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Working Party on Nuclear Criticality Safety

22nd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

SUMMARY RECORD

6 July 2018
NEA Headquarters, Boulogne-Billancourt, France

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OECD Nuclear Energy Agency
Nuclear Science Committee

22nd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)
6 July 2018

NEA Headquarters, Room BB1
46, quai Alphonse Le Gallo
Boulogne-Billancourt, France

The Working Party on Nuclear Criticality Safety (WPNCS), and its associated Expert Group met during the week of 2-6 July 2018 at NEA Headquarters. For the transition to the Sub-Group system, kick-off meetings of the proposed SG and an ad hoc meeting for finalization of EGUNF benchmark were also held in the week:

- The Expert Group on Advance Monte Carlo Techniques (EGAMCT)
- Ad hoc meeting for finalization of EGUNF benchmark
- SG-1: Role of Integral Experiment Uncertainties and Covariance Data in Criticality Safety Validation
- SG-2: Blind benchmark on MOX damp powders
- SG-3: Criticality Benchmark: A proposal for a benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies
- SG-4: Analysis of Past Criticality Accident
- SG-5: Experimental needs for criticality safety purpose

1. Introduction and Welcome

The new Chair, Stéphane Evo (IRSN) opened the meeting, welcomed the participants, who briefly introduced themselves. The meeting was attended by thirty-eight participants from Belgium, Canada, Czech republic, Finland, France, Germany, Hungary, Italy, Japan, Spain, Sweden, Switzerland, the UK and the US (see participant list in Annex C).

2. Review of Actions from Previous Meeting

There were no outstanding actions to review.

3. Approval of the Previous Summary Record and Agenda

The summary record of the previous meeting was approved and country reports that had been submitted were included. The agenda (Annex B) was approved without any modification.

4. Feedback from the Nuclear Science Committee Meeting

T. Ivanova (Head of Division of Nuclear Science) reported on the outcomes of the last NSC meeting held on 12-14 June 2018. She gave an overview of progress and future directions in Nuclear Science. A workshop on Enhancing Experimental Support for Advancements in Nuclear Fuels and Materials held on 8-10 January 2018 was introduced. This workshop aimed to discuss the NSC's role in providing experimental support in facilitating the deployment of innovative components in existing and future nuclear power systems with the high-level speakers from utilities, fuel vendors, TSOs, and regulatory bodies.

She announced a proposal for establishing an NEA Joint Project to establish an international framework aimed at enhancing experimental support for innovations in fuels and materials. A meeting on "Studying

clad load mechanism during LWR transients" is scheduled for October 4-5, 2018 at NEA HQ as a first step towards building a breakthrough experimental program for fuel and material testing.

5. Reports from the WPNCS Expert Groups and Sub-Groups

Individual progress of all the WPNCS Expert Groups was presented by their respective Chairs and is summarized below.

Expert Group on Advanced Monte Carlo Techniques (EGAMCT)

E. Dumonteil (IRSN) reported on the progress of activities. The main focuses of activity in this EG are completion of the final report and follow-up activity, since the mandate was the end of June 2018. Regarding the final Report on *Calculating local tallies defined over loosely coupled systems with Monte Carlo criticality codes,* it is expected to be delivered at the end of 2018.

As a follow-up activity related to Monte Carlo Techniques, one SG was proposed by F. Brown (LANL) and approved at the WPNCS meeting.

SFCOMPO Technical Review Group (SFCOMPO TRG)

J. Martinez Gonzalez (NEA) reported the current status, on behalf of G. Ilas (ORNL) official candidate for Chair. The technical review groups in charge of the SFCOMPO database keep their current Expert Group structure, as well as ICSBEP. SFCOMPO TRG will be held on 4-5 March 2019.

Expert Group on Used Nuclear Fuel Criticality (EGUNF)

U. Mertyurek (ORNL) reported the ad hoc meeting of the former EGUNF for finalization of the Burnup Credit Criticality Benchmark Phase IIB, *Code Comparison for Gadolinium-bearing Fuel Pins in Boiling Water Reactor Assemblies*.

International Criticality Safety Benchmark Evaluation Project (ICSBEP)

J. Bess (INL) reported on progress made on the ICSBEP database. The technical review group met in October 2017 and reviewed six new evaluations and seven revised evaluations. The *2018 International Handbook of Evaluated Criticality Safety Benchmark Experiments* will include 37 revised evaluations, 4 new evaluations (LEU-COMP-THERM-98, LEU-COMP-THERM-100, LEU-SOL-THERM-012, IEU-MET-FAST-024), reference guide and IRPhEP Uncertainty guide.

6. Reports from ongoing and new Sub-Groups for discussion/approval

Individual proposal of all the potential Sub-Groups was presented by their respective coordinators and is summarized below. All the proposals were finally approved.

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

M. Stuke (GRS) reported the new Sub-Group, Role of Integral Experiment Uncertainties and Covariance Data. The objectives include the completion of the EGUACSA Phase IV benchmark, formulate the "State-of-the-art" and definition of future needs with respect to the generation and use of uncertainties and covariance matrices of critical experiments.

SG-2: Blind benchmark on MOX damp powders

C. Carmouze (CEA) reported the new SG, Blind benchmark on MOX damp powders, to evaluate the ability of validation methods and tools for criticality safety assessment of systems with MOX damp powders. The former EGUACSA Phase V Benchmark will be completed for the next WPNCS meeting in 2019.

SG-3: Criticality Benchmark: A proposal for a benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies

S. Gan reported the new SG, Criticality Benchmark: A proposal for a benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies.

SG-4: Analysis of Past Criticality Accident

Y. Yamane reported the new SG for Analysis of Past Criticality Accident. The Phase II benchmark (Ramp mode Experiments with Uranyl) of the former EGCEA will be completed in 2019.

SG-5: Experimental needs for criticality safety purpose

I. Duhamel (IRSN) reported the new SG for Experimental needs for criticality safety purpose, to compile high-priority needs for experiments in criticality safety, discuss the methods used to identify and to justify experimental needs, and to exchange on the capabilities of existing experimental facilities for criticality safety purpose.

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

F. Brown (LANL) reported the new SG for Statistical tests for diagnosing fission source convergence and undersampling in Monte Carlo criticality calculations.

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

C. Carmouze (CEA) reported the new SG, "On the definition of a benchmark on sensitivity/uncertainty analysis on used fuel inventory". The objectives are to specify a detailed benchmark that involves S/U analysis on used fuel inventory in order to assess the impact of nuclear data uncertainties on fuel assembly depletion calculations and to analyze the contribution of ND uncertainties in calculation over experiment bias.

7. Preparation of ICNC 2019

S. Evo (IRSN) presented the preparation status of International conference on nuclear criticality safety (ICNC) that will be held on 15-20 September 2019 in Paris. ICNC will be organized by National Organizing Committee, International Advisory Committee (IAC), and International Technical Programme Committee (ITPC). Regarding IAC, since the members will be selected from mainly WPNCS members, S. Evo will call for volunteers by the end of July 2018.

8. Updates on Nuclear Criticality Safety National Programmes

Delegates were requested to submit a written country report providing an overview of criticality safety related programmes or issues to report from their home countries. Country reports aim to:

- Provide convenient formats for disseminating information on national programmes/ incidents/policies.

- Identify items of common interest for consideration by WPNCS as potential collaborative activities within NSC programmes of work.
- Highlight significant changes in national programmes at subsequent meetings.
- Help NEA identify items of common/special interest.
- The written reports received are included in Annex A.

9. Date of Next Meeting

The next meeting will be held on 23-27 September 2019, the following week of ICNC2019.

10. Other business

B. Rearden (ORNL) presented the new crosscutting program of nuclear data and benchmarking for the advanced reactor community among industry, NRC, and other programs.

11. List of Actions

During the meeting it was agreed that:

- C. Carmouze to send SG-7 proposal to WPNCS members for announcing the activity;
- Duhamel to share the information of the high-priority list in WPEC to the members;
- All to send country report to S.Evo / NEA secretariat;
- Co-ordinators of SG to reply to NEA secretariat if the mailing list system is needed;
- All to inform S. Evo / NEA secretariat if they are volunteers to participate to the IAC of ICNC2019.

OECD Nuclear Energy Agency
Nuclear Science Committee
Working Party on Nuclear Criticality Safety

ANNEX A

Country Reports on Nuclear Criticality Safety National Programmes

1. France

National Context (Overview)

- EDF stated that the EPR reactor at Flammanville will be delayed a couple of months. Therefore, it should start operations rather in 2019. (Note that the EPR at Taishan, in China, went critical in June.)
- The 2 PWR of the oldest French NPP, at Fessenheim, will close after the Flammanville reactor comes online.
- The Jules Horowitz reactor (Research reactor of 100 MWth) is under construction. Should not start before 2021-2022.
- The research reactor CABRI performed its first experiment for the CIP program (behavior of the cladding) in April 2018.
- The periodic safety review of the fuel fabrication facility, CERCA, for research reactor has been completed.
- The periodic safety review of the UP2-800 reprocessing plant is ongoing.
- The RES (Réacteur d'ESsais) reactor dedicated to the validation of the neutron transport package for naval propulsion (NARVAL) is in operation. The fuel has been charged in June 2018 and the criticality is planned for August 2018. The first experimental program HIPOCCAMPE will be dedicated to the in-core measurement of the neutron flux.
- The CEA EOLE and MINERVE research reactors shut down on December 2017.
- AREVA NP, the branch of AREVA in charge of nuclear power reactors and UOX fuel fabrication, has been transferred to EDF and is renamed Framatome. And the new name of the remaining part (mining, front end, back end, transport) of AREVA has been renamed ORANO. Moreover, AREVA TA, the part of AREVA in charge of the naval propulsion and research reactor studies, is no longer a subsidiary of AREVA and has been renamed TechnicAtome.

There is no significant criticality event to report.

R&D Programmes, in particular:

- A new version of the French criticality package, CRISTAL V2.0, has been issued in March, and is being tested by NEA for release by the databank.
- MORET 5.D.1 should be distributed by NEA in a few months.
- A new version of the depletion code VESTA 2.2 has been developed. The validation is underway.
- Continuation on R&D on UQ methods for depletion calculation codes ➔ proposal for a new WPNCS subgroup.
- Continuation on R&D for burnup credit and used SFR fuels valorization.
- In the frame of the US-DOE NCSP program, IRSN participated in a dosimetry exercise on the Flat-top reactor to test our capabilities to measure the dosimetry in case of a criticality accident
- 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,…

- A PIRT approach on the Zero Power Experiments PHYsics Reactor (ZEPHYR) is ongoing. The preliminary design is planned for December 2018 and the investment committee will meet on the first semester on 2019.

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, etc.
- Following a work undertaken and reported in the frame of the EGAMCT group, IRSN and LANL initiated an experimental program to measure spatial correlations in zero power experimental reactors. Conclusive results have been presented this week within the EGAMCT.
- IRSN/JAEA collaboration 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
- IRSN and CEA participation on various WPNCS, WPEC and WPRS subgroups
- CEA /European collaboration on nuclear data evaluations, measures and validations through the CHANDA program is done. A new proposition is ongoing.
- CEA 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.

Future Challenges

- A Criticality Safety Guide, supplementing the Criticality-Safety Resolution of the French Safety Authority, is expected in 2018-2019.
- Organization of the ICNC'2019 in Paris

Input to/from NEA/NSC Programmes of Work

France has actively participated to former Expert groups of the WPNCS, and is now ready to participate in new subgroups.

- Report of the EGAMCT
- Within the subgroup on MOX Damp Powders validation, establish the report summarizing the participants' results
- Subgroup on fuel depletion calculations and ND uncertainty quantification
- Subgroup on the analysis of the effects of spatial perturbations in Monte Carlo criticality calculations
- Subgroup on experimental needs

2. Italy

National Context:

As outlined in the Summary Record of the 17th WPNCS meeting (2013), the general situation in Italy is characterized by the decommissioning of the four nuclear power plants that operated until the 1980's, of the various pilot fuel fabrication and reprocessing plants and of a number of research reactors. Nearly all the spent fuel from the power plants has been sent abroad (France, U.K.) for reprocessing. There remain three operating research reactors (two TRIGA's and one fast).

The duties of regulation and control in the nuclear field in Italy, currently the authority of the National Centre for Nuclear Safety and Radiation Protection, part of ISPRA ("Istituto Superiore per la

Protezione e la Ricerca Ambientale") which has responsibilities in the wider environmental context, will shortly pass to ISIN (the National Inspectorate for Nuclear Safety and Radiation Protection).

R&D Programmes:

- At ENEA (the National Institute for Nuclear Energy Research), development of Monte Carlo algorithms to remove decoupling in the calculation of responses in and around near-critical configurations has continued, with papers presented at ICRS-13 and PHYSOR-2018. MCNP is employed as the "vehicle" for such algorithms. The necessity of employing "superhistories" has been demonstrated. So far the technique has mainly been applied to calculating radiation responses within and outside reactor cores. It is of interest to employ it to calculate local responses (e.g. a neutron detector signal) around typical criticality safety configurations.
- One of the research reactors (TAPIRO at ENEA, Casaccia) is currently being evaluated for a campaign of actinide cross-section measurements (see next section).

International Collaborations:

- The code development is carried out in collaboration with IRSN, France. In the coming year, ENEA will participate with IRSN in a criticality safety calculational benchmark.
- In the framework of the NEA Expert Group on Integral Measurements for Minor Actinide (MA) Management, a joint collaboration between ENEA and CEA, France was established with the aim of studying the feasibility of an irradiation campaign of some MA's (237Np, 242Pu, 241Am, 243Am, ….), named AOSTA (Activation of Osmose Samples in TAPIRO), in the TAPIRO fast neutron research reactor.
- A recent IAEA mission to Italy was made, at the request of the Italian authorities, to review the decommissioning work carried out by SOGIN ("Società Gestione Impianti Nucleari") at the Trino and Garigliano power plant sites. The ARTEMIS (Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation) report, following that of 2017, will be published shortly.

3. Spain

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 has been licensed for high-burnup fuel transportation in a PWR bare fuel cask in which, for the first time, 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. .

The licensing process of the Centralized Interim Spent Fuel Storage (ATC) continues. The ATC generic design was approved by the Consejo de Seguridad Nuclear (CSN) in 2006, and is based in a vault system. At the ATC facility the spent fuel and HLW, coming from the plant 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. Th 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 ATC Interim Loaded Cask Storage Building

has also been performed, including the different transportation casks arriving to the (DPT, HI-STAR 100, ENUN52B…) in bounding storage configurations.

A Spent Fuel and Radioactive Waste Research Laboratory is also projected in the ATC 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. An NCS analysis of this laboratory is needed, but has not been submitted yet. This laboratory will be open to international collaboration.

R&D

As reported to EGADSNF, 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. . It is planned to continue the project with new sample evaluations in a new phase of similar scope and duration, focused in BWR fuel.

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. There is lack of experimental isotopic composition data for burnup code validation, and a new measurement project is currently being considered. Analytical work to reproduce the experimental results of other samples continues.

International Collaborations

Participation in NEA working/expert groups:

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

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 review of the preliminary criticality safety demonstration of the Centralized Interim Spent Fuel Storage (ATC) is under licensing process, also as a new licensing challenge because of two reasons. In the first place, it will be the first time that Design Extension conditions for the facility will be directly included in the licensing basis. In addition, the initial licensing period requested is 60 years, but 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.

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

National Context (Overview)

The Swiss regulatory body ENSI is currently reviewing the guidance for the design and safety assessment of deep geological disposal. Whereas rather general requirement for criticality safety under normal and abnormal conditions has been set in the current version, the new revision foresees the fulfillment of the German standard DIN 25472 being currently the only international standard for this topic. This is in line with recent revision of the guidance for design and operation of nuclear fuel that points to other DIN standards with regard to application of the BUC during handling and storage in nuclear facilities.

R&D Programmes

The works on upgrading PSI CSE methodology, based on addition of the new calculation capabilities on the nuclear data uncertainties propagation and systems correlation analysis, have been formalized this year with release of the journal paper

- "On the options for incorporating nuclear data uncertainties in criticality safety assessments for LWR fuel", Annals of Nuclear Energy 116 (2018) 57–68.
- In addition, the refinement of the CSE methodology in the particular case of the BUC application for the final geological repository has been discussed in the paper presented at the recent BEPU-2018 conference:
- "Criticality Safety Evaluations for the Concept of Swiss PWR Spent Fuel Geological Repository".

Other publications relevant to CSE topics and released by PSI within the past year include:

- Nuclear data correlation between different isotopes via integral information; EPJ Nuclear Sci. Technol. 4, 7 (2018).
- Uncertainties for Swiss LWR spent nuclear fuels due to nuclear data. EPJ Nuclear Sci. Technol. 4, 6 (2018).
- Analysis of reactivity worths of burnt PWR fuel samples measured in LWR-PROTEUS Phase II using a CASMO-5 reflected-assembly model. Progress in Nuclear Energy 101 (2017).

Assessment of the latest ND libraries ENDF/B-VIII and JEFF3.3 is planned for 2018. Preliminary results show a systematic increase of k-eff values computed with JEFF-3.3 as compared with JEFF-3.2 for the LCT cases.

Next, an additional capability has been added to the PSI in-house tool COMPLINK: the automatic conversion of MCNP models into SERPENT models. The validation of SERPENT code for CSE applications using the PSI suite of 149 LCT benchmark models is also planned for 2018-2019.

Finally, a methodology for consistent calculations of k-eff, emission source (neutron and gamma) and decay heat at the level of a disposal canister loaded with spent nuclear fuel assemblies with realistically evaluated fuel compositions is under development and verification at PSI to support NAGRA's needs on optimization of the spent fuel loading curves. Individual history of each irradiated fuel assembly is considered and the calculation scheme involves CASMO5/SIMULATE3(5)/SNF and MCNP codes integrated with COMPLINK. Also the tools SHARK-X (works with CASMO) and NUSS (works with MCNP) are used for the nuclear data uncertainties propagation. The most recent work has been published in the paper

- Consistent criticality and radiation studies of Swiss spent nuclear fuel: The CS2M approach. Journal of Hazardous Materials. Volume 357, 5 September 2018, Pages 384–392

The Nagra experimental program at the JRC Karlsruhe on spent fuel integrity during interim storage is progressing. Other impact tests on real SF rods were conducted in the hot cell facilities of JRC Karlsruhe. These impact tests performed on individual rods are confirming that no defueling or large fuel release took place, also for the high burnup fuel case. This may serve as experimental bounding case for criticality safety assessment in fuel handling facility as well as for licensing process of the T/S SF casks.

International Collaborations

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

Future Challenges

Primary –the same as reported at the previous meetings.

In addition to that, it is anticipated that an efficient methodology for simplified/approximate criticality safety assessments for storage/transport containers with mixtures of fissile materials could be of interest for development at PSI to facilitate regulatory approvals for the on-site manipulation with various and sufficiently subcritical configurations. A dedicated research project proposal is under development at NES and LOG departments of PSI.

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.

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 (e.g. in the case of civil nuclear fuel manufacture and power stations) or contracted out, to consortia employed by the NDA to manage former British Nuclear Fuels Ltd (BNFL) and United Kingdom Atomic Energy Authority (UKAEA) nuclear sites.

As a result of the UK Nuclear Industry Strategy, the Department for Business, Energy & Industrial Strategy (BEIS) is now funding a number organisations via various national programmes. Consequently, the UK government owned National Nuclear Laboratory (NNL) now receives some limited government funding, to assist with issues that are (or will be) of strategic importance to the future of the UK nuclear industry.

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 European Pressurised Reactor (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.

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

b.i Industry Capability and Skills

In addition to the Nuclear Skills Strategy Group (NSSG), the 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 (e.g. 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 co-operation on high priority activities of common interest to the UK criticality safety community, e.g. through identifying and establishing appropriate Working Groups and maintaining a 'high priority 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, e.g. 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 (e.g. the Shielding Forum).
- Promote international collaboration in the field of criticality safety, e.g. by establishing co-operative arrangements with criticality professionals and bodies in other countries.

Working with the Safety Directors' Forum, WPC has recently 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

b.ii Training

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.
- A number of UK organisations are also partnering up with universities to provide placement opportunities for MSc / PhD students with the intention of enhancing future skills.
- WPC holds annual 1-day professional development workshops. Recent topics (from 2014) have covered "training our trainers"; "criticality anomalies", "good practices in criticality safety" and "the elements of criticality safety assessments". The 2018 topic will be "criticality fault analysis". "These workshops are open to all, including international attendees.
- WPC members also support the criticality module provided by the Nuclear Technology Education Consortium (NTEC).
- Every two years, NNL team up with the US University of New Mexico (UNM) to run a week long criticality safety management course in the UK. The next such course will be held in September 2018.
- There has been good recent UK attendance at the "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.

R&D Programmes, in particular:

a. Code development

a.i "Low Temperatures"

As part of continual improvement, the UK Office for Nuclear Regulation (ONR) in 2016 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 k_{eff} 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. The dutyholder should therefore demonstrate that any change in the neutron physics due to their 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 within MONK.

Additional work is being carried out by ANSWERS with support from ONR research funds. When available, ONR will be publishing the results from that work.

These developments have also resulted in the WPNCS benchmark proposal "SG-3: Criticality Benchmark: A proposal for a benchmark examining the effect of temperature on the neutron multiplication factor for PWR fuel assemblies", from Reg Wilson at Sellafield Ltd.

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 these have resulted in 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 has 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 Lawrence Livermore National Laboratory (LLNL) (USA) in the development of low temperature experiments.

c. Experimental needs

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

International Collaborations

a. Ongoing

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

Both SL and NNL actively participate in ANS standards working groups with Fred Winstanley (SL) representing the UK on the ANS-8 standards sub-committee. NNL and SL are also represented on the ANS Nuclear Criticality Safety Division (NCSD) Executive committee, Deb Hill (NNL) is the 2017/18 chair, Fred Winstanley (SL) is the 2017/19 NSCD Treasurer and ANS-8 chair. There are also a number of active or 'watching brief' UK members of various ANS-8.X standards; as well as Fred Winstanley (SL) and Neil Harris (NNL), Deb Hill (NNL) is co-chair of ANS-8.20, a member of ANS-8.22 and has offered to sit on ANS-8.17.

b. Planned

A Ministry of Defence (MoD) / BEIS proposal to host PHYSOR 2020 in Oxford was accepted at the ANS meeting held in June 2018. Kirk Atkinson (MoD) will be the Technical Program Chair. Deb Hill (NNL) has been asked to sit on their Technical Program Committee and to lead the Nuclear Criticality Safety track.

Future Challenges

Nothing to report

Input to/from NEA/NSC Programmes of Work

a. Items for discussion at WPNCS.

None

b. Items to be discussed in WPNCS Expert Groups

None

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 rod of iron-based accident tolerant cladding currently under irradiation in an operating plant. 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 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 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. In June 2018, the applicant requested the NRC to resume the review. 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 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 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 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 Nevada Field Office 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 300 students have taken the NCS hands-on training courses.

With regard to information preservation and dissemination, the NCSP revised a previous benchmark evaluation, LEU-COMP-THERM-079, through the course of its activities to prepare several additional benchmark evaluations for submission to the International Criticality Safety Benchmark Evaluation Project (ICSBEP) in the upcoming year. 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: demonstration of a nuclear reactor for low power space applications (KRUSTY-Kilowatt Reactor Using Stirling Technology), completion of 6 of 10 novel plutonium (Pu) and tantalum (Ta) critical experiments using ZPPR (Zero Power Physics Reactor) fuel (part of the TEX series of experiments), a nuclear accident dosimetry exercise using Flattop, design work for HEU (highly enriched uranium) and ^{233}U TEX experiments, subcritical measurements such as SCRαP using the BERP ball, design of experiments to study the critical effects of plutonium aging, and design of titanium sleeve experiments in the BUCCX reactor at SNL. SNL efforts also include 7uPCX experimentation with varying large pitches. There is also ongoing interest in subcritical experiments at LANL using a Np sphere. 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, 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. 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 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. LANL released a new version of MCNP – MCNP6.2 – through RSICC. The release includes the Whisper code to support sensitivity-uncertainty based methods for NCS

validation. There are estimated to be 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 6.2 over the past two 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 continues its support for research 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 is examining beyond peak reactivity, is currently underway and is planned to be completed by the end of 2018. 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 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. 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.

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}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 Office of Nuclear Energy Nuclear Data and Benchmarking Program now 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.

OECD Nuclear Energy Agency
Nuclear Science Committee

22nd Meeting of the Working Party on Nuclear Criticality Safety (WPNCS)

PROPOSED AGENDA

ANNEX B

Proposed Meeting Schedule: ***9h00 – 17h00***

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 the WPNCS Expert Groups and Sub-Groups	
• Advanced Monte Carlo Techniques Expert Group (EGAMCT)	E. Dumonteil
• SFCOMPO TRG	J. Martinez Gonzalez
• Ad hoc meeting for finalization of EGUNF benchmark	U. Mertyurek
• Status of the ICSBEP - July 2018	J. Bess
5. Reports from ongoing and new Sub-Groups for discussion/approval	
• 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
• Criticality Benchmark: A proposal for a benchmark examining 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
• Monte Carlo technique	F. Brown
• UNF benchmark	C. Carmouze
6. Preparation of ICNC 2019	S. Evo
7. Updates on Nuclear Criticality Safety National Programmes	All
8. Any other business	Chair

9. Date and place of the next meeting	Secretariat
10. Adjourn	Chair

OECD Nuclear Energy Agency
Nuclear Science Committee
Working Party on Nuclear Criticality Safety

ANNEX C

Registrants to the 2018 Working Party on Nuclear Criticality Safety meetings

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