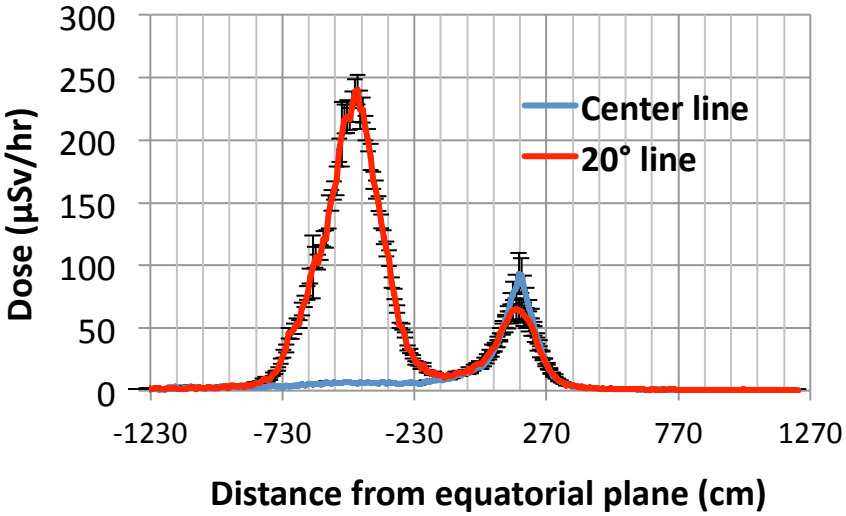
Dose rates at outboard bioshield surface







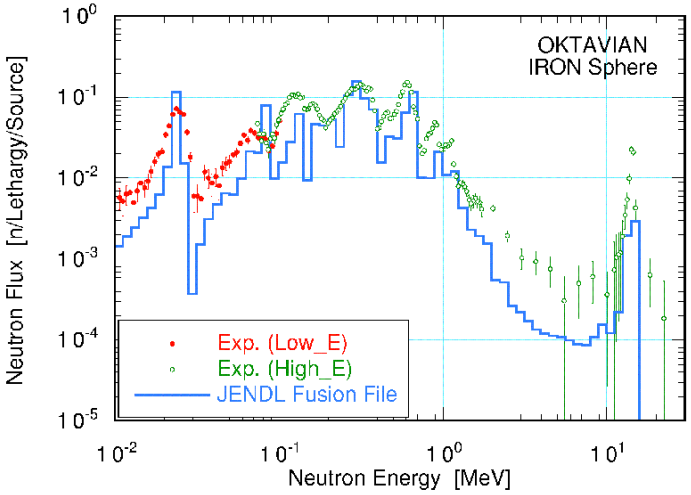
Dose rates along two lines behind bioshield

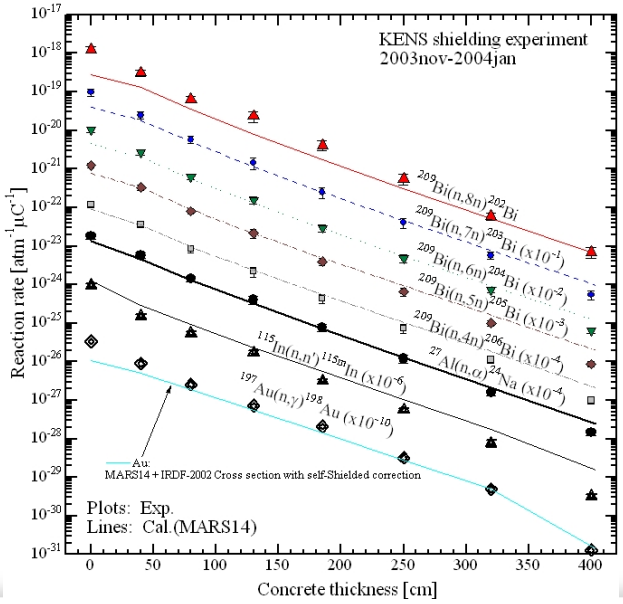


Port openings In vacuum vessel

- **Factor of 1000 peaks in dose because of ports and complex inboard equipment arrangements**
- **These calculations *not tractable without ADVANTG***
- **Without this capability, the design will be significantly over- or under-conservative**

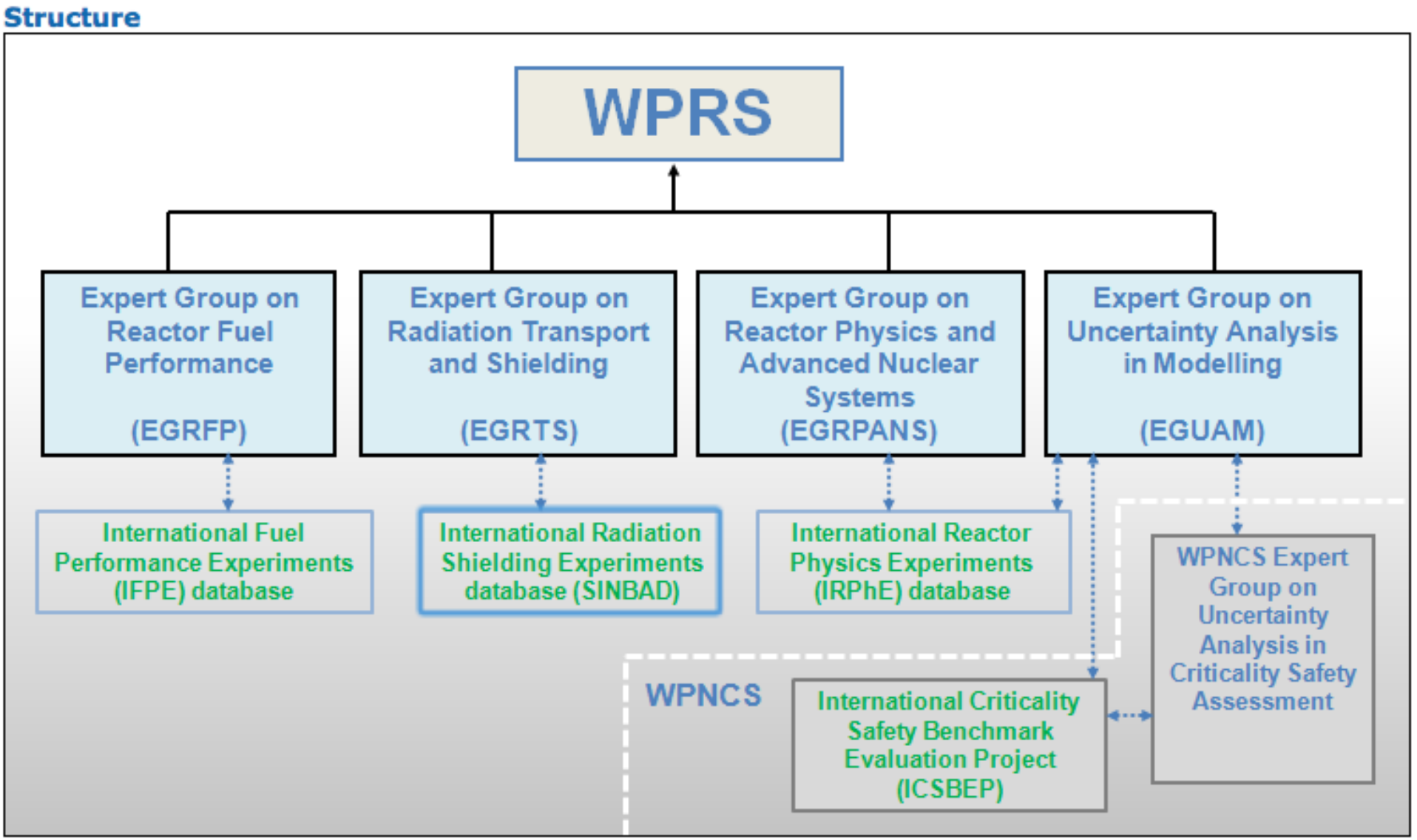
RSICC's Shielding Integral Benchmark Archival Database (SINBAD)





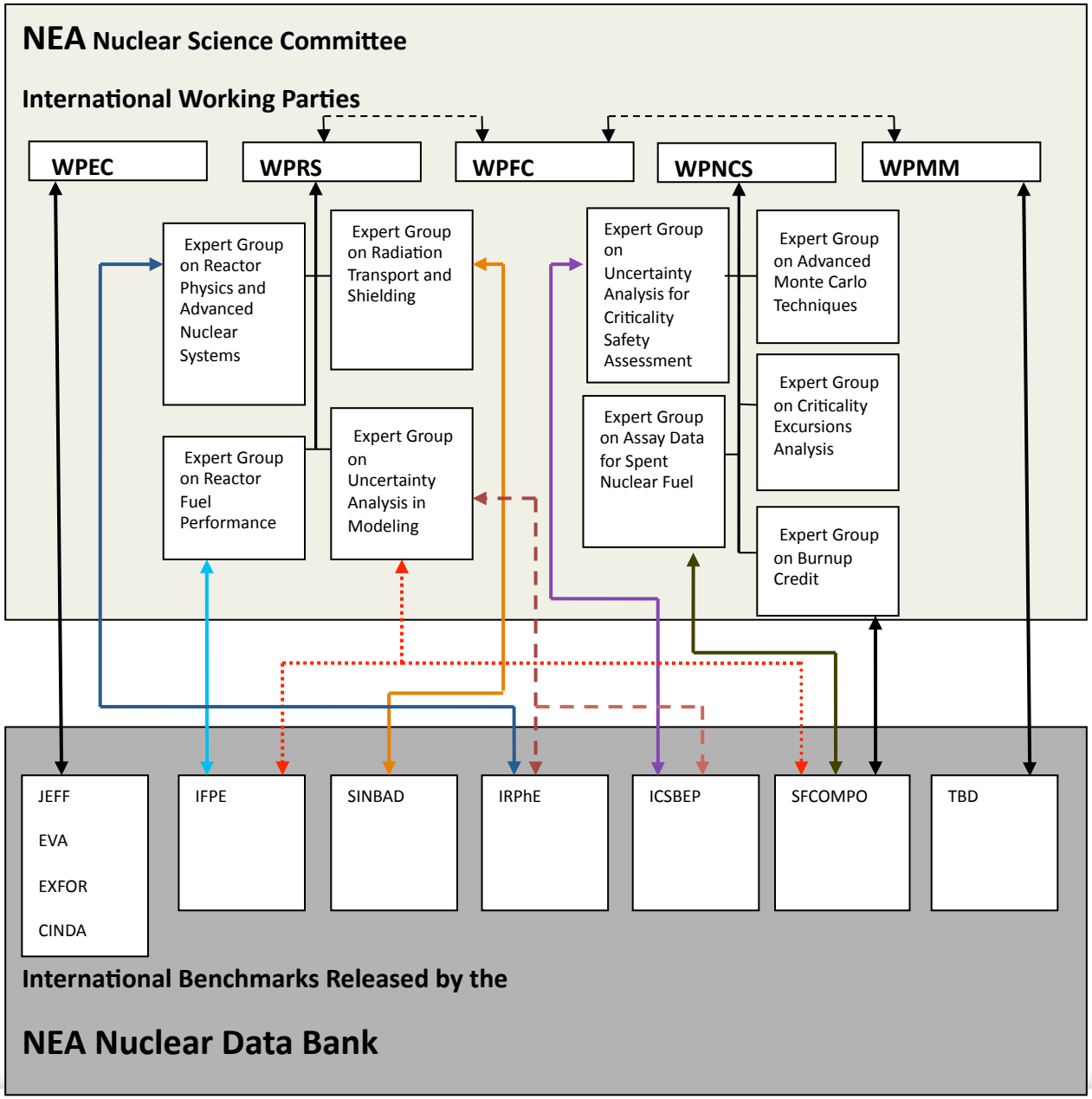
- Initiated in the early 1990s
- Joint effort between RSICC and the Nuclear Energy Agency Data Bank (NEADB)
- Shielding benchmarks for
  - Nuclear reactors (45 exps.)
  - Fusion devices (29 exps.)
  - Accelerators (23 exps.)
- Basis for validation and verification of radiation shielding codes and data
- RNSD nuclear and M&S expertise coupled with RSICC capabilities can be leveraged to improve and expand SINBAD for fusion V&V needs
- Active US participation in SINBAD is needed to maintain leadership in establishing priorities for reviews along with the OECD/NEA

OECD-NEA WPRS Structure



NEA Science Committee and Data Bank

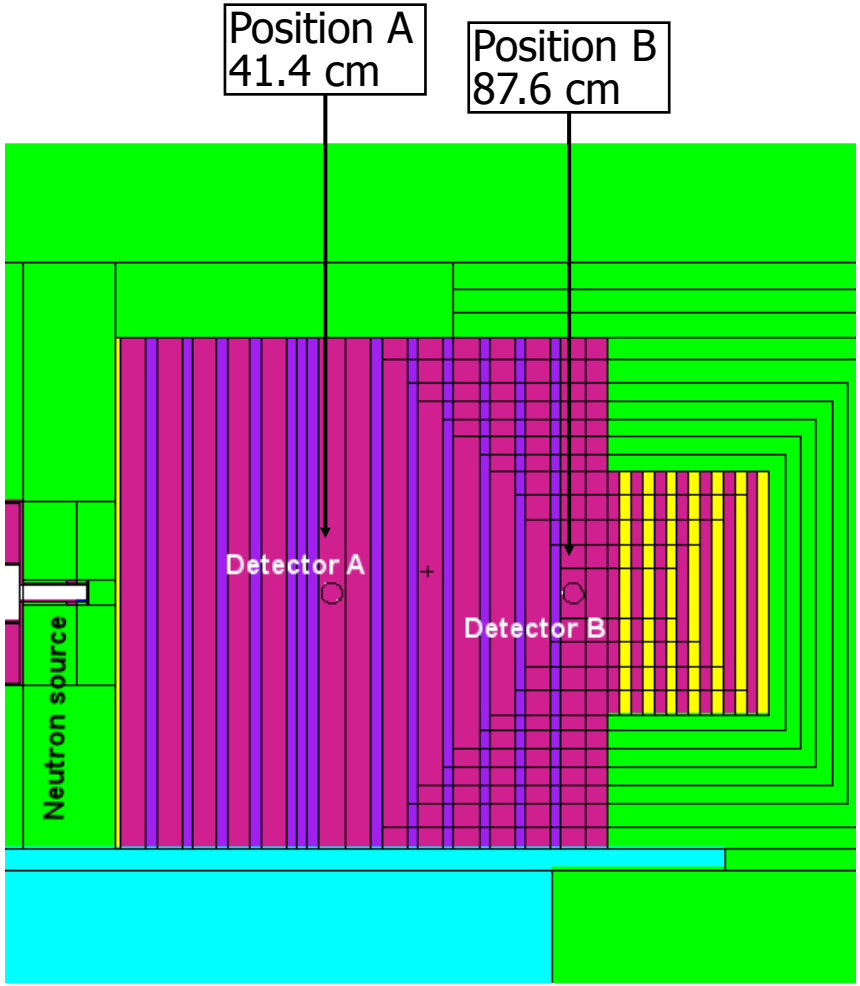
U.S. leadership and participation in the expert groups is critical for U.S. nuclear research programs



Example SINBAD Benchmark: ITER Bulk Shield Mock-up Experiment at FNG

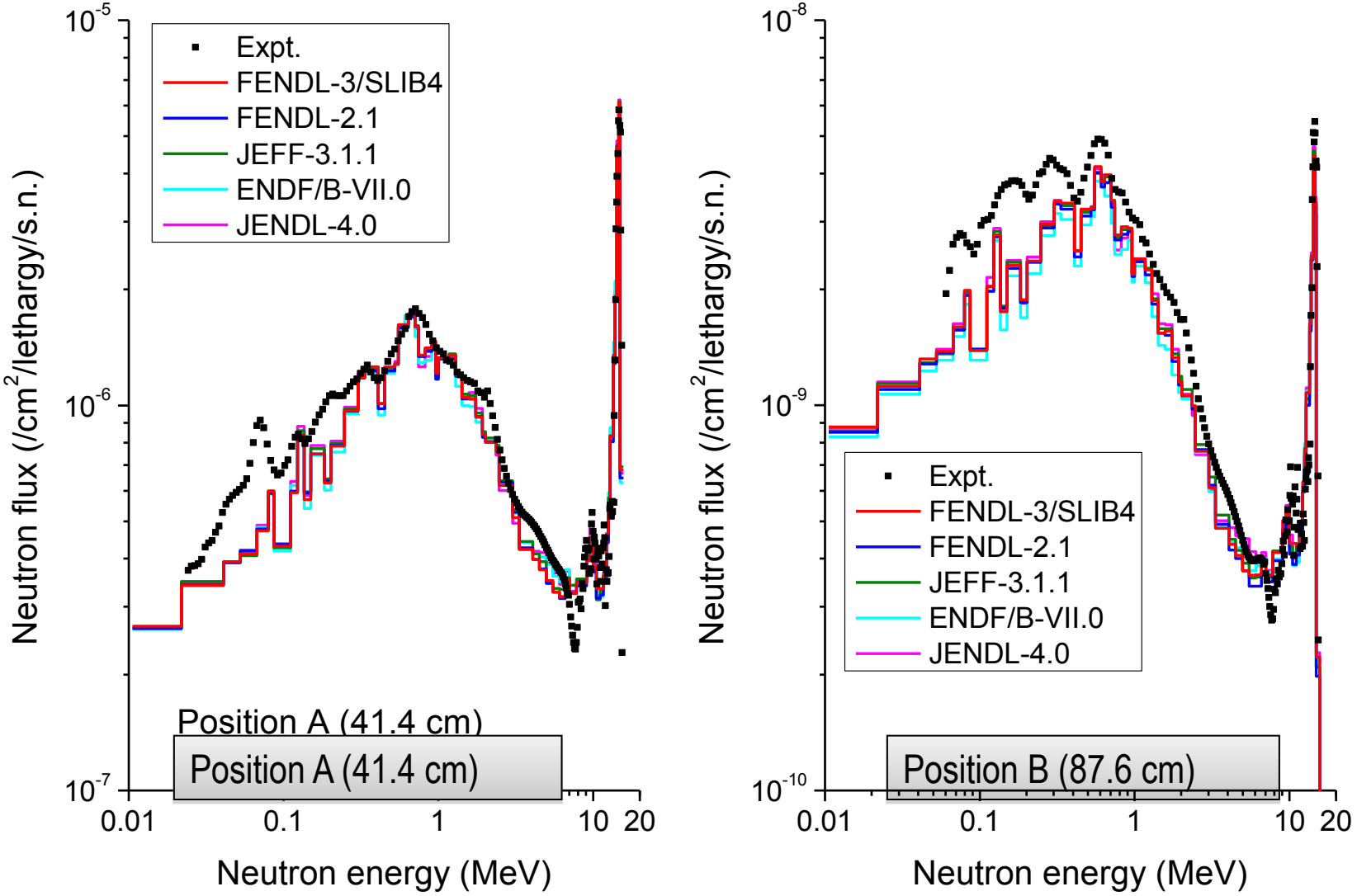
Measurements of neutron/photon flux spectra by TUD (K. Seidel et al.)

- Mock-up of ITER inboard blanket/shield system with thickness of 94 cm (alternating plates of SS-316 and of Perspex).
- Backed by 30 cm thick block of alternating SS-316 and Cu plates simulating TF-coil.
- Neutron and photon flux spectra measured at positions A (41.4 cm) and B (87.6 cm)
- Neutron spectra measured in the energy range between about 20 keV and 15 MeV.
  - A set of gas-filled proportional counters and a stilbene scintillation spectrometer used in the energy range up to 3 MeV.
  - NE-213 scintillation spectrometer for energy range 1 to 15 MeV.
- Photon flux spectra measured with NE-213 spectrometer above 0.2 MeV.



K. Kondo, U. Fischer, et al.. FENDL-3 Benchmarking

Neutron spectra (ITER bulk shield expt.)



K. Kondo, U. Fischer, et al.. FENDL-3 Benchmarking

Benefits of an Evaluated SINBAD

- An Evaluated SINBAD provides several benefits to the fusion community:
  - Ability to leverage the database tools being developed by the OECD-NEA
  - Provide standardized set of benchmark descriptions for validating computational tools and nuclear data
  - Ensure historical knowledge gaps are accurately documented and addressed while retired experimenters are still available
  - Provide guidance for collection and evaluation of future experiments to ensure that adequate data are collected for benchmarking purposes
  - Engage universities to conduct benchmark evaluations
    - Engages the next generation of fusion scientists
    - Makes optimal use of the limited fiscal resources

Summary

- ORNL/RNSD has demonstrated support fusion R&D in 3 primary focus areas:
  - Nuclear data and IAEA CRP efforts to develop and deploy FENDL-3
  - State-of-the-art radiation transport capabilities and analyses (e.g., hybrid MC/ Deterministic)
  - SINBAD benchmark database management in addition to contributions and V&V analyses
- Continued R&D needed in the 3 focus areas
  - Nuclear Data
    - Continued participation in IAEA FENDL CRP to provide improved nuclear data evaluations
    - V&V and uncertainty propagation to assess nuclear data uncertainty impact in fusion analyses—identify target nuclear data accuracies needed for improved nuclear data
  - Use and improvement of radiation transport M&S capabilities to solve problems that are not tractable with standard Monte Carlo analysis capabilities
    - Example analyses: nuclear heating, radiation damage, gas production, material/biological dose
  - SINBAD database developed and maintained per QA plan
    - Define consistent format for documenting experiment and evaluation of uncertainties
    - Provide standardized format consistent with other benchmark databases (e.g., ICSBEP)
    - Focus on data improvements needed for fusion applications