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Sixth Workshop on Structural Materials for Innovative Nuclear Systems (SMINS-6)

Summary Report
12–15 September 2022
Idaho Falls, United States

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Sixth Workshop on Structural Materials for Innovative Nuclear Systems (SMINS-6): Summary Report

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Foreword

The Expert Group on Innovative Structural Materials (EGISM) was created in 2008 under the auspices of the OECD Nuclear Energy Agency (NEA) Nuclear Science Committee (NSC) and the Working Party on Scientific Issues of the Fuel Cycle (WPFC) to conduct joint and comparative studies to support the development, selection and characterisation of innovative structural materials that can be implemented in advanced nuclear fuel cycles under extreme conditions such as high temperatures, high-dose rates, corrosive chemical environments and long-service lifetimes.

One of the objectives of the expert group is to organise a series of workshops on Structural Materials for Innovative Nuclear Systems (SMINS) in order to stimulate an exchange of scientific information on current and innovative materials research programmes for different advanced nuclear systems, with a view to identifying and developing potential synergies. This workshop covered fundamental studies, modelling and experiments on innovative structural materials including cladding materials for the range of advanced nuclear systems such as thermal/fast and subcritical systems, as well as fusion.

Each edition of the workshop has looked to address a key theme that is topical at the time of the workshop in order to reflect how the sector has progressed since the previous edition. For SMINS-6, the theme was high entropy alloys (HEA), which had been the focus of increasing attention in material research since the 2010s with the potential for achieving some enhanced properties compared to conventional alloys. Therefore, an expert panel presentation and discussion was held to consider the question “Are we on the path to introducing high-entropy alloys to next generation nuclear systems?”

This document presents a summary of the presentations given during the workshop and of the various discussions held during the sessions and panel discussions.

The continued series of SMINS will now be organised by the Expert Group on Structural Materials (EGSM) established in January 2023, under the auspices of the NSC and the Working Party on Materials Science Issues in Nuclear Fuels and Structural Materials (WPFM), keeping the workshop’s ambition intact.

Acknowledgements

The Nuclear Energy Agency (NEA) expresses its sincere gratitude to the members of the Scientific Advisory Committee for their help with the organisation of this workshop. Special thanks go to the Idaho National Laboratory (INL), especially to Dr Jian Gan for hosting the event. Finally, the NEA acknowledges Fanny Balbaud, chair of the Expert Group on Innovative Structural Materials (EGISM) and Céline Cabet, co-chair of EGISM, for their efforts in preparing this summary report.

Attendees of the Sixth Workshop on Structural Materials for Innovative Nuclear Systems (SMINS-6), 12-15 September 2022 in Idaho Falls, United States.

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List of abbreviations and acronyms

A-DREAM	Accelerated Development of corrosion-REsistAnt Materials (Développement accéléré de matériaux résistants à la corrosion)
ADSS	Alumina-forming duplex stainless steels
AFA	Alumina-forming alloys
AGC	Advanced graphite creep
AM	Additive manufacturing
AMMT	Advanced Materials and Manufacturing Technologies
AMR	Advanced modular reactor
ANL	Argonne National Laboratory (United States)
ANSTO	Australian Nuclear Science and Technology Organisation (Australia)
APT	Atom probe tomography
ASME	American Society of Mechanical Engineers
ATF	Accident-tolerant fuel/advanced technology fuels
ATR	Advanced test reactor
BARC	Bhabha Atomic Research Centre (India)
BCC	Body centred cubic
CDRW	Capacitive discharge resistance welding
CEA	Commissariat à l'énergie atomique et aux énergies alternatives (France)
CIAE	China Institute of Atomic Energy
CIEMAT	Centre for Environmental and Technological Energy Research (Spain)
CINR	Consolidated Innovative Nuclear Research
CNEA	National Atomic Energy Commission of Argentina (Argentina)
CNL	Canadian Nuclear Laboratories (Canada)
CRIEPI	Central Research Institute of Electric Power Industry (Japan)
CVR	Centrum výzkumu Řež / Research Centre Řež (Czechia)
DIADEM	DIscovery Acceleration for the Deployment of Emerging Materials (Dispostifs Intégrés pour l'Accélération du Déploiement de Matériaux Emergents)
DOE	Department of Energy (United States)
Dpa	Displacements per atom
EBSD	Electron backscatter diffraction
EERA	European Energy Research Alliance
EGISM	Expert Group on Innovative Structural Materials
EGSM	Expert Group on Structural Materials
ENICKMA	Evaluation of Nickel-based Materials for MSR Applications (NRG project)
FCC	Face-centred cubic
FEM	Finite element method
FIDES-II	Second Framework for Irradiation Experiments
FZJ	Forschungzentrum Juelich (Research Centre Juelich, Germany)
GARS	Gas atomisation reaction synthesis

GEMMA	Generation IV Materials Maturity (EU Horizon project)
HAZ	Heat-affected zone
HITEP	High Temperature Design Evaluation Program
HEA	High-entropy alloy
HEDM	High-energy x-ray diffraction microscopy
HFEF	Hot Fuel Examination Facility
HRP	Halden Reactor Project
HT	High temperature
HTGR	High-temperature gas-cooled reactor
IAEA	International Atomic Energy Agency
IFE	Institute for Energy Technology (Norway)
IMCL	Irradiated Materials Characterisation Lab
INL	Idaho National Laboratory (United States)
IOZ	Internal oxidation zone
ISAC	Innovative System for Actinides Conversion
JAEA	Japan Atomic Energy Agency
JPNM	Joint Programme on Nuclear Materials
JRC	Joint Research Centre (European Commission)
KAERI	Korea Atomic Energy Research Institute (Korea)
KAIST	Korea Advanced Institute of Science and Technology (Korea)
KIT	Karlsruhe Institute of Technology (Germany)
LAM	Laser additive manufacturing
LANL	Los Alamos National Laboratory (United States)
LFR	Lead-cooled fast reactor
LPBF	Laser powder bed fusion
LVDT	Linear variable differential transformer
LWR	Light water reactor
MFC	Materials and Fuels Complex
MOOSE	Multiphysics Object-Orientated Simulation Environment
MSR	Molten salt reactor
MYRRHA	Multi-purpose Hybrid Research Reactor
NCBJ	Narodowym Centrum Badań Jądrowych (National Centre for Nuclear Research, Poland)
NEA	Nuclear Energy Agency
NEAMS	Nuclear Energy Advanced Modelling and Simulation
NIRO	Nuclear Innovation and Research Office (United Kingdom)
NNL	National Nuclear Laboratory (United Kingdom)
NRC	Nuclear Regulatory Commission (United States)
NRG	Nuclear Research and Consultancy Group (Netherlands)
NSC	Nuclear Science Committee (NEA)
NSUF	Nuclear Science User Facilities (United States)
ODS	Oxide dispersion strengthened
OECD	Organisation for Economic Co-operation and Development

ORIENT-NM	Organisation of the European Research Community on Nuclear Materials
ORNL	Oak Ridge National Laboratory (United States)
PNNL	Pacific Northwest National Laboratory (United States)
PSI	Paul Scherrer Institute (Switzerland)
PWR	Pressurised water reactor
R&D	Research and development
RIS	Radiation-induced segregation
RPV	Reactor pressure vessel
RTE	Rapid turnaround experiment
SALIENT	Salt Irradiation Experiment (NRG project)
SCK CEN	Belgian Nuclear Research Centre
SEM	Scanning electron microscopy
SINQ	Swiss Spallation Neutron Source
SLM	Selective laser melting
SMINS	Structural Materials for Innovative Nuclear Systems
SMR	Small modular reactor
SRO	Short-range order
SS	Stainless steel
TEM	Transmission electron microscopy
ToF SIMS	Tim of flight secondary ion mass spectrometry
TRIP	Transformation-induced plasticity
TWIP	Twinning-induced plasticity
UKAEA	United Kingdom Atomic Energy Authority
UTS	Ultimate tensile strength
WEC	Westinghouse Electric Company
WPFC	Working Party on Scientific Issues of the Fuel Cycle (NEA)
WPFM	Working Party on Materials Science Issues in Nuclear Fuels and Structural Materials (NEA)
XRD	X-ray diffraction

Executive summary

Since 2007, the Nuclear Energy Agency (NEA) has been organising a series of workshops on Structural Materials for Innovative Nuclear Systems (SMINS). The sixth workshop, SMINS-6, was held on 12-15 September 2022 in Idaho Falls, Idaho (United States), hosted by the Idaho National Laboratory (INL), in co-operation with the International Atomic Energy Agency (IAEA) and the European Energy Research Alliance (EERA), through the Joint Programme on Nuclear Materials (JPNM), with Westinghouse Electric Company (WEC) and Thermo Fisher Scientific. The workshop received 75 abstracts. In total, around 120 delegates from five continents attended, with 64 presentations (47 oral presentations and 17 posters) and 14 invited talks.

The main purpose of the SMINS workshop series is to stimulate an exchange of scientific information on current and innovative materials research programmes for different advanced nuclear systems with a view to identifying and developing potential synergies. SMINS-6 covered fundamental studies, modelling and experiments on innovative structural materials, including cladding materials for a range of advanced nuclear systems such as thermal/fast and subcritical systems, as well as fusion and small modular reactors (SMRs).

During the workshop, the technical sessions discussed the following topics for which the key aspects are summarised below.

- Fundamental and experimental studies on irradiation damage:

  Presentations were given on various theoretical and practical aspects of radiation damage accumulation in nuclear materials. The case studies mostly focussed on metallic materials, pure metals, and alloys that are of interest in the context of advanced fission and fusion reactors. While ion irradiations were widely used to investigate radiation resistance, neutron-irradiated materials were also tested. From this perspective, Lin Shao's (Texas A&M University) talk was of great interest in terms of unifying understanding and experimental practices. The authors concluded that, if strict rules are followed to avoid point defect recombination due to surfaces and interstitials, then accelerator-based testing is a reliable method of emulating swelling due to neutron damage.

- Corrosion for advanced nuclear systems:

  Presentations were given on the corrosion of structural alloys in liquid lead and in UCl_3-containing chloride molten salts. It was concluded that best practices and standardisation of corrosion tests were key to producing sound results and analyses, to support the development of Generation IV reactors and advanced modular reactors (AMRs).

- Advanced manufacturing and materials including complex concentrated alloys and advanced cladding:

  The development of advanced manufacturing processes, including various additive manufacturing techniques, could transform the nuclear sector in the same way that it has transformed other industrial domains. However, as was outlined at SMINS-5, the nuclear sector presents specific challenges in terms of testing additive manufactured materials, qualifying components and certifying processes. The advanced manufacturing of innovative alloys, such as high-entropy alloys, derivative high-entropy alloys and self-passivating “Smart alloys”, offers a fast track for screening new alloys in line with the establishment of materials acceleration platforms. The desire for advanced, often accident-tolerant, fuel

cladding drives material innovation. This critical area of research aims to improve the safety and performance of nuclear reactors by developing materials that can withstand harsher conditions. Overall, the workshop showcased the diversity of approaches being pursued to develop advanced cladding materials and emphasised the importance of ongoing research in this field.

- Materials for high-temperature applications with a specific session on development of molten salt reactors:

  The presentations, which addressed different materials and their processing for various high-temperature nuclear applications, demonstrated the range of environments and damage encountered in advanced nuclear systems. Three talks considered the critical topic of welding/bonding for high-temperature applications. Two presentations also emphasised the importance of corrosion research and the testing of materials for irradiation in molten salt reactor (MSR) development. These presentations demonstrated the need for international collaboration and consortiums to accelerate the development of high-performance materials capable of surviving the challenging environments of AMRs, which are characterised by high temperatures, corrosive media and radiation.

The technical sessions were enriched by eight overviews of different national and international programmes, which demonstrated the dynamism surrounding nuclear innovation. The poster session provided an opportunity for younger researchers, in particular, to showcase studies dealing with structural materials for advanced nuclear applications, as well as the development of irradiation devices and methods, and areas of more focussed research.

A specific panel discussion was held on "*Are we on the path to introducing high-entropy alloys to next generation nuclear systems*?" Four keynote lectures by E. Martinez Saez, E. Pickering, A. Clarke and A. Couet introduced the roundtable of experts. The consensus can be summarised as follows:

- There was confidence that there would be future applications of high-entropy alloys (HEA), but even if there are no actual future applications, a lot can be learned about other alloys by studying HEA or complex alloys.
- HEA are expected to be initially used in non-safety critical, or non-structural and replaceable components, such as the fuel wrapper or clad. For these, performance needs to be either as good as current alloys at lower cost, or better.
- Other systems for HEA applications would be those with more "relaxed" regulation requirements such as materials test reactors, spallation sources or space reactors.
- It was noted that additive manufacturing may be suitable for some HEA fabrication, opening the possibility for spatial adjustments in composition.
- A major challenge to the qualification of HEA for nuclear application is that the level of knowledge on HEA is still very low, even of the thermodynamics for phase prediction. In addition, irradiation data are missing and even if ion irradiation data are useful for screening, neutron data remains essential to have confidence (for example) in precipitation under irradiation.
- HEA are currently immature, so their implementation in advanced nuclear systems could occur at least a decade from now. However, it could be accelerated significantly if a specific industrial application was identified.

- The development of HEA alloys with non-nuclear near-term applications in large volumes would significantly accelerate the process.

Session 1. Overview of programmes

Session 1 was chaired by Jian Gan of Idaho National Laboratory (INL, the United States), Alfons Weisenburger of Karlsruhe Institute of Technology (KIT, Germany), Fanny Balbaud of Commissariat à l'énergie atomique et aux énergies alternatives (CEA, France) and Manuel Pouchon of the Paul Scherrer Institute (PSI, Switzerland). In this session, there were eight programme overviews, three lunch talks and one dinner talk.

The first programme overview was given by Sue Lesica from the Department of Energy (DOE, United States), Office of Nuclear Energy (DOE-NE) on their programme on materials for innovative nuclear systems. The presentation covered R&D integration, co-ordination, collaboration, industry engagement on advanced reactor technologies, advanced materials, code qualification for Alloy 617 and 709, licensing and American Society of Mechanical Engineers (ASME) code rules, the redirection of advanced graphite creep (AGC) irradiation programme, advanced materials R&D, light water reactor (LWR) sustainability, advanced materials and manufacturing technologies (AMMT), and the new Programme of Innovative Nuclear Materials.

The second programme overview was given by Dong-Jin Kim from the Korea Atomic Energy Research Institute (KAERI), focussing on the Korean research activities in the field of nuclear structural materials. The scope included Korean nuclear power plants (24 existing and four under construction), five research groups at KAERI (mechanical, corrosion, microstructural damage, innovative materials for advanced nuclear energy and innovative materials processing) and their ongoing projects. He also discussed the programmes of materials harvesting from the decommissioned Kori Unit-1, SMRs, high-temperature gas-cooled reactors (HTGRs) and materials R&D for accident-tolerant fuels (ATFs).

The third programme overview was presented by Mike Ickes from Westinghouse Electric Company (WEC) covering materials development for the WEC lead-cooled fast reactor (LFR). His talk included an overview of their LFR, the materials strategy for fuel cladding and heat exchangers, the materials R&D programme, and WEC's activities on code and standards development.

The fourth programme overview was given by Andrea Jokisaari from INL on behalf of Meimei Li from Argonne National Laboratory (ANL), focussing on the DOE Advanced Materials and Manufacturing Technologies (AMMT) Programme. The talk detailed AMMT's mission, vision and strategy, and goals, taking into account the technology landscape and materials needs for nuclear energy, and their five-year roadmap. Further details were presented on AMMT's work on rapid material qualification including: their work to address challenges for the qualification of materials made by additive manufacturing (AM) through their phased approach; opportunities in materials science advances and modelling, including the example of ASME code for AM 316 stainless steel (SS); advanced materials and manufacturing development; and environmental effects (irradiation, compatibility and high-temperature effects). She also presented their approach to developing a multidimensional data correlation platform, and their approach to technology demonstration and deployment, including capability development and transformative research, and their novel approaches to materials concept and design.

The fifth presentation was given by Peter Hosemann from University of California Berkeley on materials selection and graded components using AM. His talk covered materials selection challenges for nuclear applications, materials properties considering

neutron capturing, low-activation materials based on decay time after service, transmutation of irradiated materials and materials' grading using AM. He elaborated on microstructurally graded materials, the work done to correlate electron backscatter diffraction (EBSD)/microstructure with mechanical properties and ways to tailor microstructure. He also discussed compositional grading via AM and printed vs. cast HEAs.

The sixth overview presentation was given by Céline Cabet from CEA on behalf of Lorenzo Malerba from the Centre for Environmental and Technological Energy Research (CIEMAT, Spain), entitled "*A unified European strategic research agenda for nuclear materials."* The presentation discussed the projected total installed nuclear power in Europe in 2040, facts concerning reactor life extension, SMRs, Generation IV, materials challenges, materials R&D synergy between fission and fusion energy, materials R&D for other clean energy technologies, and the European Union partnership on nuclear materials via the Organisation of the European Research Community on Nuclear Materials (ORIENT-NM) Horizon project and their 5- and 10-year programme goals.

The seventh overview talk was given by Alfons Weisenburger from Karlsruhe Institute of Technology (KIT, Germany) on European activities in the frame of the European Union Horizon Generation IV Materials Maturity (GEMMA) project, focussing on alumina-forming alloy (AFA) steels for LFRs. After describing the GEMMA project, he elaborated on the motivation to use Pb and Pb–Bi as liquid metal coolants for Generation IV and the impact on the fuel cycle. He detailed the challenges related to the use of liquid Pb/Pb–Bi, such as corrosion in liquid Pb alloys, the working window (temperature and dissolved oxygen) for austenitic steels, corrosion control, AFA development, AFA oxidation in high-temperature steam, mechanical property testing in air and in liquid Pb–Bi, ion irradiation studies of AFA, and bend testing of AFA welds.

The last overview talk was given by Caleb Massey from Oak Ridge National Laboratory (ORNL, United States) on current gaps in modelling deformation behaviour of oxide dispersion strengthened (ODS) alloys for fission/fusion applications. He discussed materials design windows, precipitates as a function of processing for ODS FeCrAl alloys, microstructural characteristics vs. processing, microstructure vs. performance in cladding burst tests, "BISON" fuel performance code simulations (temperature and pressure, visco-plastic response, and thermal creep), experiments vs. modelling for cladding burst tests, significant anisotropy in cladding as a function of microstructure, complex interplay between dislocations and precipitates in ODS creep behaviour, and challenges and opportunities on developing a deformation map for ODS alloys.

The first lunch talk was given by Jian Gan from INL on the advanced characterisation capabilities at INL, with an emphasis on the R&D capabilities at the Irradiated Materials Characterisation Laboratory (IMCL). IMCL can support advanced characterisation (microstructure, physical properties, mechanical and thermal properties) of highly radioactive materials over eight orders of magnitude in length scale (1 cm to 0.1 nm).

The second lunch talk was given by Peng Xu from INL on the harvesting of structural materials from decommissioned commercial nuclear power plants and test reactors, to support reactor life extension and future reactor needs, as a recent effort for the Nuclear Science User Facility (NSUF) Materials Library.

The third lunch presentation was given by Benjamin Spencer from INL on structural materials and chemistry R&D in the DOE-NE's Nuclear Energy Advanced Modelling and Simulation (NEAMS) programme. He elaborated on the work done in the technical areas of fuel performance, reactor physics, structural materials and chemistry, thermal fluids and multi-physics applications. He presented the Multiphysics Object-Orientated Simulation

Environment (MOOSE) computational framework and discussed the work done in the fields of MSR chemistry and corrosion, structural component integrity, molten salt thermophysical property and the NEAMS' efforts on structural materials, high-temperature creep and simulation of concrete materials degradation.

The dinner talk was given by Rory Kennedy from INL on the NSUF programme support on advanced reactor structural materials R&D. He summarised that the NSUF structural materials projects totalled 293 at the time of presenting. These included 40 Consolidated Innovative Nuclear Research (CINR) projects at a total of approximately USD 50M (26 projects at universities, nine at national laboratories and five in industry/small business) and 253 Rapid Turnaround Experiment (RTE) projects at a total of approximately USD 13M (190 projects at universities, 56 at national laboratories, five in/for industry/small business and two at the Nuclear Regulatory Commission [NRC]).

Session 2. Fundamental and experimental studies on irradiation damage

Session 2 was chaired by Céline Cabet (CEA, France) and Yong Dai (PSI, Switzerland), and included a total of nine presentations, addressing various theoretical and practical aspects of radiation damage accumulation in nuclear materials. The case studies mostly applied to metallic materials, pure metals and alloys, of interest for advanced fission reactors and fission.

Sergei Dudarev of the United Kingdom Atomic Energy Authority (UKAEA, United Kingdom) proposed an original approach applied to the constitution of radiation damage in fusion materials, like tungsten and ultra-pure iron, but of practicality for many other metals. It was stated by S. Dudarev that experimental observables at the nano- and micro-scale, for instance from transmission electron microscopy (TEM) examination, can now be input into the finite element method (FEM). The ambition is to bridge the scale gap (in time and length) between the atomic description of point defects as calculated by ab initio methods and the FEM method widely used by nuclear engineers for structure mechanical design. Transition between discrete radiation defects to continuum damage (as in FEM) involves the homogenisation of the elastic strain field, which is a scaleless measure. In this development, the relaxation volume density of defects is an important quantity.

Lin Shao (Texas A&M University, United States) discussed the credibility of using self-ion irradiation to simulate neutron-induced void swelling. L. Shao and the co-authors of the presentation wanted to define a safe zone width in which to extract useful data for analysing radiation defects in pure iron under 5MeV Fe ion irradiation. Swelling was observed by TEM as a function of depth for beam energies from 1 to 5 MeV, dpa rates from 2 to 6.10^{-3} dpa/s and temperatures from 425 to 525°C. The effects of injected interstitials and void denuded surface have been described in previous works. However, defining a "safe analysis region" must also consider temperature and dpa rate. If strict rules are followed (to avoid point defect recombination due to surface and interstitials), it is concluded that accelerator-based swelling testing is a dependable and credible method to emulate neutron damage.

Dominic Piedmont (University of Illinois at Urbana-Champaign, United States) described an application of in situ three-dimensional high-energy synchrotron x-ray diffraction also known as high-energy x-ray diffraction microscopy (HEDM), to map the deformation behaviour of neutron-irradiated Fe–9%Cr. Information from both far-field HEDM and near-field HEDM are combined and the use of data analysis algorithms allow matching of parent and child grains across deformation levels. Thus, the evolution of individual grains under strain can be visualised in three dimensions. Irradiated samples showed a higher chance of large misorientation after deformation.

Stephen Taller (ORNL, United States) examined the key processes for microstructural evolution at high temperatures in nickel-based superalloy 718, using in situ ion irradiation. Irradiation experiments were conducted under a krypton ion beam with 1.10^{-3} dpa/s at 500, 600 and 700°C. Each in situ ion irradiation experiment generates a vast amount of information and a neural network algorithm was used to identify every feature in each frame of the TEM videos. The initial microstructure contained a high density of precipitates, which take part in the alloy's creep strength and helium swelling resistance. Dissolution of pre-existing γ and δ precipitates occurred early (< 1 dpa) for all conditions. At 500°C, small cavities nucleated, and γ and δ phases emerged. At 600 and 700°C, both cavity nucleation and precipitate dissolution were accelerated.

Lingfeng He (North Carolina State University, United States) gave a presentation on radiation effects in additively manufactured 316L SS and Hf-added variants. The global objective was to better understand the role of Hf in reducing radiation-induction damage and hardness. A directed energy deposition process was used as a method of rapid prototyping of different compositions and 2 MeV proton irradiation at 360°C (to 2.5 dpa at ~10 μm) completed the high-throughput experimentation. TEM observations confirmed that the density of dislocation loops decreases in Hf-doped irradiated 316L SS and a percentage of 1% Hf showed maximum suppression. As-built steel was shown to be superior to the thermo-mechanically treated recrystallised AM steel due to the presence of Cr and Mo precipitates. Finally, the Rel-rod dark field TEM imaging technique was, in this case, not reliable to calculate dislocation loop parameters due to the pre-existing stacking faults from AM, and further work was intended to distinguish between stacking faults and radiation loops.

Vladimir Krsjak (Slovak University of Technology, Slovak Republic) introduced the use of positron annihilation spectroscopy for studying the early stage of radiation defect evolution in fusion conditions. He-implanted F/M steel and ODS steel were investigated. Positron annihilation lifetime spectroscopy and TEM are complementary techniques to characterise the evolution of small vacancy clusters formed in the incubation period into large cavities. For ODS steel, the incubation period for helium bubble growth was directly linked to open-volume (vacancy-type) defects at oxide/matrix interfaces and the better swelling resistance was attributed only to a shift in the incubation phase, which is notable up to a helium concentration of ~1 at.%. At higher helium concentrations, both steels have the same swelling tendency. It was concluded that the superior radiation resistance of ODS steels originates in the early stages of bubble evolution while nano-oxides act as efficient traps for vacancy clusters.

Yong Dai (PSI, Switzerland) presented a microstructural analysis by atom probe tomography (APT) and TEM of ODS Eurofer irradiated to 20 dpa in the Swiss Spallation Neutron Source (SINQ) spallation target at 300 and 480°C. The global objective was to qualify the evolution of nanoparticles under irradiation in ODS alloys due to dissolution during the cascade phase, and subsequent growth through the radiation-induced segregation (RIS). After irradiation at 300°C, the density of oxide-clusters has increased by ~50% and the average size has decreased by ~20% (with compositional changes). In the meantime, smaller nitrogen-clusters (rich in MnSiTiCaScK) are present in much higher density. After irradiation at 300°C, a bimodal population of oxide-clusters was observed, with a group corresponding to initial clusters (>10%Y) and newly formed nanoparticles (diameter of 3.6 nm) with a lower Y content.

Dominic Piedmont (University of Illinois at Urbana-Champaign, United States) gave a talk on behalf of James Stubbins on microstructure analysis of advanced test reactor (ATR)-irradiated HT9 to 10 dpa at target temperatures of 300, 450 and 550°C. TEM examination of the dose and temperature evolution of dislocation loop size correlates with the evolution of microhardness with dose as expected in the standard dispersed barrier-hardening model. At higher irradiation temperatures, early onset strengthening occurs before evolving to lower values. “G-phase”, sigma phase and other RIS contribute at lower temperatures (below 400°C). This ongoing work will be completed by further analysis of ductility losses.

The presentation given by Malwina Wilding (INL, United States) on the development of an in-pile creep testing capability for the ATR reactor closed the session. The INL test rig design, based on an Institute for Energy Technology (IFE)/Halden Reactor Project (HRP) design, was presented. Work is ongoing to optimise the linear variable differential transformer (LVDT) transducer, which measures dimensional changes, and to test it in

pressurised water reactor (PWR) prototypic conditions in an autoclave. This development is performed in co-operation with the NEA, as part of the Second Framework for Irradiation Experiments (FIDES-II).

Session 3. Corrosion for advanced nuclear systems

Session 3 was chaired by Alfons Weisenburger (KIT, Germany) in which two presentations were given, one on corrosion in liquid Pb and the other on corrosion in UCl_3 containing chloride molten salts.

Lukas Kosek (Narodowym Centrum Badań Jądrowych / National Centre for Nuclear Research, NCBJ, Poland) presented the performance of selected structural materials, two ferritic-martensitic steels (T91 and Eurofer97) and three austenitic variants (S316L, S318 L(N)-IG and 15-15Ti stabilised AIM1 20% cold worked) in oxygen-controlled flowing Pb at 480°C. The three austenitic steels have a 3 µm thin, fine crystalline, work-hardened scale on top due to the final sample preparation step. Both ferritic-martensitic steels exhibit no dissolution attack but did show the formation of the typical three-layered oxide scales, including the internal oxidation zone (IOZ) with a maximum thickness of 30 µm for the T91 and 60 µm for the Eurofer97 after 16 000 hours. The Eurofer97, which contains less Cr but some W, tends to form a thicker IOZ scale under the same conditions, which can be attributed to the lower Cr content, the larger grain size and the W content. The different austenitic steels showed only a little dissolution attack, even with 20% cold working. A thin ferritic layer formed on all three austenitic steels, but with only little oxidation and dissolution, while the samples after 4 000 hour exposure showed higher oxidation than the 16 000 hour specimens. Electropolishing to remove the 3 µm outer work-hardened scale resulted in clear dissolution attack of the order of µm and clearly demonstrated the positive influence of such a scale. The discussion highlighted this fact and the need to consider the manufacturing process when discussing corrosion experiments.

Trishelle Copeland-Johnson (INL, United States) presented the corrosion mechanism of Ni-based superalloy Inconel 617 in NaCl-MgCl and LiCl-KCl-UCl_3 at 700°C. In NaCl-$MgCl_2$, the depletion of Ni and Fe, and the formation of pores accompanied by the formation of MgAlO and Cr-oxide, was observed. Whether the oxygen results from inadequate cleaning of the salts prior to the exposure or from the exposure itself could not be answered in the discussion. In U-containing chloride salts, this changed dramatically. Uranium penetrated large parts of the specimen in which Ni and Cr were now also seen to be depleted. A porous network filled with Li and Cl atoms was the consequence of this penetration. The post-test investigation of the samples exposed to UCl_3 containing salts will be continued to clarify the final questions.

Session 4. Advanced manufacturing

Session 4 was chaired by Fanny Balbaud (CEA, France) and included a total of four presentations addressing developments on advanced manufacturing processes for nuclear applications.

In the frame of the Advanced Materials and Manufacturing Technologies (AMMT) programme, Isabella van Rooyen from the Pacific Northwest National Laboratory (PNNL, United States) presented the extensive work performed on the development of the material score cards to support the DOE-NE's prioritisation and decision making processes. These material score cards allow them to be evaluated for each type of nuclear reactor with respect to various criteria such as code availability, gaps in data availability for performance values and measurements, technical maturity for end use, supply chain availability, etc. The materials scored included stainless steel, SiC, graphite and nickel alloys. In the end, the scores obtained allow for defining the developments required to achieve the desired properties.

Stuart Maloy (PNNL, United States) presented work on the development of Grade 91 steel produced by additive manufacturing for affordable nuclear reactor components with improved radiation tolerance. The primary objective of this work was to develop a method and process model that provides in situ tempering of a Grade 91 steel (a radiation tolerant steel) during laser additive manufacturing (LAM). Several test samples were produced by Optomec using a direct energy deposition laser process with varying amounts of preheating. Microstructural characterisations were performed as well as hardness characterisation and tensile testing, which showed a strong correlation between the microstructure and the mechanical properties. Using input from the experimental measurements and controlled heat treatment studies, a process model has been developed to predict the changes in mechanical properties during additive manufacturing.

Tianyi Chen (Oregon State University, United States) presented results on the mechanical properties and radiation response of 304 ODS steel additively manufactured via selective laser melting (SLM). First, the process of manufacture was detailed showing that even with powders that are not fully mechanically alloyed, SLM can fabricate 304L ODS alloys with a high density (99%) and uniform distribution of oxide particles. Then, microstructural characterisations showed that the as-fabricated ODS alloys have a uniform distribution of the oxide particles, and that both morphology and composition of the particles were maintained after SLM. After thermal treatment, it was revealed that the oxide particles are stable and were believed to contribute to the microstructural thermal stability and elevated-temperature mechanical strength. Finally, oxide particles survived under ion irradiation and suppressed void swelling by serving as defect sinks (or dislocation network pinning sites).

Manuel Pouchon (PSI, Switzerland) presented work on in situ observation of powder- and gel-based additive manufacturing processes for ceramics. First, an overview of the work performed at PSI on ceramics/fuel production was presented. Then, the details of a project on three-dimensional printing were presented showing developments in high resolution (10 µm) printing as well as activities on droplet-based gel printing. In situ observations performed during the additive manufacturing process were also presented; for example, *operando* powder diffraction and *operando* tomography during laser power bed fusion (LPBF) of alumina. These in situ observations allow for identifying the effect of process parameters such as laser power on the morphology of printed alumina, visualising the melt pool and its stability, and observing pore formation and crack growth.

Session 5. Materials for high-temperature applications

Session 5 was chaired by Stuart Maloy (PNNL, United States) and included eight presentations on different materials and their processing for various high-temperature nuclear applications. Welding/bonding for high-temperature application appears to be a critical topic and was considered in three of the talks.

Ondrej Muransky (Australian Nuclear Science and Technology Organisation [ANSTO], Australia) introduced two data-driven frameworks for the prediction of high-temperature fatigue life. The data set provided by INL contains 44 high-temperature fatigue tests on Alloy 617 at two temperatures. After data pre-processing, 11 tests were used to develop the models, 22 tests were used to train the models and 11 tests were used for validation. Regularised linear regression showed incorrect tendencies. Recurrent neural networks could process time-dependent data but the standard error still happened to be quite large. In this specific use case, an empirical approach like the Coffin-Manson model may be performed instead.

After an introduction of the National Atomic Energy Commission of Argentina (CNEA), its activities on materials and the nuclear programme in Argentina, Martin Iofrida (CNEA, Argentina) gave a talk on isothermal and continuous cooling transformations in a solution-annealed 508 Grade 3 Class 1 steel. Microscopy and dilatometry were employed for qualitatively describing the steel metallurgical state as a function of the austenisation treatment parameters: temperature and cooling rate.

Injin Sah (KAERI, Korea) examined the solid-state diffusion welding of Ni-based alloys in the context of designing plate heat exchangers for SMRs and AMRs. Plates from three materials were diffusion welded and tested: Alloy 617, Alloy 800H and Alloy X. Characterisation included microstructure examination especially to quantify the grain boundary porosity, migration and precipitation state, as well as mechanical tests such as tensile, Charpy impact, fatigue and creep tests. In line with the inferior grain boundary quality, the mechanical properties of the diffusion welded specimens were equivalent or inferior to those of base alloys in the unwelded condition. In particular, the occurrence of grain boundary precipitation during welding can impact ductility.

Wenjing Li (Canadian Nuclear Laboratories [CNL], Canada) presented a thorough investigation of filler materials for welding Alloy 800H for high-temperature application. Double weld joints were produced using different filler alloys: 625, 82, 617, 230 and 316L were characterised. Weld characterisation was based on hardness measurements, room and high-temperature tensile tests, and creep tests complemented with microstructure analysis. Low-cycle fatigue tests were still ongoing. In all welds, fracture did not occur in the fusion zone nor in the heat-affected zone (HAZ). The ultimate tensile strengths (UTS) at 760°C of all welds met the requirements with only limited ductility decreases. The creep rupture time at 80 MPa and 760°C was longer for filler materials than base metal, with a loss of creep ductility following the order 316<617<625<230. This series was related to the metallurgical and precipitation state.

Hyeong-Yeon Lee (KAERI, Korea) reviewed the commonalities and differences of three mechanical construction codes: ASME Section III Div. 5, ASME-HB and RCC-MRx for designing high-temperature welded joints of nuclear components. Some rules from the ASME Section VIII, Div. 2, that are non-specific to nuclear components were also considered. Different rules are implemented for creep-fatigue assessment of base metal and welded joint. In addition, the datasets may not cover the entire temperature range. KAERI

was performing tensile, fatigue and creep rupture tests of 316L SS up to 700°C, and developing design coefficients. The plan was to input the data into RCC-MRx. The High Temperature Design Evaluation Program (HITEP) platform unites the rules of the three codes for reliably evaluating welded joints. As an example, HITEP was applied to design a laboratory device made of 316L SS for testing energy storage with liquid sodium.

Sam Sham (INL, United States) presented an analysis of the code qualification needs for Alloy 709 as a high-temperature structural material. The analysis shows that Alloy 709 performs well and even better than 316H SS regarding creep strength and compatibility with liquid sodium. However, long experimental tests would be necessary to implement design rules for Alloy 709 in the ASME code. For instance, creep tests of one-fifth of the targeted creep life are expected for austenitic SS, which poses a high challenge as regards to a 60-year design life. A staged qualification approach is favoured, which would generate short-term data first with a preliminary application for code case, then data from very long tests would enable extension of the case.

Difan Zhang (PNNL, United States) discussed an unconventional manufacturing route for ODS alloys, which does not involve a ball milling step. This alternative route, called gas atomisation reaction synthesis (GARS) enables making precursor ODS steel powders. The GARS precursor powder was then used to manufacture ODS steel through solid state processing, including friction consolidation and extrusion. Preliminary results showed that Y/Ti/O species were intimately mixed and rapidly reacted to form nano-oxides with a number density of $\sim 10^{22}/m^3$, a particle mean diameter of 4.33 nm and a bimodal distribution with compositional difference.

David Frazer (INL, United States) described a high-level sample holder for high-temperature tensile tests in a scanning electron microscopy (SEM) setup for accommodating radioactive materials. This enables small scale mechanical testing up to 800°C. Indention tests in situ within the SEM are also feasible. Examples were given on the analysis of a FeCrAl alloy and a zirconium alloy specimen coated with Cr by cold spraying. Tensile and compression tests were performed on 7 µm x 7 µm specimens and the in situ microscopy allowed for the observation of crack propagation, interface failure or coating fracture.

Session 6. Materials development for molten salt reactors

Session 6 was chaired by Manuel Pouchon (PSI, Switzerland). The two presentations in the session highlighted the importance of corrosion research and irradiation testing of materials for MSR development.

Fanny Balbaud (CEA, France) discussed the CEA's research programme on corrosion in molten chlorides. The Innovative System for Actinides Conversion (ISAC) project aims to investigate the feasibility of NaCl-$PuCl_3$ type salts for developing a fast MSR for Am transmutation. The CEA is conducting research on the influence of salt chemistry on corrosion, materials screening, corrosion mechanisms and long-term behaviour evaluation, as well as exploring coatings and other protection solutions to mitigate corrosion. The DIADEM (DIscovery Acceleration for the Deployment of Emerging Materials) and A-DREAM (Accelerated Development of corrosion-REsistAnt Materials) initiatives were also highlighted.

Ralph Hania (Nuclear Research and Consultancy Group [NRG], Netherlands) discussed the irradiation testing of nickel-based alloys for MSRs, specifically in the context of the Evaluation of Nickel-based Materials for MSR Applications (ENICKMA) project. The project involves the testing of five different nickel-based alloys under neutron irradiation at high temperatures to study material degradation behaviour. The results of tensile tests and oven testing of the nickel-based alloys were presented, showing different behaviours under different annealing conditions. The Salt Irradiation Experiment (SALIENT-03) project, focussed on in-pile corrosion testing of Hastelloy N in different salt chemistries, was also introduced.

These presentations demonstrated the need for international collaboration and consortiums to accelerate the development of high-performance materials that can survive the very challenging environment of MSRs, characterised by high temperatures, corrosive salts and radiation.

Session 7. Properties of complex concentrated alloys

Session 7 was chaired by Alfons Weisenburger (KIT, Germany). This session included two presentations, one focussing on modelling and the other on experimental techniques.

The presentation of Duc Nguyen (UKAEA, United Kingdom) discussed the composition stability of derivate high entropy alloys and SMART alloys for nuclear fusion bases on multi-scale modelling approaches. Understanding the composition stability of multi-component systems, including defect concentration as a function of irradiated temperatures, was achieved by combining first-principles Continuous Energy Hamiltonian and Monte Carlo simulations. This new thermodynamic approach allows for predicting the composition stability in defective multi-component alloys for which the short-range order (SRO) is directly derived. Cr/V rich segregation plays a significant role in the outstanding radiation resistance in W-based derivative HEAs. The mechanism of void decoration by transmutation products in neutron-irradiated W was simulated, and a comparison with TEM and APT experiments exhibited strong correlation between Re and Os as a function of solute and defect concentrations. The spinodal decomposition between W and Cr played an important role in understanding microstructure evolution of W-Cr-Y-Zr self-passivating SMART alloys under neutron irradiation. Finally, the disorder-order transition was being investigated to understand the relationship between SRO and mechanical properties, via the development of machine learning potential for predicting the stress-strain relationship in complex concentrated alloys.

Amey Khanolkar (INL, United States) presented a rapid screening methodology for high entropy alloys using laser ultrasonics. By using laser ultrasonics, the elasticity modulus can be measured and correlated to changes in grain size and phase changes of the material. Ultrasonic waves are strongly affected by material microstructure and, therefore, serve as a facile means to probe elastic properties, phase content, and their size distributions and volume fractions. This technique was demonstrated on FeCrNiCo-HEA alloys by monitoring the temporal evolution of precipitate-induced strengthening. Laser-generated ultrasonics showed potential in in situ (real-time) and non-destructive monitoring of microstructural changes including phase changes. Combining laser-generated ultrasound measurements with rapid, sample production and machine learning might be a holistic approach towards accelerated material discovery, and could accelerate HEA development.

Session 8. Materials development for advanced cladding

Session 8 was chaired by Manuel Pouchon (PSI, Switzerland) and brought together findings on the development of advanced cladding materials, many of which may also offer benefits for accident tolerance. This critical area of research aims to improve the safety and performance of nuclear reactors by developing materials that can withstand harsher conditions.

The first presentation, by Chaewon Kim from Korea Advanced Institute of Science and Technology (KAIST, Korea), introduced a new class of materials, alumina-forming duplex stainless steels (ADSS), which show great promise as accident-tolerant fuel cladding materials. The ADSS alloy exhibited high strength, ductility and corrosion resistance, and demonstrated improved performance in high-temperature steam oxidation and creep behaviour.

Ben Garrison (ORNL, United States) then presented on the development of mechanical testing methods for nuclear fuel cladding materials. His research focusses on producing high-confidence mechanical performance values for out-of-reactor materials, using techniques such as digital image correlation to evaluate deformation. This work aims to improve the understanding of cladding material behaviour under various conditions.

Kester Clarke from the Colorado School of Mines (United States) presented on the role of nitrogen in the structure and properties of proton irradiated 12Cr1MoWV ferritic-martensitic steels for advanced reactors. The precipitation state of the various conditions was characterised by TEM and time of flight secondary ion mass spectrometry (ToF-SIMS), and correlated to tensile properties and internal friction.

Finally, Calvin Lear from Los Alamos National Laboratory (LANL, United States) explored the impact of capacitive discharge resistance welding (CDRW) on the radiation tolerance of 14YWT cladding. His research demonstrated that CDRW can produce high-quality welds with minimal evolution at the joint, and that the material exhibits minimal swelling and dispersoid stability under ion irradiation. However, the presentation also highlighted the need for further research into the potential risks of embrittlement associated with CDRW.

Overall, the session showcased the diversity of approaches being pursued to develop advanced cladding materials and highlighted the importance of continued research in this area.

Poster session

The poster session was chaired by Jian Gan (INL, United States). Each of the 17 poster presenters gave a short, 3-minute oral presentation at the start of the session. The session was well attended, with many participants inspired by the various posters to engage in extensive discussion with the presenters. INL's Associate Laboratory Director also attended.

The poster session covered a broad range of topics including: corrosion in nuclear components, corrosion of ODS in Pb–Li coolant, ion irradiation study of graphite, creep rupture strength improvement, surface alloys by electron-beam modification, metal hydride moderator for micro-reactors, modelling of creep in U–Mo, castable nanostructured alloys for fusion reactors, SiC/SiC composites for fusion reactors, local strain mapping for micromechanical testing, additive manufacturing for functionally graded materials, assessment of ATF concepts using "BISON" code, creep validation test for the "GRIZZLY" materials performance code, creep rupture life of Alloy 617, radiation resistant steel with nanosized NbC precipitates, strain mapping in graphite and MAX phase ceramics, and the effect of P on precipitation in reactor pressure vessel (RPV) steel elucidated by APT studies.

Conclusory panel discussion: Are we on the path to introducing high entropy alloys to next generation nuclear systems?

The panel discussion was chaired by James Marrow (University of Oxford, United Kingdom).

The panel discussion was preceded by presentations from Duc Nguyen (UKAEA, United Kingdom) on behalf of Enrique Martinez Saez (Clemson University, United States), Edward Pickering (University of Manchester, UK), Amy Clarke (Colorado School of Mines, United States) and Adrien Couet (University of Wisconsin-Madison, United States). The panel comprised Peter Hosemann (University of California, Berkeley, United States), Edward Pickering, Amay Clarke and Adrien Couet, with contributions from the floor.

Enrique Martinez Saez (Thermodynamic study of Hf addition to refractory W-Ta-Cr-V high-entropy alloy from First Principles) noted that to design an HEA, the aim was to choose elements to combine with W that transmute to low-activity products. This led to a nanocrystalline W-Ta-Cr-V alloy, which was produced as single-phase body centre cubic (BCC) by magnetron sputtering. Analysis by APT found layered segregation, which was very thermally stable. Cr-V rich precipitates also formed with irradiation but did not cause significant hardening. The formation of precipitates was explained by SRO: Hf introduces more than one order/disorder transition, and this predicts the pairing of CrV and CrHf to form precipitates. This approach leads to a design methodology to study thermal stability and concentration landscapes.

Ed Pickering (Properties of high-entropy alloys for nuclear applications) posed the question "*Do HEA have special irradiation properties*?" He noted that there was evidence that face centre cubic (FCC) HEA had smaller more numerous loops and less swelling, less irradiation hardening, and excellent phase stability under irradiation. However, not all studies supported these trends. Many explanations for this refer to entropic stabilisation, the severely distorted lattice, slow diffusion or the "cocktail effect". However, these effects are not universal and may be important only in particular systems. He gave the example of fusion plasma facing components, where the aim is to design alloys with low activation and with a BCC structure for low-irradiation swelling, and a high-melting point. The systems explored include V, Cr, Mn with Ti or Fe or Fe+Al. It was noted that potential issues in the longer term include the effects of interstitials, hydrogen retention and alloy ductility. Nonetheless, investigations into HEA can be considered a good vehicle for understanding metallic alloys in general.

Amy Clarke (Multi principle element alloys for extreme environments) noted that equiatomic alloys offer interesting property combinations such as high toughness and strength due to twinning, where the atomic size mismatch can be used to predict solution strengthening. Thermodynamic modelling has been used to screen alloys by searching for a metastability (e.g. transformation-induced plasticity [TRIP], twinning-induced plasticity [TWIP] and phase equilibria of brittle phases). This has been verified using in situ synchrotron X-ray diffraction (XRD), including in situ observations of twinning at high strain rates. It was found that the stacking fault energy was an important predictor for this. Other factors to address were recrystallisation during thermo-mechanical processing and the effects of interstitials, and it was noted that heterogeneity of composition was important in refractory alloys due to slow diffusion of alloying elements.

Adrien Couet (Irradiation response of FCC high-entropy alloys) discussed a study with a focus on single-phase alloys in order to explore the benefits of compositional complexity

independent of other effects, such as precipitates. Low-temperature irradiation and high-temperature irradiations can be used to look at mechanisms of defect suppression and mobility, and increased complexity is observed to reduce defect density. Stacking fault energy is an important parameter and compositional complexity gives improvement in void swelling. A novel methodology to test large numbers of alloys in a short time was described, aided by careful ion irradiation experiment design to save time, which used direct energy deposition to manufacture multiple samples for ion irradiation that were then tested by nano indentation and analysed by machine learning.

The panel discussion addressed a structured series of questions, with the consensus summarised below:

What confidence do you have that there will be future applications of HEA?

- There was confidence that there would be future applications, but even if there are no actual future applications, a lot about other alloys will be learned about by studying HEA or complex alloys.

In what types of components and in what systems do you foresee HEA being used?

- Initially in non-safety critical, or non-structural and replaceable components, such as the fuel wrapper or cladding. For these, the performance needs to be either as good as current alloys at lower cost, or better.
- Other systems for HEA applications would be those with more "relaxed" regulation requirements such as materials test reactors, spallation sources or space reactors.

What are the key challenges and opportunities in the fabrication methods required for HEA?

- These are very dependent on the materials system. Additive manufacturing may be suitable for some, and this gives the opportunity for spatial adjustments in composition.

What are the main stages and challenges to the qualification of HEA for nuclear applications?

- A major challenge is that the level of knowledge on HEA is still very low, even of the thermodynamics for phase prediction.

What is the need for irradiation data (and of what type), and are they becoming available?

- Ion irradiation data are useful for screening, but neutron data are essential to have confidence (for example) in precipitation behaviour under irradiation.

What are the likely timescales for the implementation of HEA in advanced nuclear systems?

- HEA are currently immature, so this could be at least a decade. However, it could be accelerated significantly if a specific industrial application was identified.

How might progress be accelerated?

- The development of HEA alloys with non-nuclear, near-term applications in large volumes would have a significant effect.

The active discussions throughout the workshop highlighted the interest the scientific community has in this workshop series. The next edition of SMINS, SMINS-7, was planned to be organised in Europe in 2025.

Appendix A. Agenda

Monday, 12 September, Room BSUB-232, Student Union Building (1784 Science Center Dr., Idaho Falls) INL bus will pick up guests at Residence Inn at 8:00, and Springhill Suites at 8:10.		
8:30 – 9:30	**Registration (**room BSUB-232 in Student Union building**)**	
	Opening session	
9:30 – 9:40	**Welcome address from INL**	M. Walck, INL Deputy Director
9:40 – 9:50	**Welcome address from OECD-NEA EGSM**	F. Balbaud (CEA)
Session 1:	**Overview of Programmes**	**Chair: Jian Gan**
9:50 – 10:10	Overview on DOE program on materials for innovative nuclear systems	S. Lesica (DOE)
10:10 – 10:30	Research activity on nuclear structural materials in Korea	D.-J. Kim (KAERI)
10:30 – 11:00	**Coffee break**	
Session 2:	**Fundamental and experimental studies on irradiation damage**	**Chair: Yong Dai**
11:00 – 11:20	Defects and dislocations as sources of stress and deformation produced by irradiation: from microscopic models to FEM of reactor components	S. Dudarev (UKAEA)
11:20 – 11:40	Comprehensive fundamental studies using pure iron to assess the credibility of using self-ion simulation of neutron-induced void swelling	L. Shao (Texas A&M University)
11:40 – 12:00	In-situ High-energy X-ray Diffraction Study on Deformation Behaviour of Neutron-Irradiated Fe-9%Cr	D. Piedmont (Univ. of Illinois at Urbana-Champaign)
12:00 – 12:20	Microstructural Evolution of Alloy 718 Under High Temperature In-situ Ion Irradiation	S. Taller (ORNL)
12:20 - 13:30 **Lunch talk:**	**Working Lunch (**BSUB-232, Student Union Bldg**).** **Advanced Characterization for Reactor Structural Materials**	**Presenter: J. Gan (INL)**
Session 2:	**Fundamental and experimental studies on irradiation damage**	**Chair: Céline Cabet**
13:30 – 13:50	Radiation Effects in Additively Manufactured 316L Stainless Steels and its Modified Variants	L. He (North Carolina State University)
13:50 – 14:10	Experimental study of the incubation period for helium bubble swelling in ferritic steels	V. Krsjak (Slovak University of Technology)
14:10 – 14:30	Microstructural analysis of nanocluster evolution in ODS Eurofer irradiated to 20 dpa in a spallation target	Y. Dai (PSI)
14:30 – 14:50	Mechanical Properties and Microstructure of Neutron-Irradiated T91 and HT9	J. Stubbins (Univ. of Illinois at Urbana-Champaign)

14:50 – 15:10	Development of Real-Time In-pile Creep Testing Capability for Characterizing the Structural Material	M. Wilding (INL)
15:10 – 15:30	**Discussion**	
15:30 – 16:00	**Coffee break**	
Session 1:	**Overview of Programme**	**Chair: Alfons Weisenburger**
16:00 – 16:30	Materials Qualification Testing for the Westinghouse Lead Fast Reactor	M. Ickes (Westinghouse)
Session 3:	**Corrosion for advanced nuclear systems**	**Chair: Alfons Weisenburger**
16:30 – 16:50	Performance of LFR structural materials in the oxygen-controlled lead at 480°C	L. Kosek (CVR)
16:50 – 17:10	Elucidating the corrosion mechanism of Ni-based superalloys in UCl3-containing chloride molten salt	T. Copeland-Johnson (INL)
17:10 – 17:30	**Discussion**	
17:30	**Adjourn** INL bus will pick up guests and send back to Residence Inn and Springhill Suites	
Tuesday, 13 September Bus will pick up guests at Residence Inn at 8:15, and Springhill Suites at 8:25		
8:45 – 9:00	**Registration**	
Session 1:	**Overview of Programmes**	**Chair: Fanny Balbaud**
9:00 – 9:30	Overview of Advanced Materials and Manufacturing Technologies (AMMT) Program	M. Li (ANL) and A. Jokisaari (INL)
9:30 – 10:00	Materials Selection and Graded Components Using Additive Manufacturing	P. Hosemann (Univ. of California, Berkeley)
Session 4:	**Advanced Manufacturing**	**Chair: Fanny Balbaud**
10:00 – 10:30	**Coffee break**	
10:30 – 10:50	Advanced Nuclear Materials technology development prioritization enabled by material score cards	I. van Rooyen (PNNL)
10:50 – 11:10	Additive Manufacturing of Grade 91 Steel for Affordable Nuclear Reactor Components with Improved Radiation Tolerance	S. Maloy (PNNL)
11:10 – 11:30	Microstructural and Mechanical Responses of Ion-Irradiated 304 SS and 304 Oxide- Dispersion-Strengthened Steel Additively Manufactured via Selective Laser Melting	T. Chen (Oregon State University)
11:30 – 11:50	In situ observation of powder and gel based additive manufacturing processes for ceramics	M. Pouchon (PSI)
11:50 – 12:10	**Discussion**	
12:10 – 13:20 **Lunch talk:**	**Working Lunch** **Harvesting of Structural Materials from Decommissioned Commercial NPP and Test Reactors to Support Reactor Life Extension and Future Research Needs**	**Presenter: P. Xu (INL)**
Session 5:	**Materials for high-temperature applications**	**Chair: Stuart Maloy**
13:20 – 13:40	Development of data-driven (machine learning) models for predictions of the high-temperature fatigue life of Alloy 617	O. Muransky (ANSTO)

13:40 – 14:00	Study of isothermal and continuous cooling transformation in a SA 508 grade 3 class 1 steel	M. J. Iofrida (CNEA)
14:00 – 14:20	Solid-state diffusion welding of Ni-based alloys	I. Sah (KAERI)
14:20 – 14:40	HT property and microstructure of Incaloy 800H and its weldments using different filler materials	W. Li (CNL)
14:40 – 15:00	High temperature design of welded joints for Generation IV nuclear reactor systems	H.-Y. Lee (KAERI)
15:00 - 15:30	**Coffee break**	
15:30 – 15:50	Code Qualification of Alloy 709 for High Temperature Reactor Structural Applications	T. Sham (INL)
15:50 – 16:10	No ball milling needed: Alternative ODS steel manufacturing with GARS and friction-based processing	D. Zhang (PNNL)
16:10 – 16:30	Small Scale Mechanical Testing of Nuclear Structural Materials	D. Frazer (INL)
16:30 – 16:50	**Discussion**	
16:50 – 17:00	**Break**	
17:00 – 18:00	**Poster presentations (3 min each) in BSUB-232**	**Chair: Jian Gan**
18:00 – 19:30	**Poster session in BSUB-232 INL** Drink and snack refreshment will be provided	**Associate Lab Director Jess Gehin will attend**
19:30	**Adjourn** INL bus will pick up guests and send back to Residence Inn and Springhill Suites	
Wednesday, 14 September Bus will pick up guests at Residence Inn at 8:30, and Springhill Suites at 8:40		
Session 1:	**Overview of Programmes**	**Chair: Manuel Pouchon**
9:00 – 9:20	A unified European strategic research agenda for nuclear materials	C. Cabet (CEA)
Session 6:	**Materials development for Molten Salts Reactors**	**Chair: Manuel Pouchon**
9:20 – 9:40	Corrosion in molten chlorides - CEA developments and research program	F. Balbaud (CEA)
9:40 – 10:00	Irradiation Testing of Nickel-based Alloys for Molten Salt Reactors	R. Hania (NRG)
10:00 – 10:20	**Discussion**	
10:20 - 10:50	**Coffee break**	
Session 7:	**Properties of Complex Concentrated Alloys**	**Chair: Alfons Weisenburger**
10:50 – 11:10	Composition stability of derivative high-entropy and SMART alloys for nuclear fusion applications	D. Nguyen (UKAEA)
11:10 – 11:30	Rapid Screening of High Entropy Alloys using Laser Ultrasonics	A. Khanolkar (INL)
11:30 – 11:50	**Discussion**	
12:30 – 13:40 **Lunch talk:**	**Working Lunch** **Structural Materials and Chemistry Research and Development in the NEAMS Program**	**Presenter: B. Spencer (INL)**

Panel	**Are We on the Path to Introducing High-Entropy Alloys to Next Generation Nuclear Systems?**	**Chair: James Marrow**
13:40 – 14:10	Thermodynamic study of Hf Addition to Refractory W-Ta-Cr-V High Entropy Alloy from First- Principles	E. Martinez Saez (Clemson University)
14:10 – 14:40	Properties of high entropy alloys for nuclear applications	E. Pickering (University of Manchester)
14:40 – 15:10	Multi-Principal Element Alloys for Extreme Environments	A. Clarke (Colorado school of Mines)
15:10 – 15:40	Irradiation response of FCC High-Entropy Alloys using in-situ and ex-situ experiments	A. Couet (Univ. of Wisconsin-Madison)
15:40 - 16:10	**Coffee break**	
16:10 – 17:10	**Panel discussion** **Chair: James Marrow** **Panellists: A. Couet, A. Clarke, E. Pickering, E. Martinez Saez**	
17:10 – 18:00	**Taking group picture**	
18:00 – 20:00 **Dinner speech**	**Dinner Reception at BSUB-232 in Student Union Bldg.** **NSUF program support on advanced reactor structural materials R&D**	**INL ALD Ronald Crone will attend** **presenter: Rory Kennedy (INL)**
20:00	**Adjourn** INL bus will pick up guests and send back to Residence Inn and Springhill Suites	
Thursday, 15 September Bus will pick up guests at Residence Inn at 8:10, and Springhill Suites at 8:20		
Session 1:	**Overview of Programmes**	**Chair: Manuel Pouchon**
8:40 – 9:00	AFA-steels for Lead alloy cooled nuclear reactors – an overview of the European activities in the GEMMA project	A. Weisenburger (KIT)
9:00 – 9:20	Current Gaps in Modeling Deformation Behavior of Oxide Dispersion Strengthened Alloys for Fission/Fusion	C. Massey (ORNL)
Session 8:	**Materials development for Advanced Cladding**	**Chair: Manuel Pouchon**
9:20 – 9:40	Evaluation of alumina-forming duplex stainless steels (ADSS) as accident tolerant fuel cladding materials	C.-W. Kim (KAIST)
9:40 – 10:00	Recent progress in mechanical testing of the nuclear fuel cladding materials	B. Garrison (ORNL)
10:00 – 10:20	The Role of N in the Structure and Properties of Proton Irradiates 12Cr1MoWV Ferritic Martensitic Steels for Advanced Reactors	K. Clarke (Colorado school of Mines)
10:20 - 10:50	**Coffee break**	
10:50 – 11:10	Impact of Capacitive Discharge Resistance Welding on the Radiation Tolerance of 14YWT Cladding	C. Lear (LANL)
11:10 – 11:30	**Discussion**	
11:30 – 12:00	**Meeting Summary** from the session chairs and open discussion	
12:00 – 12:10	Closing Speech	
12:10	Bus will first pick up guests not going to MFC tour and send back to hotels	

12:10 – 12:45	**Badging for MFC tour**. **Lunch** (boxed lunch only for people on the tour)	
12:45	Bus will pick up MFC tour participants at student union bldg.	
14:00 – 17:00	**Technical Tour at MFC** **H**ot **F**uel **E**xamination **F**acility (HFEF) & **I**rradiated **M**aterials **C**haracterization **L**ab (IMCL) Foreign visitors must be on the approval list of security plan to participate the tour Max tour participants are 50 and will be divided into 4 groups	
17:00	Bus will pick up tour participants at MFC and send back to Residence Inn and Springhill Suites	

Day 1 – Tuesday, 24 October 2023					
ID	**Item**	**Speaker**	**Start**	**End**	
	Registration		**08:15**	**9:15**	
	Introduction		**09:15**	**09:35**	**00:20**
	Welcome address from the NEA Welcome address from the Chair	Director-General William D. Magwood, IV Robin Taylor (NNL)			
SPS	**Special Panel Sessions**		**09:35**	**12:00**	**02:25**
SPS-I	**Panel Session I – "30th Anniversary + 3"** • Bernard Boullis (France) • Takehiko Mukaiyama (Japan) • Vincenzo Rondinella (European Commission) • Jan Uhlíř (Czechia)	Moderator: Christian Ekberg (Chalmers University of Technology)	09:35	10:35	01:00
	Coffee break		*10:35*	*11:00*	*00:25*
SPS-II	**Panel Session II – "Towards the Future"** • Hamid Aït Abderrahim (Belgium) • Kristine Madden (International Youth Nuclear Congress) • Ken Marsden (United States) • Dan Mathers (United Kingdom) • Bertrand Morel (France)	Moderator: Sungyeol Choi (Seoul National University)	11:00	12:00	01:00
	Lunch break		***12:00***	***13:30***	***01:30***
S01	**Session 1 – Plenary Session: International organisations and national programmes** Chairs: Gabriele Grassi (NEA), Clément Hill (IAEA) *(15' presentation + 5' Q&A)*		**13:30**	**17:35**	**04:05**
S01.01	Nuclear Energy Agency (NEA)	Tatiana Ivanova (NEA)	13:30	13:50	00:20
S01.02	International Atomic Energy Agency (IAEA)	Clément Hill (IAEA)	13:50	14:10	00:20
S01.03	European Commission (EC)	Vincenzo Rondinella (JRC)	14:10	14:30	00:20
S01.04	Belgium	Hamid Aït Abderrahim (MYRRHA)	14:30	14:50	00:20
S01.05	China	Guoan Ye (CIAE)	14:50	15:10	00:20
	Group photo		15:10	15:20	00:10
	Coffee break		15:20	15:50	00:30
S01.06	France	François Sudreau (CEA)	15:50	16:10	00:20
S01.07	India	Smitha Manohar (BARC)	16:10	16:30	00:20
S01.08	Japan	Kenji Nishihara (JAEA)	16:30	16:50	00:20
S01.09	Korea	Jong-Hyuk Baek (KAERI)	16:50	17:10	00:20
S01.10	United Kingdom	Dan Mathers (NIRO)	17:10	17:30	00:20
S01.11	United States	Ken Marsden (INL)	17:30	17:50	00:20
	Introduction to Poster Chair: Paul Schuurmans (SCK CEN)		17:50	18:00	00:10
Close Day 1 – 18:00					

Day 2 – Wednesday, 25 October 2023					
ID	**Item**	**Speaker**	**Start**	**End**	
S02	**Session 2 – Fuel cycle strategies and scenarios** Chairs: Francisco Álvarez-Velarde (CIEMAT), Kenji Nishihara (JAEA), Josh Turner (NNL) *(15' presentation + 5' Q&A)*		**09:00**	**11:45**	**02:45**
S02.01	PATRICIA: Partitioning and Transmutation Research Initiative in a Collaborative Innovation Action	Paul Schuurmans (SCK CEN)	09:00	09:20	00:20
S02.02	PUMMA, a European project devoted to Plutonium management in the whole fuel cycle	Nathalie Chauvin (CEA)	09:20	09:40	00:20
S02.03	MIMOSA: an EU funded project aiming at demonstrating multi-recycling strategies based on the use of molten salt reactors in European countries	Isabelle Morales (Orano)	09:40	10:00	00:20
S02.04	NEA Task Force on Demonstration of Fuel Cycle Closure including Partitioning and Transmutation (P&T) for Industrial Readiness by 2050	Hamid Aït Abderrahim (MYRRHA)	10:00	10:20	00:20
	Coffee break		*10:20*	*10:45*	*00:25*
S02.05	Fuel Cycle Requirements for Deployment of Demonstration Reactors for Achieving Net-Zero Emissions Economy in the United States	Jin Whan BAE (ORNL)	10:45	11:05	00:20
S02.06	Management of MOX spent fuel from LWR: Assessment of material flow	Kenji Nishihara (JAEA)	11:05	11:25	00:20
S02.07	Scenario Study on Sustainable Nuclear Energy Utilisation using Dynamic Nuclear Fuel Cycle Simulator NMB4.0	Kenji Takeshita (Tokyo Institute of Technology)	11:25	11:45	00:20
	Lunch break		***11:45***	***13:15***	***01:30***
S03	**Session 3 – Advanced fuel recycling** Chairs: Pavel Souček (JRC), Tsuyoshi Murakami (CRIEPI), Iván Sánchez-García (CIEMAT) *(15' presentation + 5' Q&A)*		**13:15**	**15:55**	**02:40**
S03.01	Current status of R&D on MA separation process using solvent extraction technique for P&T technology	Tatsuro Matsumura (JAEA)	13:15	13:35	00:20
S03.02	Selective actinide(III) separation using 2,6-bis[1-(propan-1-ol)-1,2,3-triazol-4-yl]pyridine (PyTri-Diol) in the innovative-SANEX process: laboratory scale counter current centrifugal contactor demonstration	Andreas Wilden (FZJ)	13:35	13:55	00:20
S03.03	Neptunium behaviour in advanced flowsheets	Billy Keywood (NNL)	13:55	14:15	00:20
S03.04	Rapid Photochemical Reduction of U(VI) for the Development of New Mixed Metal Oxide Fuel Production Processes	Colin Boxall (Lancaster University)	14:15	14:35	00:20
S03.05	Effects of metal complexation on radiolytic stability of important minor actinide extractants for advanced nuclear fuel cycles	Iván Sánchez-García (CIEMAT)	14:35	14:55	00:20
S03.06	Fluoride Partitioning Technologies Development in the Czech Republic	Jan Uhlíř (ÚJV Řež)	14:55	15:15	00:20
S03.07	Synthesis of actinide chlorides for Molten Salt Reactor fuels	Pavel Souček (JRC)	15:15	15:35	00:20
S03.08	Pyrochemical Reprocessing of Spent Fuel Salt of Molten Salt Fast Reactor	Tsuyoshi Murakami (CRIEPI)	15:35	15:55	00:20
	Coffee break		*15:55*	*16:20*	*00:25*
S04	**Session 4 – Waste management and innovative utilisations of actinides and fission products** Chairs: Sungyeol Choi (Seoul National University), Rebecca Sanderson (NNL) *(15' presentation + 5' Q&A)*		**16:20**	**18:00**	**01:40**
S04.01	The Role of the NEA Expert Group in Fuel Recycling and Waste Technology Supporting the Development of Advanced Fuel Cycle Options	Robin Taylor (NNL)	16:20	16:40	00:20
S04.02	NEA "Treatment of Volatile Fission Products" Report	Josh Turner (NNL)	16:40	17:00	00:20
S04.03	Optimization study of high-level waste repository thermal design by response surface methodology on ANSYS Workbench software	Masahiko Nakase (Tokyo Institute of Technology)	17:00	17:20	00:20
S04.04	Separation of Americium-241 for Space Power Systems	Rebecca Sanderson (NNL)	17:20	17:40	00:20
S04.05	Recovery of Cesium-137 from fission products for Societal Applications	Rahul Tripathi (BARC)	17:40	18:00	00:20
Close Day 2 – 18:00					

Day 3 – Thursday, 26 October 2023					
ID	**Item**	**Speaker**	**Start**	**End**	
S05	**Session 5 – Advanced fuels for plutonium management and minor actinide transmutation** Chairs: Nathalie Chauvin (CEA), Luca Capriotti (INL), Martina Di Gennaro (Polimi) *(15' presentation + 5' Q&A)*		**09:00**	**12:05**	**03:05**
S05.01	Effect of O/M, temperature, Pu and MA content, and irradiation on the oxygen potential of MOX fuels	Daniel Shepherd (NNL)	09:00	09:20	00:20
S05.02	Fabrication of Am-containing transmutation targets	Gamze Çolak (SCK CEN)	09:20	09:40	00:20
S05.03	Overview of US Postirradiation Examination of Transmutation Metallic Fuel Alloys	Luca Capriotti (INL)	09:40	10:00	00:20
S05.04	DIAMINO irradiation on $(U0.85Am0.15)O_2$ transmutation targets: post irradiation examinations	Catherine Sabathier (CEA)	10:00	10:20	00:20
	Coffee break		*10:20*	*10:45*	*00:25*
S05.05	Advanced interpretation of the SPHERE irradiation experiment with neutronics and fuel performance codes	Marc Lainet (CEA)	10:45	11:05	00:20
S05.06	OpenFOAM-informed TRANSURANUS simulation of the fuel pin behaviour in the MYRRHA reactor during Beam Power Jump transient scenario	Martina Di Gennaro (Polimi)	11:05	11:25	00:20
S05.07	Preliminary assessment of GERMINAL V3 against homogeneous transmutation irradiations	Tommaso Barani (CEA)	11:25	11:45	00:20
S05.08	Study of the AM-1 homogeneous transmutation experiment using the GERMINAL V2 fuel performance code	Florian Marconi (CEA)	11:45	12:05	00:20
	Lunch break		***12:05***	***13:35***	***01:30***
S06	**Session 6 – Advanced systems and R&D infrastructures for advanced fuel cycles and P&T** Chairs: Andrea Salvatores (CEA), Takanori Sugawara (JAEA), Gamze Çolak (SCK CEN) *(15' presentation + 5' Q&A)*		**13:35**	**16:15**	**02:40**
S06.01	LBE coolant chemistry research for MYRRHA	Alessandro Marino (SCK CEN)	13:35	13:55	00:20
S06.02	Material property determination of LBE exposed 15-15Ti steel in support of MYRRHA design	Stefan Holmström (SCK CEN)	13:55	14:15	00:20
S06.03	Overview of R&D Activities of J-PARC Center for the ADS Development	Fujio Maekawa (JAEA)	14:15	14:35	00:20
S06.04	Status of LBE/Gas Interaction Based Oxygen Concentration Control in JAEA	Hironari Obayashi (JAEA)	14:35	14:55	00:20
S06.05	PSi - Proton accelerator-driven subcritical virtual system project in JAEA	Takanori Sugawara (JAEA)	14:55	15:15	00:20
S06.06	Molten Salt Thermophysical Examination Capability for Characterisation of TRU and Irradiated Salts	Toni Karlsson (INL)	15:15	15:35	00:20
S06.07	Corrosion failure analysis in molten salt thermal convection loop using NaCl-MgCl2 salt mixture	Byung Gi Park (Soonchunhyang University)	15:35	15:55	00:20
S06.08	Development of Machine Learning Model for Estimating Electrode Surface Area via Cyclic Voltammetry	Sungyeol Choi (Seoul National University)	15:55	16:15	00:20
	Coffee break		*16:15*	*16:30*	*00:15*
PS	**Poster Session** Chair: Paul Schuurmans (SCK CEN)		**16:30**	**18:30**	**02:00**
Close Day 3 – 18:30					

Day 4 – Friday, 27 October 2023					
ID	**Item**	**Speaker**	**Start**	**End**	
S07	**Session 7 - Modelling and data** Chairs: Luca Fiorito (SCK CEN), Maxime Fache (DTU & JRC) *(15' presentation + 5' Q&A)*		**09:00**	**11:30**	**02:30**
S07.01	Monte Carlo nuclear data uncertainty propagation in inventory calculations	Francisco Álvarez-Velarde (CIEMAT)	09:00	09:20	00:20
S07.02	Evaluating Spent Fuel Characteristics Based on Lattice Physics Calculations of Hydrogen Moderated High Temperature Gas-cooled Reactors with Uranium and Plutonium Annular Fuel	Daniel Wojtaszek (CNL)	09:20	09:40	00:20
S07.03	NEA Task Force on Dose Rate Calculations for Irradiated Assembly	Francisco Álvarez-Velarde (CIEMAT)	09:40	10:00	00:20
	Coffee break		*10:00*	*10:30*	*00:30*
S07.04	Thermophysical properties of the molten salt fuel NaF-KF-UF4: an experimental and modelling study	Maxime Fache (Technical University of Denmark & JRC)	10:30	10:50	00:20
S07.05	Modelling of the distribution of Technetium between nitric acid solutions and TBP-in diluent in the presence of uranium	Hongyan Chen (University of Manchester)	10:50	11:10	00:20
S07.06	Experimental Program on Nuclear Data for Accelerator-Driven Systems Using FFAG Accelerator	Hiroki Iwamoto (JAEA)	11:10	11:30	00:20
	Lunch break		***11:30***	***13:00***	***01:30***
S08	**Summary Session** Chair: Robin Taylor (NNL)		**13:00**	**15:30**	**02:30**
	Chairpersons' reviews	Session Chairs	13:00	13:35	00:35
	Poster review	Poster Chair	13:35	13:55	00:20
	Discussion	All	13:55	15:10	01:15
	Closing remarks	Chair	15:10	15:30	00:20
Close Meeting – 15:30					

ID	Title	First author
P01	A nuclear fuel cycle analysis for a small and sustainable electricity mix	Iván Merino (Universidad Católica del Maule)
P02	Management of MOX Spent Fuel from LWR: (1) Thermal design of direct disposal	Takumi Abe (JAEA)
P03	Multifaceted Assessment of P&T Technologies to Current LWR Fuel Cycle	Masahiko Nakase (Tokyo Institute of Technology)
P04	Optimization of Reprocessing Capacity Deployment under Parametric Uncertainty	Jin Whan Bae (ORNL)
P05	NEA co-ordinated online catalogue of tools for nuclear fuel cycle simulation	Francisco Álvarez-Velarde (CIEMAT)
P06	Decay heat prediction for the irradiated MOX fuel of MYRRHA	Federico Di Croce (SCK CEN)
P07	Implementation status of MYRRHA phase 1 (MINERVA) and its accelerator reliability demonstration approach	Ulrich Dorda (SCK CEN)
P08	Molten Salts and Pyrochemical Processing Capabilities at the UK's National Nuclear Laboratory	Moya A. Hay (NNL)
P09	Acoustic Monitoring of Pyroprocessing Equipment	Luis A. Ocampo Giraldo (INL)
P10	Drafting Zero-Power Reactor Core Configurations for a Multi-Purpose Molten Salt Reactor Experiment	Bruno Merk (University of Liverpool)
P11	Flowsheet design for the AmSEL process using TODGA and SO3-Ph-BTBP	Vincent Vanel (CEA)
P12	Process simulation study on a hybrid process combining solvent extraction and low pressure loss extraction chromatography for a reasonable MA(III) recovery process	Yuichi Sano (JAEA)
P13	Chromatographic Reprocessing Process with Nuclide Separations in Hydrochloric Acid Solution System	Tatsuya Suzuki (Nagaoka University of Technology)
P14	Adsorption/Elution Performance of TEHDGA/SiO2-P for Am/Cm Recovery from Genuine HLLW	Daisuke Sato (JAEA)
P15	Redox Reactions of Fe(III) and Hydroxamic Acids in Nitric Acid Solutions in the Context of an Advanced PUREX Process	Suzanne Jones (Lancaster University)
P16	Studies into the effect of insoluble fission products on the generation of Ag(II) for the dissolution of MOx fuel	Nick Bramah (Lancaster University)
P17	The Role of Mass Transfer and Chemical Kinetics in Advanced Nuclear Fuel Partitioning and Reprocessing	Stephen Ogezo (Lancaster University)
P18	Development of a TRUEX Digital Twin for Minor Actinide Recycling using Spectral Data Acquisition	Justin T. Cooper (INL)
P19	Advanced Analytical Chemical Separation Techniques for Highly Radioactive Nuclear Fuel Analyses	Jacob Brookhart (INL)
P20	US Heavy Actinide Production at Oak Ridge National Laboratory— Ongoing Actinide Partitioning and Transmutation Programs	Emory D. Collins (ORNL)