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NUCLEAR ENERGY AGENCY
NUCLEAR SCIENCE COMMITTEE

Working Party on Nuclear Criticality Safety

23rd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

Summary Record

27 September 2019
NEA Headquarters, Boulogne-Billancourt, France

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OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee

23rd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

FRIDAY 27 SEPTEMBER 2019

OECD NEA Headquarters (Room BB2)

46, quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

1. Introduction and Welcome

The Chair, Stéphane Evo (IRSN) opened the meeting, welcomed the participants, who briefly introduced themselves. The meeting was attended by thirty-two participants from Belgium, Canada, Finland, France, Germany, Japan, Russia, Spain, Sweden, Switzerland, the UK and the US (see participant list in *Annex A*).

2. Administrative

The proposed agenda (*Annex B*) and summary record of the previous meeting were approved without any modification.

3. Feedback from the Nuclear Science Committee Meeting

T. Ivanova (Head of Division of Nuclear Science) reported the progress and future directions in Nuclear Science since last WPNCS meeting. The ongoing NEA internal discussion of restructuring organisation was introduced. It was emphasized that this opportunity must be taken positively for increasing productivity of the long-lasting organisations, though this happened due to the recent tight financial problems in NEA.

To facilitate the continued evolution of fuel and materials technology, after closing of Halden reactor project, NEA has launched a new multinational framework for in-pile fuels and material testing: Framework for IrraDiation ExperimentS (FIDES). The main objective of FIDES is to strengthen fuel- and material-related experimental capabilities for the benefit of a broad community of users and a core aspect is to develop a coordinated approach for performing key experiments using facilities around the world through Joint Experimental Programmes (JEEPs).

Joint bureau meeting with the Committee on the Safety of Nuclear Installations (CSNI) will be held in December 2019 in regards with the cross-cutting issues of criticality safety.

Finally, the update of official delegates list on the NEA working area was requested to the participants.

4. Reports from Sub-Groups

SG-1: Role of Integral Experiment Uncertainties and Covariance Data in Criticality Safety Validation

The co-ordinator, M. Stuke (GRS), reported the current status and the presentation of this Sub-Group activity in ICNC2019. The draft EGUACSA Phase IV benchmark report was discussed and finally approved for publication. To shorten the time line for publication in NEA, it was proposed that the report should be divided in two parts; main results and appendices from each benchmark participants. NEA secretariat explained the publication process and current condition in NEA, and decided to investigate the way to publish the report as soon as possible.

Information of the correlation-coefficients data from participants was regarded as a good start to feedback to ICSBEP, instead of publication of the state-of-the-art report. It was decided that A. Hoefer (Framatome), W. Marshal (ORNL), D. Mennerdahl (EMS), P. Smith (Wood), and F. Sommer (GRS) voluntarily prepared short paragraphs based on their own information of correlation-coefficients, and send them to Co-ordinator / NEA secretariat. Co-ordinator would integrate the paragraphs and send to all and to J. Bess, the chair of ICSBEP.

A. Hoefer (Framatome) made a new Sub-Group proposal as a follow-up activity of SG-1. It was decided that the proposal would be submitted to WPNCS in 2020.

SG-2: Blind benchmark on MOX damp powders

After the overview of the technical track on sensitivity/uncertainty analyses in ICNC2019, C. Carmouze (CEA) presented the draft report of the Phase V benchmark of the former EGUACSA. Some sections were remained to be unfilled but the calculation results for this report have been fully collected. It was agreed that C. Carmouze would distribute the 1st draft to the participants by end of October 2019, and comments would be received by end of January 2020. The report would be approved at the next meeting in July 2020.

SG-3: The effect of temperature on the neutron multiplication factor for PWR fuel assemblies

S. Gan (SELLAFIED) chaired the final meeting of SG-3 activity. This Sub-Group activity was also presented in ICNC2019. The draft report had been distributed to the participants in advance. In the comparison of the benchmark data, some remarkable difference were found and discussed regarding the results using the JENDL-4.0 nuclear data library. For further improvement of the report, it was decided to receive comments or revise data by end of January 2020. The final approval would be in June 2020.

SG-4: Analysis of Past Criticality Accident

Y. Yamane (JAEA) reported the current activity of SG-3 and some technical presentations were done. Participants had been asked to select one or more cases from JCO, Windscale, and Y-12 accidents, and estimate number of fissions, peak power, profile of power and temperature. However, there were limited participations only from JAEA and Wood. Therefore it was agreed that Co-ordinator would ask M. Eaton (Imperial College London) about his group’s participation to the calculation. It was also agreed that comparisons of calculation results using different method/code would be performed only for the cases of the JCO accident.

Y. Yamane presented the major results of the former EGCEA Phase-II draft report, which had been distributed to the members in advance of the meeting. Finally it was determined that the benchmark results from five codes (AGNES, CRITEX, INCTAC, TRACE, and FETCH) would be reported in this report. It was agreed that P. Smith would manage to send the FETCH calculation results by 25 December 2019. The COMSOL results were expected last meeting, however, the results had not been received by Y. Yamane / NEA secretariat by this meeting. Y. Yamane asked participants to send the input files by 1 November 2019.

SG-5: Experimental needs for criticality safety purpose

I. Duhamel (IRSN) reported the current status and the results of the survey that had been done before the meeting. The results were received from 8 organizations, 5 countries (US, Japan, France, Canada, Czech Republic), 20 Forms (+ 5 sent before the meeting, which need to be completed), and 2 Mails describing briefly the needs. The results showed that the requested integral experiments are highly related to low temperature experiments, chlorine effects, experiments in intermediate energy spectra, structural materials in whole energy range, thermal scattering laws validation, and criticality accidents. The request of one-year extension of this SG was approved at the WPNCS meeting.

SG-6: Statistical tests for diagnosing fission source convergence and undersampling in Monte Carlo criticality calculations

F. Brown (LANL) presented the current status of SG-6 activity by showing the presentation in ICNC2019. Timeline of the final report was shown. The 1st draft report would be distributed to the members by end of 2019 and F. Brown/NEA secretariat would wait for comments by end of March 2020, to finalise the report at the next meeting in July 2020. By using the mailing list of SG-6, frequent communication will be taken among the members.

C. Larmier (CEA) made a new SG proposal, on behalf of A. Zoia, and presented "Transport in random media", regarding neutron transport calculation in heterogeneous materials. A. Zoia and C. Larmier have been developing the method using the TRIPOLI code. K. Tonoike (JAEA) showed his strong interest on the new subgroup and proposed to determine the benchmark specification. In addition to JAEA – Salomon code, Wood – MONK code, ORNL – SCALE & MCNP groups will participate, but the problem could be that methods of modelling and capable geometry settings are different among the codes. It was determined therefore among the participants that the proposal would be postponed until next WPNCS meeting in 2020 while the preparation among the potential participants regarding benchmark specification should be proceeded. NEA secretariat will submit the proposal sheet of this new SG to WPNCS, as soon as it is formalized.

SG-7: On the definition of a benchmark on sensitivity/uncertainty analysis on used fuel inventory

C. Carmouze (CEA) and L. Jutier (IRSN) presented the survey results of 50 responses from 19 countries. It was found that PWR-UOx (95%) with higher burnup (45 GWd/T (48%)) is found to be of high interest among the respondents. Based on these results, ARIANE GU3 sample was proposed to be selected as an experimental case from the SFCOMPO 2.0 database. The benchmark specifications would be determined and shared among the participants by end of 2019.

The draft report of this survey was presented and it was agreed that the 1st draft would be distributed to the participants by end of October 2019.

A new activity based on this benchmark specifications that would be determined by SG-7 was presented and discussed among the participants with its timeline. It was proposed to be split into sequential sub-groups from 2020, considering the short span under the Sub-Group system. A new proposal sheet should be circulated from March 2020.

5. Reports from the technical review groups

International Criticality Safety Benchmark Evaluation Project (ICSBEP)

J. Bess (INL) reported the progress made on the ICSBEP database. The latest 2019 edition, released in October 2019, contains 10 revised evaluations and 5 new evaluations (LEU-COMP-THERM-99, LEU-COMP-THERM-103, LEU-COMP-THERM-104, FUND-NCERC-PU-HE3-MULT-003, and FUND-LLNL-ALPHAN-U235-MULT-001). The annual ICSBEP & IRPhEP TRG meetings are planned to be held on 21-25 October2019 at the NEA headquarters.

SFCOMPO Technical Review Group (SFCOMPO TRG)

G. Ilas (ORNL) reported the current status. The kick-off meeting of technical review group was held in March 2019 and the next SFCOMPO TRG meeting will be held in the same week of the WPNCS meetings, to collect more attention from the participants of the WPNCS meetings.

6. Updates on Nuclear Criticality Safety National Programmes

Delegates from Canada, Finland, France, Germany, Japan, Russia, Sweden, Switzerland, the UK, and the US made country reports. The written reports received are included in *Annex C*.

7. ICNC

S. Evo (IRSN) reviewed the eleventh edition of the International Conference on Nuclear Criticality safety (ICNC), organized by the French Institute for Radiological Protection and Nuclear Safety (IRSN) under the auspices of the Nuclear Energy Agency of OECD. The summary of each technical track is shown in *Annex D*.

K. Tonoike (JAEA) presented the next ICNC, ICNC2023, as a representative of host country, and WPNCS endorsed this plan. This will be sent to the NEC bureau meeting in Jan. 2020 for approval. Though the venue has not been finally determined yet, it was announced that ICNC2023 would be held in Sendai in October 2023.

8. Other business

C. Percher (LLNL) announced the ANS meeting on 12-16 June 2020 at Anaheim (US).

W. Wieselquist (ORNL) presented a proposal for a new subgroup “Preservation of Expert Knowledge and Judgement Applied to Criticality Benchmarks”. The objective of this activity is to develop a methodology for collecting and disseminating feedback on evaluations from qualified experts to better serve users of the ICSBEP benchmarks. WPNCS members accepted this proposal.

9. Date of Next Meeting

The next meeting will be held on 6-10 July 2020, in the same week of the technical review group meeting of SFCOMPO.

10. List of Actions

During the meeting it was agreed that:

- I. Duhamel to share the information of the high-priority list in WPEC to the members (**Action from 22nd WPNCS**);
- NEA secretariat to send current list of NSC/WPNCS delegations on the “delegation area“ to all;
- All to send updated list of NSC/WPNCS delegations to S.Evo/NEA secretariat;
- D. Heinrichs to share the articles with S. Evo/NEA secretariat (Done, during the meeting);
- NEA secretariat to distribute the new SG proposal not only to SG-6, also WPNCS members;
- NEA secretariat to inform the dates of WPEC/SG-46 to all;

ANNEX A

Participant list

23rd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

FRIDAY 27 SEPTEMBER 2019

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ANNEX B

OECD NUCLEAR ENERGY AGENCY

Nuclear Science Committee

23rd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

FRIDAY 27 SEPTEMBER 2019

OECD NEA Headquarters (Room BB2)

46, quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

PROPOSED AGENDA

Meeting Schedule:

9h00 – 18h00

1. Welcome	Chair
2. Administrative	Secretariat/All
• Approval of the agenda	
• Approval of the summary record from the previous meeting	
• Review of Actions from the previous meetings	
3. Feedback from the Nuclear Science Committee Meeting	T. Ivanova
4. Reports from Sub-Groups	
• Role of Integral Experiment Uncertainties and Covariance Data in Criticality Safety Validation (SG-1)	M. Stuke
• Blind benchmark on MOX damp powders (SG-2)	C. Carmouze
The effect of temperature on the neutron multiplication factor for PWR fuel assemblies (SG-3)	S. Gan
• Analysis of Past Criticality Accident (SG-4)	Y. Yamane
• Experimental needs for criticality safety purpose (SG-5)	I. Duhamel
• Statistical tests for diagnosing fission source convergence and undersampling in Monte Carlo criticality calculations (SG-6)	F. Brown
• On the definition of a benchmark on sensitivity/uncertainty analysis on used fuel inventory (SG-7)	C. Carmouze

5. Reports from the technical review groups	
• Status of the ICSBEP - September 2019	J. Bess
• SFCOMPO TRG	G. Ilas (via WebEx)
6. Updates on Nuclear Criticality Safety National Programmes	All
7. ICNC	
• Report and feedback from ICNC 2019	S. Evo
• Introduction of ICNC2023	K. Tonoike
8. Any other business	Chair
9. Date and place of the next meeting	Secretariat
10. Adjourn	Chair

ANNEX C

Country Reports on Nuclear Criticality Safety National Programmes

1. France

1.1 National Context (Overview)

- Two major reports have been ratified by the French Government charting the French Energy Strategy:
  - The French Government Energy Strategy (PPE) is a multiannual energy plan stating the 50% share of nuclear power in the electricity mix by 2035 (the current share is about 72%) and maintaining the current reprocessing strategy and recycling of nuclear fuel until the 2040's horizon.
  - The Strategy Policy for Nuclear Industry (CSFN) places the nuclear fuel recycling as key element of French Strategy for ensuring the sustainability of Nuclear Energy and conceives the *"Nuclear Plant of the Future"* initiated by EDF, CEA and Framatome and development of the Small Modular Reactor technology.

- The French government has decided to stop the ASTRID project (Sodium Fast neutron Reactor demonstrator)

- In 2020, the 2 PWR of the oldest French NPP, at Fessenheim, will close as a consequence of the French Government Energy Strategy.

- The Jules Horowitz reactor (Research reactor of 100 MWth) project continuation has been endorsed by the French government in May 2019.

- The MASURCA mock-up facility (for fast breeder reactor studies at CEA, Cadarache) shut down in December 2018.

-The periodic safety review of "major" French fuel cycle facilities:
  - La Hague reprocessing plant : improvements in terms of Nuclear Criticality Safety and Improvements regarding maintenance operations (with NCS concerns)
  - UOx Fuel fabrication plant of Romans-sur-Isère
  - Several CEA labs
  - HFR reactor under periodic review

- Regarding burnup credit activities, Orano TN implemented burnup credit not only with the major actinides but also with some fission products for spent fuel transportation. For this purpose, ORANO TN validates of the criticality code by using the French HTC (high Burnup) and Fission Products experiments program. On this basis, the French certificate of approval of the TN 17 MAX was issued in October 2018.

There is no significant criticality event to report.

1.2 R&D Programmes, in particular:

- Release of the French criticality package, CRISTAL V2.0 (CEA, IRSN, Framatome, Orano) available at the NEA the databank since October 2018.

- MORET 5.D.1 (continuous energy Monte Carlo code developed by IRSN) is distributed by the NEA databank since May 2019.
- PRINCESS Project: PRINCESS is the practical implementation of IRSN's international partnership strategy to build relations with organizations that are equipped with experimental facilities for criticality safety and reactor physics research. The aim is to analyze experimental data from programs already performed and to conduct joint research programs on topics of interest for both parties.
- Revised R&D roadmap to implement and support French energy policy for low CO2 energy systems with a stepwise approach for a complete closure of fuel cycle (circular economy) with investigation of fuel multi-recycling in PWR:
  - Mid-term R&D stakes: Investigation of fuel multirecycling in PWR using MOX2 fuels (e.g. CORAIL assemblies with Pu recycling rods and enriched uranium rods or MIX assemblies with rods containing both).
  - Long term R&D stakes: R&D program for Generation IV reactors and closure of the fuel cycle, including sodium fast neutron reactors and corresponding cycle plants.

- Nuclear data and integral experiments at low temperature, PIE for fuel assemblies with burnable absorber at the reactivity peak, integral experiments for low-moderated fissile materials (MOX, UOX), covariance data for the propagation of nuclear data uncertainties, etc.

1.3 International Collaborations

- IRSN/DOE collaboration in the frame of the NCSP program of the US-DOE. IRSN contributes to different tasks relating to Analytical Methods, Nuclear data, and is particularly involved in some experimental programs with US national laboratories, as the TEX program, subcritical experiments, dosimetry in case of criticality accident, etc.
- IRSN collaborates with JAEA for the design of new experiments in the STACY facility.
- Participation in the ISO working group on NCS (ISO TC85/SC5/WG8).
- Participation in the IAEA TRANSSC Technical Expert Group on criticality
-CEA/IRSN/European collaboration on nuclear data evaluations, measures and validations through the recently accepted SANDA program.
-CEA/IRSN participation on IAEA INDEN project (following-up the CIELO project) network of nuclear data evaluators on the main isotopes U, Pu, Fe, O, Be, Ni, etc.

1.4 Future Challenges

- The development of new capabilities in the CRISTAL package and the release of a new version in 2020.
- In the long term, develop the capacity to model indefinite geometries. For example, this can be used to study the criticality risk associated with corium.

- The use of neutron noise techniques to measure criticality experiments or to better monitor subcritical systems.

1.5 Input to/from NEA/NSC Programmes of Work

France participates actively to all subgroups and TRGs of the WPNCS, WPRS, WPFC and WPEC. The 11th International Conference on Nuclear Criticality safety (ICNC 2019), organized by France, was held from 15 to 20 September 2019 in Paris at La cité des sciences et de l'industrie. Almost two hundred papers were presented and three hundred people attended the conference.

2. Germany

1. National Context

a. 1344 MWe BWR Gundremmingen B was permanently shut down after 33 years of operation. End of year 2019 NPP Phillipsburg (KKP-2) will be shut down.
b. All fuel has been permanently removed from BWR Brunsbüttel and PWRs Biblis B/C, Unterweser and Obrigheim. The spent fuel is dry-stored in dual-purpose casks.
c. Spent fuel shipped on river in Germany:
The transport of spent fuel casks with fuel elements from NPP Obrigheim to the interim storage facility at NPP Neckarwestheim on the Neckar river has been completed successfully.
d. Ownership of intermediate storage facilities Aahaus and Gorleben (HLW, ILW) and of the on-site intermediate storage facilities (besides Brunsbüttel) has been transferred to the federal state. Nearly all dry-stored HLW is now state-owned.
e. Transport and storage licenses for intermediate storage for GNS's integrated quiver system for PWR and BWR fuel was granted by the German Federal Office for the Safety of Nuclear Waste Management (Bundesamt für kerntechnische Entsorgungssicherheit/BfE). The first full loading campaigns were completed with the dispatch of PWR-quivers in the NPP Unterweser, Biblis and of BWR-quivers in Krümmel which means that the world's first handling of special fuel rods on the pool floor have been carried out successfully. The loading of the quivers was the prerequisite for the removal of all fuel from the above mentioned NPP.
f. On 17 January 2019 BfE issued the package design approval certificate for the transport and storage cask CASTOR® MTR3 as type B(U)F packaging. The cask was developed by GNS especially for spent fuel elements from research reactors.
g. In September 2019 BfE issued the package design approval certificate for the transport and storage cask CASTOR® V/52 as type B(U)F packaging for spent BWR fuel with FA-averaged burnups up to 80 GWd/t_{HM}.
h. ANF laboratory fire:
On 06.12.2018 a fire occurred at the Advanced Nuclear Fuels (ANF) laboratory in Lingen. An item of laboratory apparatus caught fire. The instrument was an evaporator. Such an evaporator serves to evaporate aqueous, non-flammable solutions, which are produced during laboratory operations. This is a common procedure in many industries for treating laboratories residues. The size of the evaporator is approximately 2 by 3 by 1 meter (HxWxD). A 40 by 40 cm part of the device had burnt by the time the emergency personnel arrived. Also at the time of the fire a small amount of uranium was present in the evaporator. There was no release of radioactive substances into the environment. This is confirmed by the measurements that were subsequently carried out. The laboratory concerned is located in the nuclear factory building, in a separate room from the nuclear production line.

2. Code Validation and Development:

a. GRS: The *Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety* supports under grant number 3617E03350 the R&D project entitled

"Development and assessment of methods for the validation of criticality calculations, taking into account correlations between critical experiments" (orig. title in german). The results of the project contribute to:

i) Improve the validation data basis for the assessment of criticality safety in transport authorization procedures for transport and storage containers;

ii) Identify possible sources of non-conservativities in the validation of computer programs for criticality safety;

ii) To make an effective contribution to the progress of the state of science and technology and the scientific debate;

iv) Further develop the validation for criticality assessment calculation programs.

In the project RS1542 of the Federal Ministry for Economic Affairs and Energy (BMWi) the burn-up and inventory codes MOTIVE and VENTINA are undergoing verification by extensive comparison with post irradiation exposure (PIE) data of irradiated nuclear fuel and benchmarks. Moreover, additional functionality will be added to the codes. This includes the introduction of predictor-corrector approaches, the coupling of an additional neutron transport code besides KENO-VI, the development of a tool for automated calculation of the fuel temperature from a given power, and the completion and automated creation of the nuclear data library needed for the calculations. Additionally, investigations in the field of burn-up specific uncertainty and sensitivity analysis will be carried out, including the continuation of the work on the integration of correlations in fission yields into the uncertainty analysis with XSUSA, participation in benchmarks on fast reactors and high temperature reactors as well as an evaluation of the TENDL nuclear data library for the use in MOTIVE/VENTINA.

In the project RS1552 (BREZL) of the Federal Ministry for Economic Affairs and Energy (BMWi) The behavior of fuel assemblies under long term dry storage conditions are investigated. The focus is put on theoretical description of fuel development, detailed temperature field predictions, and the thermo-mechanical behavior of the cladding. The investigations are performed for PWR fuel assemblies with assembly averaged burn-up values of 65 GWd/t_{HM}.

3. International Collaborations

a. GRS: Numerous bi- and multilateral cooperations with universities, research institutions, and TSO's.

4. Future Challenges

a. Criticality safety research for final disposal – site / host rock comparison;
b. Degraded fuel configurations (destructed assembly structures) under accident (SFP, transport) or disposal conditions;
c. Criticality safety of long term storage of used nuclear fuel, especially with FA-averaged burnups up to 80 GWd/(t HM)
d. Advanced criticality safety assessments of degraded fuel under accident scenarios
e. Transport and handling of spent fuel after long-term dry storage

3. Spain

1. National Update

Over the last year, no safety significant event or unusual occurrence has been reported regarding Nuclear Criticality Safety (NCS).

Transportation of high-burnup fuel is currently a licencing issue in Spain. An application was licensed for high-burnup fuel transportation in a PWR bare fuel cask where, for the first time in 2017, criticality safety analysis of reconfigured fuel have been performed to provide a defense-in-depth support to the cladding integrity methodology selected by the applicant. Two similar applications are in the licensing process, one for PWR and the other for BWR fuel, and discussions are on-going to make the decision on the design-basis or defense-in-depth acceptance criteria.

The on-going licensing process of the Centralized Temporary Storage (CTS), which accumulates long delays due to non-technical reasons, has been stalled by the Government until the current energy situation is analyzed and a new Nuclear Waste Management National Plan is issued, which was expected by 2019. This undefined delay has a great impact in the provisions of Interim Spent Fuel Storage Installations (ISFSI) requiring capacity increase and corresponding additional license renewals. The CTS generic design is based in a vault system, where the spent fuel and HLW, coming from the NPP sites ISFSIs around the country, will be unloaded from the transportation casks and encapsulated in stainless steel welded canisters specific to the facility. The canisters will be stored vertically in wells cooled by natural draft. The Prior Authorization was issued in 2015 and the final design of the facility canisters has recently been finished. A bounding NCS analysis for the different fuel designs stored (PWR 17x17, 16x16, 14x14, BWR 8x8, 9x9, 10x10) has been performed, assuming the canister is dry in all operating conditions and the fuel is fresh. Canister flooding has been analysed using BUC, as a Design Extension condition of the facility. A NCS analysis of the CTS Interim Loaded Cask Storage Building has also been performed, considering the different transportation casks designs (DPT, HI-STAR 100, ENUN 32P, ENUN52B, TN-82) in bounding storage configurations.

A Spent Fuel and Radioactive Waste Research Laboratory is also projected at the CTS facility to perform studies on spent fuel and other wastes in support of R&D objectives for long term storage and disposal. The laboratory will include a variety of concrete and metallic hot cells of different designs, as well as glove boxes. The NCS analysis of this laboratory has not been submitted yet.

2. R&D

A CSN-Enresa collaboration project performed by SEA to evaluate 7 fuel samples from the SFCOMPO database (GU3, DU1, BM5 and GU1 from ARIANE, M11 from REBUS and GGU1 and GGU2 from MALIBU) was performed in the period 2012-2016. As reported in SFCOMPO TRG meeting, it is planned to continue the project with the evaluation of 20 new samples from Fukushima Daini, in a new project phase with similar scope and duration. The project will also include additional evaluations of 4 samples from ARIANE project.

The main concerns and R&D gaps identified have to do with BWR fuel isotopic data needed to support BUC NCS methodologies for storage and transportation casks. Analytical work to reproduce the experimental results of other samples continues and a new measurement project could be considered in the near future.

There is also concern on high burnup fuel behaviour and its impact on new fuel configurations models and conditions in NCS.

3. International Collaborations

Participation in NEA working/expert groups:

- NSC/WPNCS Expert Groups
- CSNI Working Group on Fuel Cycle Safety (WGFCS).

4. Future Challenges

In the near future, new applications for BWR SNF casks criticality safety methodologies taking credit from gadolinium and/or fuel burnup are expected. There is no previous national experience on this issue regarding dry storage/transportation casks.

Adequate fuel classification as damaged/undamaged prior to cask loading is the basis to perform conservative criticality safety analysis. A number of authorized storage and transportation casks, with no damaged fuel as admissible contents in their licensing basis, will require certificate amendments to implement this option. Classification issues for BWR fuel and safety analysis scope to demonstrate criticality safety in any eventuality are expected.

HBF transportation issue is requiring new methodologies assessing the impact of fuel reconfiguration in criticality safety analysis due to difficulties to demonstrate cladding integrity of used nuclear fuel in transportation casks conditions.

The criticality safety demonstration of the Centralized Interim Spent Fuel Storage (CTS) is on-going, though now the process is temporarily stalled, also as a new licensing challenge. It will be the first time that Design Extension conditions for the facility will be directly included in the licensing basis, and the design basis is 100 years. As a result, degradation phenomena potentially affecting NCS of the SNF storage will need to be identified and addressed.

5. Input to/from NEA/NSC Programmes of Work

a. Items for discussion at WPNCS.
b. Items to be discussed in WPNCS Expert Groups
c. Items to be forwarded to Nuclear Science Committee

4. Switzerland

4.1. National Context (Overview)

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4.2. R&D Programmes

Concerning the CSE methodology development and maintenance at PSI, no major work has been done since the previous meeting apart from a) performing the standard validation analysis for the recently released ENDF/B-VIII and JEFF3.3 libraries, as well as b) realizing some studies on the nuclear data uncertainties propagation during depletion calculations using the covariance information from the recently released nuclear data libraries. The results of the validation studies as well as some associated findings and plans for future works have been reported in the PSI contribution to ICNC-2019. The studies on the integral parameters uncertainties during depletion calculations with Casmo-5 is to be presented at Physor-2020.

As regards the R&D works on the Criticality Safety methodology development and evaluations for the Swiss PWR Spent Fuel Geological Repository, the general work plan of the collaboration between Nagra and the Paul Scherrer Institut has been established for the forthcoming years. The work is a continuation of the project BUCSS-R (2014-2017) which was concerned with the derivation of loading curves for the Swiss PWR SNF final repository. The so-called Phase 2 of BUCSS-R aims at refining and optimizing the SNF loading curves for NAGRA's SNF disposal canisters as well as taking into account the possible canister/fuel evolution and degradation scenarios, as required by international safety standards.

Finally, the R&D works related to the nuclear data evaluation and associated uncertainty quantifications (primary linked to the TENDL library development and maintenance) are being continued at PSI.

4.3. International Collaborations

PSI continues participating to the OECD/NEA WPRS activities including UAM benchmark, C5G7-TD benchmark, EGMPEBV (expert group on Multiphysics Experimental Data, Benchmarks and Validation), WPEC subgroup 46 and to the JEFF project.

4.4. Future Challenges

A proposal for a small internal project is under consideration at PSI. The project would be focused on the accurate derivation of critical masses for the systems containing mixtures of different fissile materials. The background for this activity is that PSI – like many research institutes worldwide – stores various isotopic mixtures of fissile and fissionable materials (UO_2 & MOX) in different types of containers. Direct criticality calculations (i.e. estimation of the effective neutron multiplication factors) of such systems is very inefficient. However, the alternative approach based on the determination of the minimal critical masses requires adequate estimation of the biases and uncertainties in the calculation predictions of the critical masses. This task is complicated by the lack of appropriate experimental benchmarks suitable for the validation of the calculations for the particular type of systems under analysis. It is thus proposed to make use of the recent advances achieved in the field of the LWR CSE methodology upgrading (primary as result of the former UACSA EG activities on enhancement of methods for the calculation of bias and its uncertainty evaluation) for CSE of PSI's wastes. In the long term, this can potentially lead to considerable cost savings for licensing applications associated with the historical waste management at PSI and other research centers.

4.5. Input to/from NEA/NSC Programs of Work

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5. United kingdom

Aims:

- Provide convenient format for disseminating information on national programmes/incidents/policies.
- Key output is identification of items of common interest for consideration by WPNCS as potential collaborative activities within NSC programmes of work.
- After a first detailed report, the delegate from each country would highlight only significant changes at subsequent meetings.
- Secretariat to review reports with Chairs and identify items of common / special interest.

5.1 National Context (Overview)

a. Government Policies (related to issues discussed)

The UK Government provides central regulation of the UK nuclear industry via its Office of Nuclear Regulation (ONR), who regulate day-to-day operations, and its various environment agencies, who regulate waste disposals.

The UK Government also funds the central co-ordination and management of nuclear legacies, via the Nuclear Decommissioning Authority (NDA) and Radioactive Waste Management Limited (RWM).

Most of the operations in the rest of the UK industry are now either privatised (for example in the case of civil nuclear fuel manufacture and power stations) or contracted out, to consortia employed by the NDA to manage former BNFL and UKAEA nuclear sites. There is also a UK Government-owned National Nuclear Laboratory (NNL).

In 2016, the UK Government approved the EDF project to build a new nuclear power station at Hinkley Point in the UK.

https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c

This is a very significant milestone for the UK industry. As the initial construction work proceeds, work is also being set out for the station's criticality safety case. That work will need to present the established design of the EPR fuel route within the context of a "modern standards" UK safety case.

Also in the UK, there are other proposals and plans to build further new nuclear power capacity (€70 billion), at seven other sites around the UK: Sellafield, Sizewell, Oldbury, Wylfa, Bradwell, Heysham and Hartlepool.

In June 2018, the Nuclear Sector Deal was agreed between UK Government and the nuclear industry. This represents a major commitment from the UK Government to the long-term sustainability of the UK nuclear industry. Two key initiatives with the potential to impact most upon the criticality safety discipline in the next few years are:

- A major multi-million pound government investment into an ambitious nuclear research and development programme (the Nuclear Innovation Programmes) covering a wide range of topics including nuclear fuels, advanced reactors and recycle & waste management.
- Creation of the Nuclear Skills Strategy Group (NSSG) which addresses the people element of the Nuclear Sector Deal; this group is accountable for developing and leading on the Nuclear Skills Strategic Plan to address the key risks to skills and resources facing the industry.

b. Industry Requirements (skills capability, training, etc.)

b.i Industry Capability and Skills

Whilst the NSSG has been set-up to address critical skills issues, it is likely to be some time before it has a direct influence on the criticality safety area. In the meantime, UK industry collaborates to consolidate its skills and enhance its capabilities. These activities are co-ordinated by the Working Party on Criticality (WPC), which is a non-executive national committee. WPC is run as a subgroup of the industry's Safety Directors' Forum: (https://www.nuclearinst.com/Safety-Directors-Forum)

WPC focusses on criticality safety issues up to, but not including, experimental and in-core power reactor operations and considers issues relevant to fabrication, transportation, storage and other operations relating to nuclear materials (for example new build, enrichment, reprocessing, decommissioning and long-term waste management).

The objectives of WPC are to:

- Provide a forum for the discussion and distribution of information of relevance to criticality safety in the UK, particularly the sharing and development of industry good practice.
- Disseminate regulatory issues of relevance to criticality safety and facilitate the development of a UK criticality community view on such matters (and response, where appropriate).
- Promote establishing UK databases and standards relevant to criticality safety.
- Guide, promote, co-ordinate and encourage cooperation on high priority activities of common interest to the UK criticality safety community, for example through identifying and establishing appropriate Working Groups and championing a 'strategic issues' list.
- Monitor progress and publish reports of the meetings of those Working Groups established by the Committee.
- Provide opportunities for the continued professional development of criticality safety personnel, for example through involvement in the Working Groups, attendance at appropriate workshops or providing common industry training modules.
- Co-ordinate work with other organisations to avoid overlap of activities (for example the Shielding Forum).
- Promote international collaboration in the field of criticality safety, for example by establishing co-operative arrangements with criticality professionals and bodies in other countries.
- Identify to the Safety Directors Forum any strategic issues which may require their attention / review.

Working with the Safety Directors' Forum, WPC has published a Good Practice Guide to Criticality Detection at UK Nuclear Licenced Sites: https://www.nuclearinst.com/write/MediaUploads/SDF%20documents/WPC/GPG_to_Criticality_Detection_Issue_1_(2017).pdf

More recently, the format of the WPC has been altered to encourage collaborative work to develop further Good Practice Guides (GPG) and other useful resources that will be freely available to WPC member organisations. These include:

- GPG on the use of computer codes for criticality calculations.
- GPG on criticality safety margins.
- GPG on fault analysis principles and practices.

- A database for the collation and sharing of learning from experience, for example root causes of abnormal conditions.

Future topics, aligning with WPC strategic issues, are likely to include:

- Decommissioning – holistic safety cases for fissile wastes
- Nuclear science – currency and availability of handbook data
- Professional development – maintaining standards
- Safety methodology – transport assessments

<u>b.ii Training</u>

Shortages of suitably qualified and experienced criticality engineers are a recognised issue in the UK industry. Various training initiatives help to mitigate this issue, including:

- A number of UK (and other) universities provide good basic academic courses that support the industry;
- Most UK companies provided dedicated training for their staff;
- WPC holds annual 1-day professional development workshops. Recent topics (from 2014) have covered "training our trainers"; "criticality anomalies"; "good practices in criticality safety" ; "the elements of criticality safety assessments"; and "criticality fault analysis". The 2019 topic will be "UK highlights of the ICNC". These workshops are open to all, including international attendees.
- Every two years, NNL team up with UNM (USA) to run a week long criticality safety management course in the UK. The next course will be held in September 2020.
- There has been good UK attendance at the recent "hands-on" courses run in the USA.

In spite of the above measures, it can take 4 or 5 years to fully train new entrants to the field of nuclear criticality safety.

c. Operating Issues (e.g: unusual occurrences to report)

For the specific field of criticality safety, the UK has not suffered any significant recent "unusual occurrences" that need to be shared internationally. It is good to note that some other countries have been sharing their recent events. The communication of these helps the UK to avoid operational complacency.

5.2 R&D Programmes, in particular:

a. Code development

<u>a.i "Low Temperatures"</u>

In 2016, the UK Office for Nuclear Regulation (ONR) self-challenged their regulation of IAEA SSR-6 paragraph 673(a)(vi) and so, for the grant or renewal Transport Package licences, have been asking this question:

> *'A criticality safety issue has recently arisen in regard to the impact that temperature can have on the keff of the system. Paragraphs 673(a) (vi) and 679 of the IAEA Transport Regulations, SSR-6, state that low temperatures (down to -40°C) should be considered; further information is presented in paragraph 673.8 of the IAEA Transport Guidance, SSG-26. Following the fire test, the internals of the package could heat up to high temperatures. I would therefore be grateful if the applicant could confirm that any change in the neutron*

physics due to their XXXX transport package being at a low or high temperature will not lead to the criticality safety criterion being exceeded.'

To support this, ONR issued a position statement regarding the consideration of temperature on nuclear criticality safety in transport applications (http://www.onr.org.uk/transport/index.htm) and published an ONR technical assessment guide (TAG) on the criticality safety assessment of transport packages; that includes a section on temperature (http://www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-097.pdf).

UK industry has responded to these questions by means of either reasoned arguments or with the aid of explicit k-effective calculations. Supporting R&D work has been developing UK codes and data for those calculations and has been presented at recent ANSWERS Software Seminars.

- In 2017, Anton Murfin (NNL) presented the use of extrapolation methods, for the assessment of k-effective at temperatures not already covered by extant tabulations of S(α, β) data in MONK.
- In 2017 Derek Putley (EDF Energy) presented preliminary validation work for MONK at non-room temperatures. Tim Ware (ANSWERS) presented the work on the production of a wider range of S(α, β) data for water, ice and hydrocarbons and announced the development of an interpolation capability for S(α, β) data within MONK.
- In 2019 ANSWERS presented work on lower base temperatures for scattering data and results of the development work on the S(α, β) interpolation capability.

Additional work has been carried out by ANSWERS with support from ONR research funds to investigate the effect of temperature on the criticality of fissile systems. This work has recently been published on the ONR website; http://www.onr.org.uk/documents/2019/onr-rrr-077.pdf.

These developments have also resulted in the WPNCS benchmark "SG-3: Criticality Benchmark: A benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies", developed by Anthony Wilson and Sonny Gan at Sellafield Ltd. The results will be shared at the WPNCS meeting in September 2019.

It is expected that work on the topics will be shared in much more detail at the 2019 ICNC in France. These developments are allowing updated package design safety reports to include more comprehensive assessments. So far, none of those have resulted in any unduly onerous impacts on the safe transport of fissile materials.

a.ii Uncertainty Computations

ANSWERS are continuing their development of tools and methods for use with the MONK code. Research is tackling the accuracy of the methods and their needs for enormous (and potentially unduly onerous) amounts of computer power. If the UK ever needs to work in areas where there is a lack of experimental benchmarks, for example the adoption of burn-up credit including the effects of fission products and minor actinides, then these techniques may prove to be valuable.

a.iii Burn Up Credit

ONR commissioned research work for burnup credit, to set out guidelines for the regulatory acceptance of burn-up-credit calculations within the evidence base of a UK safety case: http://www.onr.org.uk/documents/2017/onr-rrr-026.pdf

b. Experiments, Facilities, Skills/Staff requirements

There are currently no experimental criticality facilities in the UK (but international collaborations are being developed to mitigate this issue). Currently NNL are collaborating with LLNL (USA) to develop a uranium critical benchmark experiment, designed to go down to approximately -40°C.

c. Experimental needs

Consideration is being given to additional international collaborations, for the development of non-room temperature benchmark experiments.

5.3 International Collaborations

a. Ongoing

The British Standards Institute provides limited funding for UK involvement in the production of ISO standards. On their behalf, NNL leads this work, including that on the development of new ISO standards for criticality. These efforts are being carried out in consultation with the Working Party on Criticality.

Both NNL and SL contribute to the development and review of American Nuclear Society (ANS) criticality standards.

b. Planned

Nothing to report

5.4 Future Challenges

Nothing to report

5.5 Input to/from NEA/NSC Programmes of Work

a. Items for discussion at WPNCS

None

b. Items to be discussed in WPNCS Expert Groups

Results of the WPNCS benchmark "SG-3: Criticality Benchmark: A benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies".

c. Items to be forwarded to Nuclear Science Committee

None

6. United states

National Context

The United States (US) 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 > 5 wt.% enrichments, in the area of industrial and government activities the focus is on production and fabrication of reactor fuel with enrichments < 5 wt.%, 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. Government and industry are also pursuing many concepts for accident tolerant fuels in cladding materials, with a lead test rods of accident tolerant fuels currently under irradiation in operating plants. These fuels include coated zirconium alloy and iron-based alloy cladding, and doped uranium oxide and uranium silicide pellets. 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. The US Department of Energy (DOE) has stopped the planned MOX fuel fabrication plant, and thus the US has limited need for criticality safety relevant to the transport or storage of MOX fuel. The US has expanded its pit manufacturing investment at both LANL and the Savannah River Site.

The current fiscal year 2019 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 2016, the US Nuclear Regulatory Commission (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 Requests for Supplemental Information (RSIs) prior to the applicant requesting the review to be placed on hold. The NRC subsequently issued a series of Requests for Additional Information (RAIs) in late 2018 and early 2019, which the applicant has partially responded to. The NRC received a second application for an interim storage facility from Holtec International in March 2017. The staff completed an acceptance review and 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.

Research and Development (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 about 20 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 National Criticality Experiments Research Center (NCERC) in Nevada, run by Los Alamos National Laboratory, and at Sandia National Laboratories (SNL) in New Mexico.

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. The SPR/CX critical assembly at Sandia is available and the Annular Core Research Reactor at Sandia is used to demonstrate the consequences of a criticality accident for course students.

The NCSP has conducted “hands-on” critical experiment training classes at NCERC during the past year. Specifically, each year the NCSP conducts two 2-week training class for NCS practitioners and two 1-week training course for regulators, managers, and operations professionals who need to understand the fundamentals of nuclear criticality safety. The 2-week classes include one week of classroom training at the National Atomic Testing Museum in Las Vegas, NV, followed by one week of hands-on critical experiment training at either SNL or NCERC. The 1-week manager’s courses focus on hands-on experience with less technical lectures and are also conducted at SNL or NCERC. Since establishing the NCSP hands-on training courses in 2011, over 415 students have taken the NCS handson training courses.

With regard to information preservation and dissemination, the NCSP through the course of its activities is preparing several benchmark evaluations for submission to the International Criticality Safety Benchmark Evaluation Project (ICSBEP) in the upcoming years. Efforts continue to encourage users of the ICSBEP Handbook to report errors and questions in order to suitably revise existing benchmark evaluation data currently found therein.

Integral experiment research over the last year has included: completion of 10 novel plutonium (Pu) and tantalum (Ta) critical experiments using ZPPR (Zero Power Physics Reactor) fuel (part of the TEX series of experiments), completion of an experimental collaboration with JAEA on lead void coefficient measurements, design work for HEU (highly enriched uranium) and ^{233}U TEX experiments, and execution of titanium sleeve experiments in the BUCCX reactor at SNL. SNL efforts also include 7uPCX experimentation with varying large pitches. LANL completed subcritical measurements of a Np sphere and are completing characterization work. Design work is being completed for two different temperature-dependent critical experiments; SNL and Oak Ridge National Laboratory (ORNL) are collaborating on a design of heating and cooling the water of the SNL water lattice and Lawrence Livermore National Laboratory (LLNL) is working with the United Kingdom's (UK's) National Nuclear Laboratory (NNL) and Los Alamos National Laboratory (LANL) to design a -40 °C variation on the uranium TEX experiments. Collaborative efforts with the Institute Jozef Stefan (IJS) in Slovenia includes benchmark evaluation of the LANL experiments using uranium foils moderated/reflected by Lucite.

With regard to Analytical Methods, Monte Carlo N-Particle (MCNP) and SCALE are key codes used for criticality safety within the DOE complex and are supported by the NCSP, the NRC, and DOE, 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, including expanded cross section covariance data are available for the key NCS analyses code packages, and support of the transition of nuclear data from the traditional ENDF-6 to the new General Nuclear Database Structure (GNDS) format. The ENDF/B-VIII.0 was released in late 2017 and has 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 (IAEA) transportation guidelines. LANL participated in the development and recent release of the ENDF/B-VIII.0 nuclear data. ACE files for use with MCNP are now available for download on a public website. Fundamental R&D work that is continuing at LANL includes the investigation and development of: region-dependent sensitivity-uncertainty data for NCS validation, methods to diagnose and accelerate Monte Carlo source convergence, diagnostic tests for undersampling and clustering, the impact of correlated fission multiplicity models in criticality calculations, studies into the validation for chlorine, and more.

The SCALE and MCNP teams both provided training classes to US and international participants. Classes in the theory and practice of Monte Carlo criticality calculations with MCNP6 are given regularly at LANL and other sites. A new 1-day training class on the use of sensitivity-uncertainty methods in NCS validation has also been conducted numerous times, by personnel from both LANL and ORNL. To help educate future nuclear engineers, the LANL methods and code developers are teaching 2 semester-long courses at the University of New Mexico. SCALE offers two weeks of training classes on criticality safety and uncertainty analysis methods at the OECD NEA. The MCNP and SCALE codes continue to be highly regarded Monte Carlo codes. MCNP includes the Whisper code to support sensitivity-uncertainty based methods for NCS validation. There are estimated to be over 20,000 users of MCNP throughout the world.

ORNL released SCALE 6.2.3 to provide enhanced capabilities and resolve various reported issues. More than 4,000 users have requested SCALE over the past few years. SCALE is the most highly requested code from the NEA Data Bank, with distributions to over 2000 Data Bank members over the past decade, with mirrored distribution also available from the RIST data center in Japan.

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 vanadium (V) and zirconium (Zr) samples. Also, substantial progress has been made to expand the Rensselaer Polytechnic Institute (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 $^{63,65}Cu$, ^{56}Fe, ^{16}O, and $^{182,183,184,186}W$. 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 provided many updated nuclear data evaluations with high quality uncertainties will become available to the community. The DOE Office of Nuclear Energy has initiated a new Nuclear Data and Benchmarking Program that is focused on identifying gaps and providing enhancements in data measurement, evaluation, and covariance generation as well as benchmark experiments and application studies import to emerging nuclear energy applications, especially focused on advanced reactors and advanced fuels.

NRC completed a research program focused on use of Burnup Credit in designing criticality control systems for Boiling Water Reactor (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 entitled “Technical Basis for Peak Reactivity Burnup Credit for BWR Spent Nuclear Fuel in Storage for Transportation Systems”. The second phase of the research, which examined beyond peak reactivity, was completed and resulted in several NUREG/CR reports on topics including: axial moderator density, control blade usage, axial burnup profile, reactor operating parameters, isotopic prediction uncertainty, and validation of k_{eff} calculations . 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.

NRC is also funding a research program to conduct precision radiochemical assay (RCA) measurements of high burnup PWR spent fuel samples at ORNL. The measurements will include over 50 actinides and fission products important to burnup credit criticality, radiation shielding, and decay heat calculations. For criticality safety, the new measurements will be included in an updated set of measurements for validation of isotopic depletion codes, and will be included in an update to NUREG/CR-7108 on depletion code validation to provide bias and bias uncertainty estimates for several codes using ENDF/B-VII.1 and -VIII.0 cross section libraries.

International Collaborations

The NNSA continues to interact with Atomic Weapons Establishment (AWE) and NNL in the UK and the Commissariat à l'Énergie Atomique (CEA) and L'Institut de Radioprotection et de Sûreté Nucléaire (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. After the closure of Fast Critical Assembly (FCA) in Japan, the US continues to perform experimental work with the Japan Atomic Energy Agency (JAEA). Likewise, personnel from AWE, NNL, and IRSN have visited the US to perform collaborative work tasks at NCSP sites. Within the DOE NCSP, ORNL and Institute for Reference Materials and Measurements (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. The NCSP has a collaboration agreement with the EU Joint Research Center in Geel, Belgium. Over the last couple of years, differential measurements have been taken with natural La and Ce-142. In FY20, measurements are planned with stable isotopes of Zirconium (Zr-90, 91, 92, 94) per the NCSP 5-year plan.

Under OECD/NEA WPEC, US National Laboratories are worked 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}U, ^{238}U, ^{239}Pu, ^{56}Fe, and ^{16}O.

In addition, the NCSP provides support for the US participation in the ICSBEP. The DOE-NE currently provides support for the US leadership of the ICSBEP following past funding provided via the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program.

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 the availability of experiments to use for benchmarks in criticality reviews to support analysis of accident tolerant fuels. A further challenge exists 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 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 US continues to engage in each of the Expert Groups and Subgroups 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 on Used Nuclear Fuel, with the recent release of SFCOMPO-2.0. US leadership continues for ICSBEP and SFCOMPO. US leadership is also provided with the Technical Monitor for Uncertainty Analysis for Criticality Safety Assessment overseeing two subgroups.

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.

ANNEX D

Summary of the tecnical tracks in ICNC2019

Technical track 1

Codes and other calculation methods

TLs: D. Heinrich, Y. Rozhikhin, E. Dumonteil

New capabilities !

- Burn up & multiphysics
- Random media
- Correlated/stochastic physics
- Transient
- Deep learning
- Automated

Maximum packing fraction
For
Track 1 !

Technical track 1

Codes and other calculation methods

TLs: D. Heinrich, Y. Rozhikhin, E. Dumonteil

« A renaissance of diverse, advanced, new and improved methods [customized to users needs] »

Dave Heinrichs

Technical track 2

Nuclear Data

TLs: D. Brown, L. Leal, R. Ichou

➢Number of papers:

- 13 oral papers 4 posters on ND were presented; The subjects covered were ND measurements, evaluation, processing, validation. Discussion on data uncertainty and propagation took place on several occasions;

➢Main outcomes

- 4 sessions, namely, three on Monday morning and afternoon and one on Tuesday afternoon;
- On the average about 40 to 50 person attended the ND sessions;
- There are ND needs and interest for data measurements for thermal scattering (water, ice, uranium-oxide, etc) Evaluation and validation is crucial in the ND activities

➢Concluding remarks

- ND subject has traditionally attracted quality papers for criticality safety applications;
- Excellent talks were presented as well great posters;

Technical track 3

Uncertainty and Sensitivity Analysis

TLs: C. Carmouze, M. Stuke, N. Leclaire

➢Number of papers: 19

- ➢ 16 oral presentations
- ➢ 3 posters

➢Main outcomes

- ➢Various codes produce sensitivity coefficients and have implemented U/S analysis techniques
  - ➢ e.g. to cover low representativity areas for "exotic" fuels
- ➢Various techniques for establishing similarity between experiments evaluated in the ICSBEP Handbook
- ➢Complementary use of GLLSM methodology and Monte Carlo calculations and comparison with alternative techniques, e.g. machine learning
- ➢Further establishment of robust nuclear data covariance matrices and integral experiment correlation coefficients
  - ➢ Need to re-evaluate experimental uncertainties of some ICSBEP benchmarks

Technical track 3

Uncertainty and Sensitivity Analysis

TLs: C. Carmouze, M. Stuke, N. Leclaire

- **Concluding remarks**

- Very lively sessions with many discussions
- Nowadays most codes include robust U/S tools, but…
  - Some concerns remain regarding the harmonization with the applicability
    - More feedback from criticality safety practitioners on the use of U/S methods
    - More guidance to help practitioners to use the new methods
- Close interaction between practitioners, code developer, and experimentalists desirable
  - International framework should be promoted

Technical track 4

Measurements, Experiments and Benchmarks

TLs: J. Bess, P. Blaise, I. Duhamel

- **Number of papers: 33 full papers (27 oral presentations and 6 posters) → 7 sessions**
- **Main outcomes**
  - **4 main topics were presented:**
    Subcritical experiments, Critical experiments, Benchmark evaluation, and Validation
  - **New methods are being developed to optimize experiments design**
  - **Representativity and accuracy of experiments are key points**
  - **Most of the new programs are international collaborations**
- **Concluding remarks**
  - **Importance to keep experimental facilities, some are being renewed**
  - **International collaborations are more than helpful**
  - **There are still experimental needs to cover**
  - **Preservation and dissimination is essential → importance of ICSBEP and IRPhEP**

Technical track 5

Standards, Assessment Methodology, Regulations
TLs: D. Bowen, F. Winstanley
L. Aguiar

- **Number of papers: 17**
- **Main outcomes**
  - 4 presentations summarizing progress on ISO & ANSI NCS standards
  - 6 presentations about safety reviews and regulatory oversight
  - 4 presentations about regulatory methodologies presented
  - 6 presentations about computational methodologies presented to support criticality safety assessments
  - 2 presentations that provide a status report for expert working groups for nuclear criticality safety: IAEA TRANSSC, Expert group on criticality, ISO/TC85/SC5/WG8 and ANS-8 subcommittee
- **Concluding remarks**
  - Excellent demonstrations provided for solution analysis
  - Regulatory perspectives were valuable to expand on expectations
  - Consensus standard discussons valuable to find participants/volunteers in the future

Technical track 6

Operational Practices and Safety Cases
TLs: B. Riazanov, S. Watson
M. Milin

- **Number of papers: 21 (17 presentations + 4 posters)**
- **Main outcomes/ Themes:**
  - **Decommissioning and Legacy Issues**
  - **Reduction in pessimisms/ penalizing assumptions – more flexible operations**
    - **Linked to balancing of risks from criticality with conventional, chemo toxic, radiological etc**
  - **Techniques to make modelling bounding cases easier and quicker**
  - **Application of modern methodology**
  - **New facilities (challenges when the facility does not yet exist)**
  - **Learning from Experience**
- **Concluding remarks**
  - **Quicker, more realistic, more flexible evaluations → more economic / feasible operations**
  - **Ensuring we continue learn from each other**

Technical track 7

Storage and Transport Issues

TLs: G. O'Connor, M. Tardy
L. Jutier

- **Number of papers: 14 + 3** (South Korea, Japan, USA, France, Sweden, Germany and UK)
- **Key Themes**
  - **Burnup Credit (6 papers)**
    - Phenix Fast Reactor
    - ORNL and USNRC - 5 Year BWR Burnup Credit Project
  - **Cask Loading Analysis (3 papers)**
    - ORNL As-Loaded Analysis - allows quantification of inherent uncredited margins for loaded canistors
    - UNF-ST&DARDS - high quality graphical interface – ideal for non-expert
  - **Temperature (2 papers)**
    - Reduction in temperature can lead to increase in keff - further work recommended
    - **Need for Low Temperature Experimental Data for Validation**
  - **Fuel Storage (3 papers)**
    - Boral – worst case blistering / pitting – insignificant impact on reactivity
    - **Research and Development required - loss of cooling accident**
  - **Transport Package Design (3 papers)**
    - New Type C Package (AWE) – air transport

Technical track 8

Final Disposal Issues

TLs: T. Tate, V. Khotylev
G. Caplin

- **Number of papers: 5**
- **Main outcomes**
  - Session highlighted criticality safety activities to support a geological disposal facility (GDF) in the UK and a post closure nuclear criticality safety assessment for licensing the Industrial Center for Geological Disposal in France
  - Criticality safety is considered during transport, operations, and post-closure phases for UK GDF
  - Presenters discussed: (1) options to demonstrate criticality safety; (2) waste package controls to ensure long-term criticality safety; and (3) criticality assessment of wastes packaged in shielded containers
  - Presenters discussed disposal facility post closure considerations, such as, evaluations to verify criticality is not likely and establishing what if events and consequences

Technical track 8

Final Disposal Issues

TLs: T. Tate, V. Khotylev
G. Caplin

- **Concluding remarks**
  - **Evaluations conducted using highly unlikely scenarios, conservative fissile material contents, and conservative moderator intrusion assumptions**
  - **Common conclusion that criticality is not likely in GDF**
  - **Future evaluations may consider higher enrichment waste inventories**

Technical track 9

Criticality Accidents and Incidents

TLs: Y. Yamane, M. Duluc

- **Number of papers: 23 papers**
- **Main outcomes**
  - CAAS: need assessment and Minimum Accident of Concern
  - Incidents: share of experience and lessons learned
  - Fukushima Daiichi NPP: many challenges (safety analysis / estimation of consequences)
  - Multiphysics tool (including MC calculations): good trial for analysis of complicated phenomena
  - Experiments: use of experimental data for validation (tool/device/method)
- **Concluding remarks**
  - **Many interests/ideas, many papers, many connections with other fields of Nuclear Criticality Safety → this field is growing!**

Technical track 10

Professional Development Issues and Training

TLs: C. Lenepveu, D. Hill, J. Miller

- **12 Papers & 3 Posters**
- **Main outcomes:**
  - **Operational and Criticality Professional Training**
    - **Hands-on Training with a reactor physics tie & the DOE NCSP**
    - **supervisors/managers/operational staff/support staff**
    - **IRSN's "in-house University" Assessment School**
  - **SARP training**
  - **Mentorship lessons learned and the University Pipeline**
  - **Augmented reality and other novel training approaches**
- **Concluding remarks:**

NCS training is being revisited in many countries, which reflects the global effort in this area.

Technical track 11

Future Challenges

TLs: A. Chambers, T. Ivanova
J-B. Clavel

- **Number of papers: 8 papers (oral presentations)**
- **Presentations:**
  - NEA presentation: international collaboration in Working Party on Nuclear Criticality Safety activities
  - US/NCSP presentations: vision of program and challenges in analytical methods, nuclear data, preservation dissemination, training & education, and integral experiments, including investigation of new critical assemblies
  - Solution critical assemblies - SOCRATES solution reactor
  - Concerns on the need for additional critical experiments experience for criticality safety practitioners
  - Japan/JAEA/Tokyo nuclear service: Progress of criticality control study on fuel debris by JAEA to support secretariat of NRA and criticality characteristics of fuel debris
  - US/Y12: NCS impacts of additive manufacturing
  - Criticality characteristics of fuel debris with differing fuel burnups and fuel loading pattern
  - GRS : Neutronic calculations for accident tolerant fuel systems

Technical track 11

Future Challenges

TLs: A. Chambers, T. Ivanova
J-B. Clavel

➢ Concluding remarks:

- International collaboration among scientists and engineers is a very powerful tool, cost-effective strategy and an increasingly important element
- Main future challenges:
  - Maintain key skills in the NCS, including hands-on critical experiment training
  - Need to maintain and develop experimental capacities and facilities - high costs and aging
  - Develop and maintain analytical methods and computer codes under strict software quality assurance requirements
  - Leverage new technologies (3D printing) to improve process and efficiency – be aware of new hazards
  - Collaboration is a powerful tool
  - Need to develop new knowledge for modeling, simulating, handling and retrieving fuel debris post accident (fuel sampling, non-homogeneous models, exchange with others communities)
  - Need to continue to explore accident tolerant fuel designs to help ensure the safety of future that must be dependent on nuclear energy