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International Atomic Energy Agency

Agence Internationale de l'énergie atomique

Международное агентство по атомной энергии

Organismo Internacional de Energía Atómica

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2017-03-21

Excellency,

I have the honour to inform you that the International Atomic Energy Agency (IAEA) requires consultants' advice on R-Matrix Codes for Charged-Particle Reactions at the IAEA's Headquarters in Vienna, Austria, from 28 to 30 June 2017.

The purpose of the consultancy assignment is to follow up on the progress in R-matrix codes and to discuss the evaluation process for charged-particle reactions in the Resolved-Resonance Region.

In this regard, I should be grateful if your Government would make available the services of

**Mr Richard James DeBoer** (225 Nieuwland Science Centre, Notre Dame, E-mail: [Richard.J.deBoer.12@nd.edu](mailto:Richard.J.deBoer.12@nd.edu)), **Mr Marco Pigni** (Oak Ridge National Laboratory, P.O. Box 2008, Bldg. 5700, Oak Ridge, E-mail: [pignimt@ornl.gov](mailto:pignimt@ornl.gov)), **Mr Mark Paris** (Los Alamos National Laboratory, Theoretical Division, MS B283, Los Alamos, E-mail: [mmparis@lanl.gov](mailto:mmparis@lanl.gov)) and **Mr Ian Joseph Thompson** (Lawrence Livermore Laboratory, L-414, Livermore, E-mail: [thompson97@llnl.gov](mailto:thompson97@llnl.gov)) for this assignment.

The IAEA will provide Mr DeBoer with a lump sum of €2550 and Mr Pigni with a lump sum of €2840 for the travel expenses to and from Vienna and for living expenses, including incidentals, connected with the assignment. The consultants would then be fully responsible for making the necessary travel arrangements and for cancellation costs, if any. This amount has been calculated on the assumption that the consultant will stay for the total duration of the assignment. Should this not be the case, the consultants would be requested to reimburse the IAEA for the appropriate difference.

We understand that all expenses incurred in connection with the consultant's services of Mr Paris and Mr Thompson will be paid by the consultants' authorities.

It should be noted that compensation is not payable by the IAEA for any damage to or loss of personal property. The IAEA also does not provide health insurance coverage for participants in meetings, workshops or training courses or for consultants. Arrangements for private insurance coverage on an individual basis should therefore be made. The IAEA will, however, provide insurance coverage for accidents and illnesses that clearly result from any work performed for the IAEA.

It would be appreciated if your Government's confirmation could reach the IAEA not later than **31 March 2017**. Ms Paraskevi Dimitriou of the Division of Physical and Chemical Sciences (Email: [p.dimitriou@iaea.org](mailto:p.dimitriou@iaea.org)) is the responsible officer who will contact the consultant directly concerning further arrangements.

Accept, Excellency, the assurances of my highest consideration.



Meera Venkatesh  
Director  
Division of Physical and Chemical Sciences  
Department of Nuclear Sciences and Applications

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**ORNL  
FOREIGN TRIP REPORT  
TA 409275**

**DATE:** October 27, 2017

**SUBJECT:** Report of Foreign Travel to Paris, France – Brad Rearden, Reactor and Nuclear Systems Division

**TO:** Angela Chambers, Nuclear Criticality Safety Program Manager, National Nuclear Security Administration / NA-511/GTN, Pantex Plant, PO Box 30020, Amarillo, TX 79120-0020

**FROM:** Brad Rearden

**MEETING:  
TITLE** Working Party on Nuclear Criticality Safety (WPNCS) and associated expert group meetings.

**MEETING:  
LOCATION** OECD NEA Headquarters, Paris, France

**LOCATION** OECD Headquarters, Paris, France

**MEETING:  
DATES** 6/26/2017 – 6/30/2017

**ATTENDEES:  
ON BEHALF  
OF NCSP** Brad Rearden

**MEETING:  
BENEFIT TO  
NCSP** Brad Rearden is the manager of the SCALE code system, which is licensed to over 8,000 users in 58 nations and includes NCSP supported methods and data for Monte Carlo neutron transport as well as sensitivity and uncertainty analysis, which are the topics of these meetings. Collaboration with international experts in these areas can lead to extended use of the NCSP-supported tools, identification of areas for improvements in existing methods, identification of new areas of research for the improvement of process design, and extended collaborative research and development.

**PURPOSE:** The purpose of the travel to Paris is to participate in the Organization for Economic Cooperation and Development (OECD) Working Party on Nuclear Criticality Safety (WPNCS) and its Expert Groups on Advanced Monte Carlo Techniques (AMCT), Uncertainty Analysis for Criticality Safety Assessment (UACSA), Assay Data for Spent Nuclear Fuel (ADSNF), and Used Nuclear Fuel (UNF).

**SITES:** NEA OECD Data Bank, Paris, France  
**VISITED** OECD Headquarters, Paris, France

**ABSTRACT:** From <https://www.oecd-nea.org/science/wpnscs/>

The WPNCS deals with technical and scientific issues relevant to criticality safety. Specific areas of interest include (but are not limited to) investigations of static and transient configurations encountered in the nuclear fuel cycle. These include fuel fabrication, transport and storage. The WPNCS's objectives are to:

- exchange information on national programmes in the area of criticality safety;
- guide, promote and coordinate high-priority activities of common interest to the international criticality safety community and to establish co-operation;
- monitor the progress of all activities and report to the Nuclear Science Committee (NSC);
- publish databases, handbooks and reports;
- facilitate communications within the international criticality safety community through relevant websites;
- co-ordinate the ongoing series of International Conferences on Nuclear Criticality Safety (ICNC), to be held every four years;
- co-ordinate WPNCS activities with other working groups within the NEA and in other international organisations to avoid duplication of activities; and
- provide a technical basis for the activities of other international organisations (e.g. International Organizations for Standardization (ISO), International Atomic Energy Agency (IAEA)).

Currently, the WPNCS co-ordinates 5 Expert Groups and the ICSBEP Project.

Dr. Rearden has been an active member of the WPNCS for the past decade. There are many technical initiatives of interest to NCSP within the WPNCS, including the development of advanced method for criticality safety validation and uncertainty quantification in the UACSA group, methods to more robustly apply Monte Carlo codes in the AMCT group. Additionally, data for the isotopic validation of spent nuclear fuel are provided in the SF-COMPO database maintained by the ADSNF group, and advanced techniques for performing burnup calculations are explored in the UNF group. Most of these group are attended by 20-40 members from 10-15 nations. An additional group on Criticality Excursion Analysis (CEA) is generally lightly attended with few active technical participants.

**Access to the information in this report is limited to those indicated  
on the distribution list and to U.S. Government Agencies and their Contractors.**

## **REPORT OF FOREIGN TRAVEL**

**Bradley T. Rearden  
Paris, France  
June 24, 2017 – July 1, 2017**

### **PURPOSE OF TRAVEL**

The purpose of the travel to Paris is to participate in the Organization for Economic Cooperation and Development (OECD) Working Party on Nuclear Criticality Safety (WPNCS) and its Expert Groups on Advanced Monte Carlo Techniques (AMCT), Uncertainty Analysis for Criticality Safety Assessment (UACSA), Assay Data for Spent Nuclear Fuel (ADSNF), and Used Nuclear Fuel (UNF).

#### **Report**

The OECD/WPNCS AMCT expert group is working to establish best practices for the application of advanced Monte Carlo simulations for criticality safety analysis. At this meeting, many code teams are represented, and this venue provides an excellent opportunity to share novel ideas and best practices. In addition to SCALE, this meeting included representatives from the MORET team at IRSN, the TRIPOLI team from CEA, the MONK/ANSWERS team from the UK, and the MCNP team from Los Alamos. Several teams presented evolving methods for Monte Carlo analysis, as outlined in the agenda provided below. ORNL is leading the Phase I benchmark to examine bias in Monte Carlo flux tallies, which are needed for reaction rate analysis as well as sensitivity analysis. Results compiled from several participants reveal that errors in the values of the tallies that exceed their reported uncertainties by an order of magnitude are possible in some regions of large fissile systems. Eric Dumonteil, the AMCT chairman, is compiling the results of this benchmark (which should conclude in the near future). Chris Perfetti presented promising results on a method that was effective at predicting the magnitude of undersampling biases for eigenvalue and flux estimates in Monte Carlo simulations.

The UACSA expert group, chaired by Brad Rearden, is working to apply advanced uncertainty analysis tools to improve confidence in criticality safety validation. This meeting focused on two sets of benchmark exercises:

- 1) The Phase IV benchmark is related to the quantification of correlation between sets of integral experiments that were performed using the same materials. Generally, two or more experiments generated with the same materials and measurement techniques are treated statistically in criticality safety assessment as independent measurements, where in reality the measurements are correlated to each and should not be treated as independent. The loss of independence reduces the statistical confidence in the criticality safety assessment and should lead to more conservative safety margins. Several approaches to quantifying correlations coefficients are being explored in the Phase IV benchmark, and some results have been presented in publications. A final report will be drafted in the coming months.
- 2) Phase V benchmark explores approaches to validation systems where few applicable benchmarks are available. CEA has provided a benchmark that includes idealistic scenarios could be encountered in the criticality safety assessment of mixed-oxide fuel fabrication facility, including both reactor grade and weapons grade plutonium vectors. In these scenarios, traditional

approaches to validation are generally inadequate, leading to the use of advanced approaches using sensitivity and uncertainty analysis methods. A few teams have generated initial results for this benchmark, with more evolving in the coming months.

This meeting attracted a wide range of participants from the U.S., U.K., Sweden, France, Germany, Japan, Korea, Slovakia, Poland, Russia, and others. Three teams presented results for the Phase IV benchmark on the quantification of experimental correlations, including ORNL's work performed by B.J. Marshall and presented by Brad Rearden. Five teams presented results for the Phase V benchmark (criticality safety assessment for MOX powder systems), including Chris Perfetti. Multiple Phase V benchmark teams independently pursued similar methods (data assimilation methods) for estimating the bias in the MOX powder systems, and the Chris Perfetti's work explored approaches to improve the confidence and rigor of these methods.

WPNCS committee consists of the elected country representatives with United States representatives Cecil Parks (ORNL) and Mikey Brady-Raap (PNNL – retired) as well as the chairs of the expert groups, which include Brad Rearden (ORNL – UACSA group), Ian Gauld (ORNL – ADSNF group), and John Bess (INL – ICSBEP). Neither Cecil Parks nor Mikey Brady-Raap were in attendance at this meeting, and John Bess sent Margaret Marshall as a substitute. The WPNCS meets in a closed-door session to discuss organizational issues related to the Working Party and each nation presents a County Report on that status of activities in their nation. The U.S. Country Report that was generated by the U.S. team is attached.

A significant restructuring that we discussed a length through the meetings is the conversion from longer running Expert Group with broader technical scope (e.g. the UACSA group is now working on a Phase V benchmark) to more targeted Sub-Groups with a narrower focus. Each sub-group would complete a single benchmark, then reorganize with an updated mandate. This new structure was met with mixed reviews, but will likely be implemented in the coming months.

The participation by ORNL and LANL ensure that NCSP Analytical Methods interests are represented in the international community. In addition, the technical information exchange will be used to improve the NCSP SCALE analytical methods to support nuclear criticality safety analyses.

A detailed agenda for the AMCT and UACSA meetings is given below.

### **Itinerary**

June 24, 2017 - Depart Knoxville

June 25, 2017 - Arrive Paris

June 26-30, 2017 – Attend OECD Nuclear Energy Agency (NEA) Working Party Nuclear Criticality Safety (WPNCS) and Expert Group Meetings

July 1, 2017 – Return to Knoxville

## **DISTRIBUTION**

1. Doug G. Bowen ([bowendg@ornl.gov](mailto:bowendg@ornl.gov))
2. Angela Chambers ([angela.chambers@nnsa.doe.gov](mailto:angela.chambers@nnsa.doe.gov))
3. Lori Scott ([Lorisc0tt@aol.com](mailto:Lorisc0tt@aol.com))
4. Kenneth W. Tobin, Jr. ([tobinkwjr@ornl.gov](mailto:tobinkwjr@ornl.gov))

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee  
Working Party on Nuclear Criticality Safety

**11<sup>th</sup> Meeting of the Expert Group on  
Assay Data of Spent Nuclear Fuel (EGADSNF)**

**MONDAY 26 JUNE 2017**

OECD NEA Headquarters (Room BB1)  
46 Quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

**PROPOSED AGENDA**

*Meeting Schedule:*  
*14h30 – 18h00*

- |  |                         |
|--|-------------------------|
| 1. Welcome   | <i>Chair</i>            |
| 2. Administrative  | <i>Secretariat</i>      |
| • Approval of the agenda                                   |                         |
| • Approval of the summary record from the previous meeting |                         |
| • Review of Actions  |                         |
| 3. Short overview of progress during the mandate           | <i>I. Gauld</i>         |
| 4. Status of SFCOMPO-2.0 release                           | <i>F. Michel-Sendis</i> |
| • SFCOMPO-2.0 reference publication                        |                         |
| 5. General presentations                                   | <i>K. Govers</i>        |
| • Update on REGAL  |                         |
| 6. Renewal of the mandate of the EG                        | <i>All</i>              |
| • Prioritization of activities for the future mandate      | <i>I. Gauld</i>         |
| • Proposal for a new WPNCS structure                       | <i>F. Michel-Sendis</i> |
| 7. Any Other Business                                      | <i>Secretariat</i>      |
| • Future transition of chairmanship of the EG              |                         |
| 8. Date and place of the next meeting                      | <i>Secretariat</i>      |
| 9. Adjourn   | <i>Chair</i>            |

***A short reception cocktail will follow to mark the official release of SFCOMPO-2.0.***

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee  
Working Party on Nuclear Criticality Safety

**3<sup>rd</sup> Meeting of the Expert Group on  
Used Nuclear Fuel Criticality (EGUNF)**

**TUESDAY 27 JUNE 2017**

OECD NEA Headquarters (Room BB1)  
46 Quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

**PROPOSED AGENDA**

*Meeting Schedule:*  
*9h00 – 17h00*

- |  |                         |
|--|-------------------------|
| 1. Welcome   | <i>Chair</i>            |
| 2. Administrative  | <i>Secretariat</i>      |
| • Approval of the agenda   |                         |
| • Approval of the summary record from the previous meeting         |                         |
| • Review of Actions  |                         |
| 3. Phase II Benchmark ( <i>Gd-bearing BWR fuel pin depletion</i> ) |                         |
| • Results by GRS, Germany  | <i>F. Sommer</i>        |
| • Results for Depletion of Gadolinium-Bearing Fuel Rods            | <i>G. Kim</i>           |
| • Status of benchmark compilation by ORNL                          | <i>(I. Gauld)</i>       |
| 4. General Presentations   |                         |
| • Criticality of damaged fuel                                      | <i>V. Chrapciak</i>     |
| • SF Pools under Loss-of-Cooling and LOCA conditions               | <i>L. Jutier</i>        |
| 5. Renewal of the mandate for the EG                               | <i>F. Michel-Sendis</i> |
| • Proposal for a new WPNCS structure                               |                         |
| 6. Any other business  | <i>All</i>              |
| • Future chairmanship of EG  |                         |
| 7. Date and place of the next meeting                              | <i>Secretariat</i>      |
| 8. Adjourn   | <i>Chair</i>            |

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee  
Working Party on Nuclear Criticality Safety

**6<sup>th</sup> Meeting of the Expert Group on  
Advanced Monte Carlo Techniques for Criticality Safety Assessment (EGAMCT)**

**WEDNESDAY 28 JUNE 2017**

OECD NEA Headquarters (Room BB1)  
46 Quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

**PROPOSED AGENDA**

*9h30 – 17h00*

1. Welcome	<i>Chair</i>
2. Administrative	<i>Secretariat/All</i>
• Approval of the agenda	
• Approval of the summary record from the previous meeting	
• Review of Actions	
3. Benchmark Phase I	<i>E. Dumonteil</i>
• Status of final report	
• UK undersampling benchmark	<i>P. Smith</i>
4. Technical Presentations	
• Bias on local tallies	<i>E. Dumonteil</i>
• MCNP Status	<i>F. Brown</i>
• Convergence in infinite rod + Extrapolation length influence	<i>D. Mennerdahl</i>
• A survey of neutron clustering	<i>A. Zoia</i>
• Continued investigation of metrics to detect undersampling biases	<i>C. Perfetti</i>
• Status of MONK	<i>P. Smith</i>
5. Discussion	<i>All</i>
6. Renewal of the mandate of the EG	<i>Secretariat</i>
• A proposed new structure for the WPNCS?	
7. Any other business	<i>Secretariat</i>
8. Date and place of the next meeting	<i>Secretariat</i>
9. Adjourn	<i>Chair</i>

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee  
Working Party on Nuclear Criticality Safety

**12<sup>th</sup> Meeting of the Expert Group on  
Uncertainty Analysis for Criticality Safety Assessment (EGUACSA)**

THURSDAY 29 JUNE 2017

*OECD Headquarters (Room CC12)  
2 rue André-Pascal, 75016 Paris, France*

**PROPOSED AGENDA**

*Meeting Schedule:  
9h00 – 18h00*

1. Welcome	<i>Chair</i>
2. Administrative	<i>Secretariat/All</i>
• Approval of the agenda	
• Approval of the summary record from the previous meeting	
• Review of Actions	
3. Benchmark Phase IV on establishment of experimental correlations	
• Final report on UACSA Benchmark Phase IV	<i>A. Hoefer</i>
• ORNL results	<i>(TBC)</i>
• MONK results for Phase IV	<i>P. Smith</i>
4. Benchmark Phase V on criticality blind benchmark of MOX damp powders	
• Status of benchmark progress	<i>A. Santamarina</i>
• IRSN presentation on ongoing calculations	<i>I. Duhamel</i>
• ORNL benchmark results	<i>C. Perfetti</i>
5. Technical Presentations	
• Progress on ICSBEP Correlations between benchmarks	<i>I. Hill</i>
• A vision of BEPU type CSE as reflection of the progress in EGUACSA activities	<i>A. Vasiliev</i>
• Convergence of MC-generated correlation coefficients	<i>M. Stuke</i>
• Bias estimation tool/activities at IRSN	<i>A. Jinaphanh/N. Leclaire</i>
6. Discussion on future activities of EGUACSA	<i>All</i>
7. Any other business	<i>Secretariat</i>
• Request for renewal of the mandate of the EG	
• Date and place of the next meeting	
8. Adjourn	<i>Chair</i>

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee

**21<sup>st</sup> Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)**

**FRIDAY 30 JUNE 2017**

OECD NEA Headquarters (Room BB1)  
46, quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

**PROPOSED AGENDA**

*Meeting Schedule:*  
*9h00 – 17h00*

1. Welcome	<i>Chair</i>
2. Administrative	<i>Secretariat/All</i>
• Approval of the agenda	
• Approval of the summary record from the previous meeting	
• Review of Actions from the previous meetings	
3. Transition of WPNCS chairmanship	<i>Secretariat</i>
4. Feedback from the Nuclear Science Committee Meeting	<i>T. Ivanova</i>
5. Discussion	
• The future of the WPNCS, proposed new sub group structure	<i>F. Michel-Sendis</i>
6. Reports from the WPNCS Expert Groups and extension of mandates	
• Advanced Monte Carlo Techniques Expert Group (EGAMCT)	<i>E. Dumonteil</i>
• Assay Data for Spent Nuclear Fuel Expert Group (EGADSNF)	<i>I. Gauld</i>
• Criticality Excursions Analyses Expert Group (EGCEA)	<i>(TBD)</i>
• Uncertainty Analyses for Criticality Safety Assessment (EGUACSA)	<i>B. Rearden</i>
• Used Nuclear Fuel Criticality (EGUNF)	<i>K. Suyama</i>
• International Criticality Safety Benchmark Evaluation Project (ICSBEP)	<i>M. Marshall</i>
6. Feedback from a UK WPNCS request: thermal scattering data for ice (H <sub>2</sub> O)	<i>O. Cabellos</i>
7. Updates on Nuclear Criticality Safety National Programmes	<i>All</i>
8. Any other business	<i>Chair</i>
9. Date and place of the next meeting	<i>Secretariat</i>
10. Adjourn	<i>Chair</i>

## **US Country Report to the OECD-NEA Working Party on Nuclear Criticality Safety (NCS)**

30 June 2017

### National Context

The United States has fissile material operations involving all portions of the nuclear fuel cycle. Research in the area of advanced reactor concepts continues to investigate use of fuel with >5wt% enrichments, in the area of industrial and government activities the focus is on production and fabrication of reactor fuel with enrichments <5wt%, and a growing interest in metallic fueled fast reactors, liquid fueled molten salt reactors, fluoride salt-cooled high temperature reactors, and high temperature gas reactors. As the industry grows and develops, many criticality safety issues on the front end and back end of the fuel cycle will need to be addressed. Delays in the MOX fuel fabrication plant (caused by funding and design/construction challenges) have limited the need for attention to criticality safety issues involving transport or storage of MOX fuel.

The current fiscal year 2018 budget request includes substantial funding to restart studies for the spent fuel repository site at Yucca Mountain, with indications from congress that this initiative will be supported. In the past year, the NRC received an application for a Consolidated Interim Storage Facility (CISF) in Andrews County, Texas from Waste Control Specialist. Staff performed acceptance reviews and issued a number of Request for Supplemental Information (RSI). The applicant responded to most RSIs. However, the applicant has requested the review to be placed on hold. The NRC received a second application for an interim storage facility from Holtec International in March of 2017. The application is currently under acceptance review. Final repository options and overall storage, transport, and disposal systems are being studied by DOE to provide the technical information for future decisions regarding the back end of the fuel cycle.

The DOE, including its autonomous National Nuclear Security Administration (NNSA), and the NRC each have responsibility for providing regulatory oversight on criticality safety – DOE for operations within the DOE complex and NRC for industry operations. The American Nuclear Society (ANS) is the US professional organization that works to develop consensus standards for criticality safety and organize technical meetings on criticality safety. Each of these organizations develops, sponsors, or supports training classes and workshops to support education and knowledge exchange in the field of criticality safety. The number of universities offering classes and degree certificates focused on criticality safety has risen over the last few years.

### R&D Programmes

The DOE and NRC both support research activities in the area of nuclear criticality safety. The DOE Nuclear Criticality Safety Program (NCSP) has provided a central focus for research and technology development for over 15 years. The DOE NCSP (see <http://ncsp.llnl.gov/>) has five elements: Integral Experiments, Analytical Methods, Nuclear Data, Information Preservation and Dissemination, and Training and Education. Integral experiments (and hands-on training classes) are conducted at the Nuclear Criticality Experiments Research Center (NCERC) and at Sandia National Laboratories (SNL). Experiments at NCERC are conducted by Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL).

All four critical experiment machines at NCERC (Planet, Godiva, Comet, and Flattop) are available, and the facility operates as a user facility to help meet national and international program needs. Operations with the Godiva pulse reactor were restarted in Dec. 2015.

The NCSP has conducted “hands-on” critical experiment training classes at NCERC during the past year.

Specifically, the NCSP conducted three 2-week training class for NCS practitioners since February 2016. The 2-week classes include one week of classroom training at the Nevada Field Office in Las Vegas, NV, followed by one week of hands-on critical experiment training at either SNL or NCERC. In addition, the NCSP conducted 1-week hands-on critical experiment training classes for regulators, managers, and operations professionals who need to understand the fundamentals of nuclear criticality safety. A 1-week manager's course was conducted at SNL in January 2017 and at NCERC in June 2017. Since establishing the NCSP hands-on training courses in 2011, over 250 students have taken the NCS hands-on training course.

With regard to information preservation and dissemination, the NCSP in collaboration with CEA completed the benchmark evaluation of the second and third of three pulsed SILENE experiments that were performed in 2010. The benchmark evaluations were published in the 2016 edition of the ICSBEP Handbook. The first experiment was previously published in the 2015 edition of the Handbook. In addition, the NCSP completed the LEU-COMP-THERM-097 benchmark for Ti/Al rods in a UO<sub>2</sub> Lattice array, and this evaluation was published in the 2016 edition of the ICSBEP Handbook. A revision was issued for the nickel reflected plutonium ball evaluation that was first published in 2015. A new evaluation was published for the tungsten reflected plutonium sphere subcritical measurements.

Integral experiment research over the last year has included: a nuclear accident dosimetry exercise using Godiva, the final design of the TEX-Hafnium experiments, design work for experiments on the plutonium sphere at NCERC using composite CH<sub>2</sub>/Ni reflector, validation of analytical methods with MC-15 measurements, the performance of the Subcritical Copper-Reflected  $\alpha$ -phase Plutonium (SCR $\alpha$ P) experiments, development of neutron multiplication measurement protocol, work on the Kilowatt Reactor Using Stirling Technology (KRUSTY) experiments, work with the Flattop experiment assembly at NCERC, design of experiments to study the critical effects of plutonium aging, and design of titanium sleeve experiments in the BUCCX reactor at Sandia.

With regard to Analytical Methods, MCNP and SCALE are key codes used for criticality safety within the DOE complex and are supported by the NCSP, with nuclear data libraries generated by NJOY and AMPX. A key area of development has been sensitivity/uncertainty methods using continuous energy data and investigating advanced validation methods. The multi-laboratory Nuclear Data Advisory Group (NDAG) prioritizes nuclear data measurements and evaluations supported by the NCSP and coordinates NCSP activities with the US National Nuclear Data Center to assure inclusion in the Evaluated Nuclear Data Files (ENDF). Funding to help support processing of ENDF data for the criticality safety codes is also provided by the NCSP and production ENDF/B-VII.1 libraries with expanded cross section covariance data are available for the key NCS analyses code packages. The ENDF/B-VIII library is in beta release with many new features including expanded thermal scattering data for reactor grade graphite and pyrolytic carbon needed for advanced reactors as well as water in ice form to temperatures below -40°C as requested by International Atomic Energy Agency transportation guidelines.

The SCALE and MCNP teams both provided training classes to US and international participants. SCALE offers two weeks of training classes on criticality safety and uncertainty analysis methods at the OECD NEA as well as a week of training on spent fuel characterization at the National Research Nuclear University MEPhI (<https://eng.mephi.ru>) under NEA sponsorship. The MCNP and SCALE codes continue to be highly regarded Monte Carlo codes. SCALE is one of the most highly requested codes from the NEA Data Bank, with distributions to over 2000 Data Bank members over the past decade.

In the Nuclear Data program element, prioritized nuclear data measurements and evaluations continue to be performed to support NCS operations in the US. During the past year, new differential measurements have been performed on natural V and Zr samples. Also, substantial progress has been made to expand the RPI linear accelerator neutron capture measurement capabilities into the keV range that is important

for many nuclei pertinent to criticality safety. Furthermore, the NCSP has partnered with NNSA Naval Reactors to invest in an accelerator refurbishment effort at RPI to ensure the US has a differential data measurement capability for performing needed cross-section measurements. With regard to new cross-section evaluation work, the NCSP has completed new resonance region evaluations for  $^{63,65}\text{Cu}$ ,  $^{56}\text{Fe}$ ,  $^{16}\text{O}$ , and  $^{182,183,184,186}\text{W}$ . These new evaluations are undergoing testing and are expected to be available with the next release of the ENDF data library. A new initiative known as the Interagency Nuclear Data Working Group recently coordinated multi-faceted funding opportunity announcement for new nuclear data evaluations to support a number of priority programmatic needs for the DOE Office of Nuclear Physics, Isotope Program, Office of Nuclear Energy, NNSA/Defense Nuclear Nonproliferation Research and Development, Department of Homeland Security, and Domestic Nuclear Detection Office. It is hoped that substantial new initiatives will provide many updated nuclear data evaluations with high quality uncertainties will become available to the community.

NRC continues its support for research focused on use of Burnup Credit in designing criticality control systems for BWR spent fuel storage casks and transportation packages. The first phase of research which was focused on BWR peak reactivity was completed by issuing a NUREG report. The second phase of the research, which is examining beyond peak reactivity, is currently underway and is planned to be completed next year. BWR research is being driven primarily by loss of geometry concerns of storing high burnup fuels and the planned extension of fuel storage time limits beyond 20 years.

#### International Collaborations

The NNSA continues to interact with AWE in the UK and CEA and IRSN in France to identify and collaborate on nuclear criticality safety issues of mutual interest, such as integral experiments, computational methods, and improved nuclear data. During the past year, the collaborations have resulted in personnel from the US performing collaborative work at IRSN, CEA, and AWE. Likewise personnel from AWE and IRSN have visited the US to perform collaborative work tasks at NCSP sites. Within the DOE NCSP, ORNL and IRMM collaborate to perform neutron cross-section measurements in the resonance region to address differential data needs identified as important to improvement of nuclear criticality safety analyses.

Under OECD/NEA WPEC, US National Laboratories are working with other international partners on the CIELO (Collaborative International Evaluated Library Organization) to improve nuclear evaluations, many of which support improved evaluations for nuclear criticality safety. Specifically, the CIELO collaboration has focused efforts on completing new evaluations for  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{239}\text{Pu}$ ,  $^{56}\text{Fe}$ , and  $^{16}\text{O}$ .

In addition, the NCSP provides support for the US participation in the ICSBEP. Additionally, the DOE Office of Nuclear Energy Advanced Modeling and Simulation (NEAMS) program provides support for the US leadership of the ICSBEP.

#### Future Challenges

Organizations face a continuing challenge to maintain a fully compliant criticality safety program with qualified personnel experienced in both the principles of criticality safety and the fissile material operations, with the need for planning to support the needs of the advanced reactor community. In addition, a challenge is related to succession planning for key staff expertise needed to support NCS. To meet this challenge, the NCSP is continuing to invest in succession planning for key NCS technology capabilities that include specialists in integral experiments, nuclear data, and analytical methods.

Holdup residues can contribute significantly to the inventory of nuclear material within process equipment and, at any time, can represent the largest portion of inventory uncertainty. As such, these

residues can challenge assumptions and limits needed for nuclear criticality safety. The NNSA has initiated work to establish a safety-related *in situ* nondestructive assay (NDA) program to manage and direct research and development (R&D) tasks needed to improve NDA capabilities for quantifying nuclear material holdup. A mission and vision document for the NDA technology program is in development and should be published in the coming year.

#### Input to/from NEA NSC Programmes of Work

The U.S. continues to engage in each of the Expert Groups of the Working Party on Nuclear Criticality Safety as well as in other NEA working parties. US participants are actively engaged or are leading activities within the Nuclear Science Committee WPNCS. The US leadership is provided for the WPNCS Expert Group and Assay Data for Spent Nuclear Fuel, with the SFCOMPO-2.0 release occurring during this meeting. US leadership is also provided for the Expert Group on Uncertainty Analysis for Criticality Safety Assessment. Involvement in other NSC activities include: Working Party on International Nuclear Data Evaluation Co-operation (WPEC), Working Party on Reactor Systems (WPRS), [Expert Group on Improvement of Integral Experiments Data for Minor Actinide Management \(EGIEMAM-II\)](#), [Expert Group on Accident Tolerant Fuels for Light Water Reactors \(EGATFL\)](#), [The Working Party on Scientific Issues of the Fuel Cycle \(WPFC\)](#), [Expert Group on Multi-physics Experimental Data, Benchmarks and Validation \(EGMPEBV\)](#), and WPEC Subgroups: 44 on [Investigation of Covariance Data in General Purpose Nuclear Data Libraries](#), 45 on [Validation of Nuclear Data Libraries \(VaNDaL\) Project](#), and 46 on [Efficient and Effective Use of Integral Experiments for Nuclear Data Validation](#). Additionally, the US engages with the activities of [Committee on the Safety of Nuclear Installations \(CSNI\)](#) not listed here. These engagements are sponsored by numerous agencies, but the DOE/NNSA or NRC are the primary sponsor of the participants and their contributions.