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Developments in Fuel Cycle Facilities after the Fukushima Daiichi Nuclear Power Station Accident

Workshop Proceedings

Aomori City, Japan
15–17 November 2016

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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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Appendix 3 is available in PDF format only in the NEA Website.

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 35 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) is responsible for NEA programmes and activities that support maintaining and advancing the scientific and technical knowledge base of the safety of nuclear installations.

The Committee constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development and engineering, to its activities. It has regard to the exchange of information between member countries and safety R&D programmes of various sizes in order to keep all member countries involved in and abreast of developments in technical safety matters.

The Committee reviews the state of knowledge on important topics of nuclear safety science and techniques and of safety assessments, and ensures that operating experience is appropriately accounted for in its activities. It initiates and conducts programmes identified by these reviews and assessments in order to confirm safety, overcome discrepancies, develop improvements and reach consensus on technical issues of common interest. It promotes the co-ordination of work in different member countries that serve to maintain and enhance competence in nuclear safety matters, including the establishment of joint undertakings (e.g. joint research and data projects), and assists in the feedback of the results to participating organisations. The Committee ensures that valuable end-products of the technical reviews and analyses are provided to members in a timely manner, and made publicly available when appropriate, to support broader nuclear safety.

The Committee focuses primarily on the safety aspects of existing power reactors, other nuclear installations and new power reactors; it also considers the safety implications of scientific and technical developments of future reactor technologies and designs. Further, the scope for the Committee includes human and organisational research activities and technical developments that affect nuclear safety.

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LIST OF ABBREVIATIONS AND ACRONYMS

ALARA	As low as reasonably achievable
ARF	Airborne release fraction
BWR	Boiling water reactor
Bfs	Federal Office for Radiation Protection (Germany)
CAPS	CSNI Activity Proposal Sheet
CSN	Consejo de Seguridad Nuclear
CSNI	Committee on the Safety of Nuclear Installations
DBA	Design-basis accident
DEC	Design-extension condition
DiD	Defence in depth
EDF	Électricité de France
EOPs	Emergency operating procedures
FCF	Fuel cycle facility
HLLW	High level liquid waste
HSC	Hardened safety core
IAEA	International Atomic Energy Agency
IRSN	Institut de Radioprotection et de Sûreté Nucléaire (France)
LPF	Leak pass factor
LWR	Light water reactor
NEA	Nuclear Energy Agency
NPP	Nuclear power plant
NPS	Nuclear power station
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PWR	Pressurised water reactor
PSA	Probabilistic safety assessment
PSR	Periodic safety review
R&D	Research and development
SAMGs	Severe accident management guidelines
SAMS	Severe accident management strategies
S/NRA/R	Regulatory Standard and Research Department, Secretariat of Nuclear Regulation Authority (Japan)
SSC	Systems, structures and components
TSO	Technical support organisation
WGFCS	CSNI Working Group on Fuel Cycle Safety

EXECUTIVE SUMMARY

The NEA Workshop on Developments in Fuel Cycle Facilities (FCFs) after the Fukushima Daiichi Nuclear Power Station (NPS) Accident was arranged in Aomori City, Japan on 15-17 November 2016. During the workshop a total of 22 presentations were given in four sessions.

The main objective of the workshop was to review and discuss national activities, plans and regulatory approaches by member countries in light of the lessons learnt from the accident at the Fukushima Daiichi NPS, in terms of new safety requirements and operational issues of FCFs. The various characteristics and particularities of FCFs, compared to nuclear power plants (NPPs) were taken into account, considering the specific aspects of FCFs such as chemical risks and taking into account a graded approach. It was known that several countries have already incorporated the results from new research into applicable codes and standards. One goal of the workshop was to address the current status of the regulatory activities in each country, identify and recommend good practices among participating countries and recognise future research needs for FCFs.

The Aomori Workshop highlighted that there are various characteristics and particularities of FCFs that may differ from NPPs, and thus the importance of using a graded approach in applying new requirements to all types and sizes of FCFs with various nuclear risks and chemical hazards; as well as the importance of taking into account the various amounts of radioactivity. A graded approach means that the application of regulatory requirements, used resources and other relevant measures are commensurate with the radiation and chemical risks associated with the exposure situation, as well as with the likelihood and magnitude of exposures. The potential hazards of the FCF could be assessed with deterministic or probabilistic tools, or with a combination of them.

The set of emergency operating procedures (EOPs) of an FCF should include specified provisions for design-extension conditions (DECs), which means extreme hazards and events developing outside the design basis situations of facility. Periodical training of EOPs supported with training of external actions and co-operation with the external organisations with simulated situations is recommended, also for reducing the stress of personnel in extreme events. Comprehensive analysis and studies on possible actions, estimated source terms of radiological and chemical releases to the environment and their trajectories in DEC situations make the measures described in EOPs more effective.

Aomori workshop discussions included the following recommendations:

1. The defence-in-depth concept applied with grading is an effective tool for ensuring safety in design and for defining the management system, quality methods and working procedures of FCFs. A grading principle could be applied through the functional safety classification of the system and components. The practice can be applied in safety improvements to design, the implementation of modifications and in responding proportionately to deviations during operation.
2. The definition of autonomy requirements (e.g. time criterion for autonomy of the plant without any material support from off-site facilities in case of unexpected events or their combinations) for design and operation of FCFs, including rare external hazards, should be based on a site specific list of hazards. Autonomy principles could be discussed in international workshops in the future. International operating experiences (e.g. FINAS database events) on events can be used in

this work. Comparison of national autonomy criteria and acceptance criteria on countermeasures of severe events of FCF could also be part of the workshop and a possible new activity of the CSNI Working Group on Fuel Cycle Safety (WGFCS).

3. It is important to share and analyse results on implementation of defence-in-depth including DECs (beyond-design basis accidents) to FCFs, for example realistic and optimised design of equipment used in DEC. Examples and lessons learnt in design modification processes of NPPs is an important part of this work.

4. All possible, even extremely rare accidental situations, are an important part of emergency exercises of FCFs. These exercises are an important method to test the EOPs, and the analysis basis of the probable facility states as well as the optimal use of equipment in the accident. The lessons learnt regarding facility exercises and experiences on the emergency procedures of FCFs could be discussed and analysed in an international level workshop.

5. Acceptable risk level for external hazards of FCFs could be a subject of international level discussions and comparisons. The assessment of combined hazards like earthquake and tsunami is a natural subject of such discussion as well as the mutual impact between facilities located on the same site. Actions for ensuring safety in case of interactions between FCFs on the same site are in many countries reviewed and assessed in periodic safety reviews (PSRs).

ACKNOWLEDGEMENTS

Gratitude is expressed to the Japanese Regulatory Standard and Research Department, Secretariat of Nuclear Regulation Authority (S/NRA/R) for hosting the Conference and to the Workshop Organising Committee, the Session Chairpersons and the workshop participants for their efforts and co-operation.

Workshop Organising Committee

Name	Country	Organisation
Véronique Lhomme	IRSN	France
Kenji Mori	S/NRA/R	Japan
Yoshinori Ueda	S/NRA/R	Japan
Kotaro Tonoike	JAEA	Japan
Jonathan Marcano	NRC	United States
Andy Buchan	Sellafield	United Kingdom
Kavita Murthy	CNSC	Canada
Olli Nevander	NEA	International

Chairpersons of sessions

K. Mori (S/NRA/R)
J. Marcano (NRC)
A. Buchan (Sellafield)
K. Murthy (CNSC)
V. Lhomme (IRSN)
K. Tonoike (JAEA)
Y. Ueda (S/NRA/R)
O. Nevander (NEA)

1. INTRODUCTION

The CSNI Workshop on Developments in Fuel Cycle Facilities (FCFs) after the Fukushima Daiichi Nuclear Power Station Accident was the third workshop of its kind held on this occasion in Aomori City, Japan, 15-17 November 2016. This report describes the presentations in the workshop and conclusions drawn during the discussions and closing panel of the workshop. The intention was to organise a workshop including regulatory bodies, TSOs and operator perspectives from OECD countries but also from major non-OECD countries with FCFs. During the workshop a total of 22 presentations were given in the following four sessions:

- Feedback of post-Fukushima safety reviews performed for FCFs
- Implementation of post-Fukushima regulatory improvements on FCFs
- Implementation of post-Fukushima technical and operational improvements on FCFs
- Post-Fukushima Studies and R&D on Accident Scenarios and source terms for FCFs

The improvements to national safety regulations and applications of new requirements as a result of the lessons learnt from the Fukushima Daiichi NPS accident have been implemented for FCFs in member countries. This work has been reviewed and approved by national regulators of member countries. During this work it was recognised that the overall hazard from FCFs can be low to the public; therefore, it is important to describe how the requirements are applied using a graded approach in member countries. Several countries have already incorporated the results from new research into regulatory requirements and/or applicable safety codes and standards.

FCFs employ many diverse technologies and a large variation of physical and chemical forms of the processed materials. The hazardous chemical substances and gases used in the production processes may be toxic, corrosive, combustible, reactive or explosive, and disturbances may lead to specific chemical releases and personnel hazards. These chemical and personnel hazards call for specific requirements in addition to the requirements for nuclear and radiological safety. Activities at FCFs include industrial processes that pose additional hazards to safe nuclear operations, site personnel and to the environment. The specific industrial hazards and their conventional requirements also need to be considered where these can interfere with safe nuclear operations. Therefore, the operational procedures for FCFs, including the emergency operating and emergency planning procedures, need extra emphasis. The need of common international understanding on the unique characteristics of FCFs in light of lessons learnt on the Fukushima Daiichi NPS accident was the driving force of the workshop.

It was recommended in the previous Toronto workshop in 2011 that the CSNI Working Group on Fuel Cycle Safety (WGFCS) should continue to support similar technical workshops and information exchanges.

2. OBJECTIVES

The main objective of the workshop was to review and discuss national activities, plans and regulatory approaches by member countries in light of the lessons learnt from the accident at the Fukushima Daiichi NPS, in terms of new safety requirements and operational issues of FCFs. Each country has identified the FCFs areas where safety can still be improved in light of the lessons learnt from the accident and these areas were reviewed. Applications of the lessons learnt from the accident to FCFs were presented at the workshop. The various characteristics and particularities of FCFs, compared to nuclear power plants (NPPs), were taken into account, considering specific aspects of FCFs such as chemical risks and taking into account a graded approach. The feedback of the stress tests concerning the extreme natural hazards and emergency planning (on-site and off-site) were also discussed by the participating countries.

In the workshop specific safety aspects and lessons learnt from the Fukushima Daiichi NPS accident applicable to FCFs around the world were covered. The Fukushima Daiichi NPS accident once again showed the importance of a comprehensive application of the defence-in-depth (DiD) principle in NPPs.

The prime responsibility for safety of the owner of the facility, the need for adequate management systems for the purpose of addressing the impacts of events caused by natural phenomena, as well as the existence of mature national legislation and rules including an independent regulatory body with adequate resources, were also important aspects in discussions of the safety basis of FCFs.

3. BACKGROUND

In September 2011, considering the impacts of the March 2011 events at Fukushima Daiichi NPS on FCFs in general, the working group carried out an exchange of information on the early actions taken as well as preliminary lessons learnt. This was done in a special session included in the workshop "Safety Assessment of Fuel Cycle Facilities – Regulatory Approaches and Industry Perspectives" held in Toronto.

Since that time, in addition to nuclear reactors, many member countries conducted safety reviews (e.g. comprehensive risk and/or safety assessments, so called "stress tests") of the design and safety of their FCFs with respect to protection of the facilities from extreme natural hazards (earthquakes, flooding, tornadoes, …) challenging the site, exceeding the levels taken into account by the design basis and current safety requirements applicable to the plants.

The safety reviews conducted by member countries led, in many cases, to the identification of improvements to maintain and/or strengthen the plants capabilities for the prevention and mitigation of accidents and associated consequences under extreme natural hazards. These assessments were performed with consideration of the defence-in-depth (DiD) concept, fundamental safety functions of the plant and emergency capabilities. Regarding FCFs, it had to take into account the large number and diversity of facilities, among which those with specific features (multiple FCFs sites with "domino effects" risks, FCFs sites with nuclear/chemical hazards).

One goal of the workshop was to address the current status of the regulatory activities in each country, identify and recommend good practices among participating countries and recognise future research needs for FCFs. During the workshop all these safety aspects of FCFs were planned to be presented and discussed.

4. PREVIOUS WORKSHOPS ON THIS SUBJECT

4.1 Workshop on Safety Assessment of FCFs – Regulatory Approaches and Industry Perspectives, Toronto, September 2011

The WGFCS has been actively pursuing an agenda of knowledge sharing and interaction between the FCFs communities among its member countries. The Toronto Workshop /1/ brought together many specialists involved in the FCFs, to discuss regulatory and operational aspects.

The following general conclusions were drawn during the Toronto workshop /1/:

- Participants recognised that the March 2011 events at Fukushima Daiichi NPS have lessons for the FCFs communities around the world. They confirmed that the FCFs community was actively seeking to learn from these events and were at various stages of review.
- Participants recognised the importance of the impact of chemical hazards on safety assessment of FCFs in addition to radiation hazards. Sometimes, public perception of low risk low radiological consequence accidents are more damaging to the reputation and safety record of the industry.
- Participants felt that there is a need for improved co-ordination between various regulatory bodies within each country.
- It was also noted that it may be beneficial to benchmark with other industries within the nuclear industries (such as NPPs) as well as outside (such as petrochemical industry) to identify cross-learning opportunities.
- It was recognised that the risk-informed decision making process is an established and useful approach not only at a macro level, but also useful for complex, technical tasks in FCFs.
- Both operators and regulators in member countries are engaged in continuous improvement initiatives, including improved evaluation methods and approaches, and recognise the importance of employing ALARA, in order to achieve better safety analysis and better protection of the workers, environment and the public.
- Ageing FCFs face a challenge in that they don't necessarily have modern design features and equipment, making fully quantitative analysis challenging.

The Toronto workshop discussions recognise the need to report the lessons learnt and good practices into an international reference library. These would likely include topics such as remediation techniques and standards used in different countries, hazard assessments and approaches used in the chemical industry as well as the regulatory approaches towards chemical hazards in chemical industries versus approaches to chemical hazards in the nuclear industry.

4.2 Workshop on Safety Reassessment for Nuclear Fuel Cycle Facilities following the Feedback from the Fukushima Daiichi Nuclear Power Station Accident, Vienna, April 2016

The purpose of the IAEA workshop /3/ was to discuss and exchange information on the experience acquired from the Fukushima Daiichi NPS accident that is relevant to the safety of FCFs. In particular, a draft IAEA publication SRS 90 was presented and discussed.

The results of recent safety reassessments and the actions that need to be taken by IAEA member states based on the feedback from the accident and the implication of corrective actions in order to avoid the recurrence was also discussed. Based on discussions in workshop the IAEA highlighted the following issues in the new publication /3/:

- Periodic review of FCFs needs to be robust and provides the starting point for regulatory confidence.
- A graded approach is necessary to focus on conditions with the highest consequences, these relate to maximise the effects of efforts spent by both the operator and the regulator.
- Severe accident conditions (design-extension conditions [DEC]) are important and need to be considered on a separate basis from the normal design basis, this DEC approach will allow for use of best estimate inputs and more realistic safety criteria to give the maximum flexibility.

5. SESSION SUMMARIES OF THE AOMORI WORKSHOP

5.1 Opening – Introduction and Objectives of the Workshop

Chaired by Kenji Mori, S/NRA/R and Kotaro Tonoike, JAEA

In the general session the CSNI objective for the workshop was presented by Olli Nevander, NEA. It was pointed out that lessons learnt and improvements taken into operation in NPPs has been many times assessed and implied also into FCFs. These applications should be presented in the workshop. However, in the opening session it was reminded that the graded approach should be applied in detailed defining safety and quality requirements of FCFs with different size and various amounts of risks of radioactive releases. It was also noted that the differences in national legislations and regulations are not changing the responsibility on safety of owner and licence holder to take the holistic responsibly of safety of facility and apply the Fukushima Daiichi NPS accident lessons learnt effectively to the FCFs.

The summaries of the four technical workshop sessions are presented below. A list of the presentations can be found in the agenda of the workshop in Appendices 2 and 3.

5.2 Session 1 -Feedback of Post-Fukushima Safety Reviews Performed for FCFs

Chaired by Jonathan Marcano, NRC, United States (USA) and Olli Nevander, NEA.

- (2) Technical evaluation of modifications to a uranium hexafluoride facility to protect against seismic and tornado missile events; *Jonathan Marcano. Nuclear Regulatory Commission, USA.*
- (3) Applicability of lessons learnt from the Fukushima Daiichi NPS accident to facilities other than power reactors in the United States; *Margie Kotzalas. Nuclear Regulatory Commission, USA.*
- (4) Post-Fukushima safety reviews performed at fuel cycle facilities in the United States *Jonathan Marcano. Nuclear Regulatory Commission, USA.*
- (7) Evaluating the Resilience of Nuclear Facilities at Sellafield; *Andrew B. Buchan. Sellafield Ltd, UK.*
- (11) Results and Consequences of Stress Tests Performed for Interim Storage Facilities of Radioactive Material in Germany; *Christian Drobniewski. Bundesamt für Strahlenschutz, Germany.*
- (17) Enusa-Juzbado Plant Stress Test Approach and Actions Taken, *Enrique Escandón Ortiz, Luis Blanco Fernández, Óscar Zurrón Cifuentes, Enusa Industrias Avanzandas, Spain.*
- (14) Feedback of complementary safety assessments for French fuel cycle facilities and research laboratories and reactors; *Emeline Cluzel, Michel Guillard, Institut de Radioprotection et de Sûreté Nucléaire, France.*

Mr Marcano (NRC, US) presented the NRC evaluation and inspections of Honeywell Metropolis Works (MTW) facility in light of the lessons learnt from the accident at the Fukushima Daiichi NPS. The purpose of the NRC review was to evaluate the readiness of the facility to address natural phenomena hazard. The result of the inspection identified that process equipment in Honeywell's Feed Materials Building lacked seismic restraints, supports and bracing to ensure equipment integrity during credible seismic events or tornadoes. After certain modifications to the facility and new analysis, the NRC accepted that Honeywell's approach to determining the facility risk levels is consistent with accepted ISA methods and guidance.

In his second presentation **Mr Marcano** described the NRC systematic evaluation and inspection of selected fuel cycle facilities, in light of the lessons learnt from the accident at the Fukushima Daiichi NPS, to confirm that licensees were in compliance with applicable regulatory requirements and license conditions; and to evaluate their readiness to address natural phenomena hazards (NPH) events and other licensing bases events related to NPH. The results of the assessments concluded that the current regulatory approach and requirements for fuel cycle licensees offers reasonable assurance of adequate protection of public health and safety.

In the third presentation of session **Ms Kotzalas (NRC, US)** presented the NRC assessments of non-reactor facilities after the Fukushima Daiichi NPS accident to ensure that no immediate safety concerns existed at those facilities. Her paper discusses the NRC staff's assessments of radioactive material users and irradiators. NRC evaluations were performed for spent fuel storage and transportation systems, radioactive material users, irradiators, low-level waste disposal facilities, uranium recovery facilities and uranium mill tailings, decommissioning reactors, and non-power reactors.

In the fourth presentation of session **Mr Buchan (Sellafield, UK)** presented the work for evaluating the Resilience of Nuclear facilities at Sellafield. Studies into beyond-design basis events and resilience evaluation required following the Fukushima Daiichi NPS accident were undertaken using a severe accident analysis methodology. These studies were used also to inform the response to Stress Tests by UK regulators and industry bodies such as ENSREG.

As part of the further development of severe accident analysis, studies have been carried out to determine the potential effects which may be caused by domino events following or during a Severe Accident Scenario in Sellafield. The output of severe accident analysis has been further progressed to derive an understanding of domino events and indicate the potential functionality of facilities and services at a site level during a full range of severe accident events allowing further development of the severe accident management strategies. The severe accident analysis and resultant severe accident management strategies have formed key inputs to further enhance of a regular programme of challenging emergency exercises.

In fifth presentation **Mr Drobniewski (Bfs, Germany)** gave an overview over the performed "Stress tests" to the FCFs in Germany and the results and consequences of those investigations. He highlighted the results of licensing work of the storage facilities for spent fuel and high level waste in Germany including a qualitative examination of extreme events by extrapolation on the design-basis accidents (DBAs). Based on the investigations, the guidelines for storage facilities for spent fuel were updated to include the results depicted and keep the safety assessment for the facilities in line with the scientific knowledge and international standards

The following presentation of **Mr Ortiz (ENUSA, Spain)** was also based on "stress test" results. Lessons learnt from the Fukushima Daiichi NPS accident brought about a systematic review of the safety analysis by the international community, defining and establishing ways of preventing and minimising the effects of these severe accidents. During 2011 and 2012, ENUSA carried out a deep and systematic review of the design basis and safety analysis of the Juzbado Fuel Fabrication Facility in Spain. During the work in the case of an earthquake "cliff-edge" situations and situations beyond-Design Basis there was need to expand the safety margins. The improvements related with the different events to increase the level of defence in depth were implemented in the facility.

In the last presentation of first session, **Ms Cluzel (IRSN, France)** presented the results of the Safety Assessments requested in France by the Prime Minister in spring 2011 after the Fukushima Daiichi NPS accident. For this review work the facilities have been divided into three categories, depending on their vulnerability to accidents like those at Fukushima and on the importance and the scale of the consequences of any accident affecting them. AREVA nuclear fuel facilities and some CEA research reactors and facilities were part of the top priority facilities. She described this analysis work and its results. The results of IRSN analysis showed that it is necessary to implement a "hardened safety core" (HSC) of robust

material and organisational measures aiming, for extreme situations. The work for HSC in the FCFs is going on.

In general the presentations in Session 1 provided an overview of safety reviews performed at FCFs in light of the post-Fukushima Daiichi NPS event. The presentations covered a multitude of facilities in the fuel cycle ranging from those with a low inventory of hazardous materials to those handling more complex quantities of hazardous materials like the Sellafield facility. The presentations covered perspectives both from regulators and operators and allowed the participants to get exposure to the strategies used by different organisations to complete the safety assessment after the Fukushima Daiichi NPS accident.

Comments from the floor and areas for potential engagement:

- The discussions served as a great platform to share information on the actions taken by regulators and operators to strengthen the regulatory framework and resilience of the facilities under severe natural phenomena events.
- Discussions included the applicability and determination of severe accident management Strategies (SAMS) for FCFs. Specifically the criterion used for the determination of the events leading to the SAMS. In addition, the criterion used for the likelihood of the events in terms of probabilistic values, training applied to ensure the effectiveness of the SAMS and resource burden for the implementation of the SAMS both internal and external to the site.
- The discussions emphasised the importance for both regulators and operators to evaluate the impact of severe natural phenomena events and to consider its consequences from radiological, chemical and environmental impacts. In addition, it allowed the participants to discuss the differences in the approach taken to evaluate the impacts to the worker.

A recommended topic for future engagements could be the use of a graded approach for FCFs. The graded approach was an area that drew a lot of attention from the participants as a useful tool to inform the methodology for the assessment of FCFs considering the rages of hazards.

5.3 Session 2 – Implementation of Post-Fukushima Regulatory Improvements on FCFs

Second session was chaired by Andrew Buchan, Sellafield, United Kingdom and Kavita Murthy, CNSC, Canada.

- (1) Current Regulation in Japan and Safety Research in S/NRA/R for Nuclear Fuel Cycle Facilities after the Fukushima Daiichi Nuclear Power Station (1F) Accident, *K. Mori, M. Yokotsuka, M. Takanashi and K. Kubota,. Regulatory Standard and Research Department, Secretariat of Nuclear Regulation Authority (S/NRA/R), Japan.*
- (23) Implementation of post-Fukushima regulatory improvements on FCFs, *Mickael Gandolin, Autorité de sûreté nucléaire, France.*
- (19) Canadian Fuel Cycle Facilities: Licensee Responses and Canadian nuclear regulatory framework changes as a result of lessons learnt from the Fukushima Daiichi disaster; *Kavita Murthy, Julian Amalraj and Jocelyn Truong, Canadian Nuclear Safety Commission, Canada.*
- (10) The New IAEA Safety Report on Safety Reassessment of Nuclear Fuel Cycle Facilities in Light of the Feedback from the Accident at the Fukushima Daiichi NPP *Ramon Gater. IAEA.*

The second session covered improvements made in regulatory requirements relating to the safety of FCFs following the Fukushima Daichi event. Whilst regulators rightly carried out activities immediately in the days and weeks following the events at the Fukushima Daiichi NPS to ensure that the necessary assurances were provided to both governments and public, this could not be treated as a onetime only activity. Indeed, as more learning was derived from the event in terms of causes and the necessary

responses undertaken in very difficult and challenging circumstances, it became more obvious that the key learning went beyond an issue only relating to withstand of facilities to external hazards.

Each regulator has sought to achieve the necessary improvements whilst extending and building upon existing robust and sound nuclear safety principles. During the session the learning from three regulatory organisations and also the IAEA showed the implementation examples. It was obvious that the Fukushima Daiichi NPS accident has brought a paradigm shift on how nuclear safety provision must be viewed going forward.

Mr Muneyuki Yokotsuka (S/NRA/R, Japan) highlighted the approach which has been developed to conduct safety assessment for fuel fabrication and reprocessing facilities with particular focus on risk assessment method. This highlighted the need for comprehensive safety assessments which are periodically reviewed. He outlined the thorough approaches developed to consider severe accident analysis and interaction effects which could occur between severe accident scenarios. This usefully reinforced the approach taken both by the UK and IAEA guidance. The research work undertaken was reported in Session 4 which highlighted the significant, detailed and thorough work carried out to underpin issues associated with some key severe accident scenarios.

Mr Mickael Gandolin (ASN, France) highlighted the Complementary Safety Assessment as a regulatory requirement following the Fukushima Daiichi NPS accident, which required the potential for severe accidents to be identified which could result from extreme external hazards or prolonged loss of utilities. This approach which delivered the requirements of the ENSREG stress tests was delivered in a graded programme which prioritised the highest hazard FCFs with fleet of NPPs. The complementary safety assessment built upon the existing safety analysis already in place for the facility, but moved beyond the historical design basis and identified design-extension conditions more appropriate for such severe events. A challenging programme was developed which had to balance the need between new robust technical studies with the required prompt assurance of continued nuclear safety to all the necessary stakeholders. This has resulted in the identification of a HSC which consists of the systems, structures and components (SSC) necessary to deal with a severe accident along the organisational resources which need to be in pace to deal with such an event for a 48 hour period. This approach has allowed the identification of an appropriate set of engineered and organisational provisions to ensure consistent levels of safety to be implemented across a large range of different types of FCFs in a timely fashion.

Ms Kavita Murthy (CNSC, Canada) highlighted lessons Learnt from the Fukushima Daiichi NPS accident by the CNSC and detailed the responses by operators of FCFs. She outlined the range of FCFs in Canada and explained how the Canadian regulatory system encouraged significant input and commentary from a range of stakeholders and the public and that the technical work undertaken had to be presented in a way to facilitate this. In addition the range of FCFs requires that a graded approach would have to be applied and that related issues such as environmental safety may have to be considered.

Mr Ramon GATER (IAEA, Austria) presented the new IAEA report in Safety Reassessment of Nuclear Fuel Cycle facilities (SRS-90) /3/. The publication provides guidance on performing safety reassessments, in the light of the Fukushima Daichi NPS accident and in accordance with a graded approach, for FCFs of all types. Although this publication focuses on the nuclear fuel cycle facilities that are in operation, the guidance it provides also applies to facilities that are in design and construction phases. It is not intended to replace or supersede any of the guidance provided by the relevant IAEA standards, including those covering safety analyses, evaluation of seismic and external hazards and emergency preparedness and response for FCFs. However the publication should be used in conjunction with these standards.

According to the Fukushima lessons learnt presented in Session 2 the human factors are key in severe accident situations; these involve responses of individuals and organisations to extreme and potentially unforeseen situations. This needs to be addressed by provision of equipment, guidelines and emergency arrangements with the supporting organisational interfaces. All of these need to anticipate the difficult and

stressful conditions in which they will be deployed. The procedures of FCFs need to ensure that the full variety of these challenging situations can be anticipated in development and simulated in training. Significant effort should be expended on preparing prior analyses and indicating a range of potentially viable response options of FCFs.

Generic competencies and the ability to adapt and develop new solutions are keys to ensuring resilience at both individual and organisational levels. Staffing levels should be developed considering that off-site support may not be available in large hazards and therefore the use of on-site skills are keys in the short term in both recognising and responding to a severe event.

5.4 Session 3 – Implementation of Post-Fukushima Technical and Operational Improvements on FCFs

The third session was chaired by Véronique Lhomme (IRSN, France) and Yoshinori Ueda (S/NRA/R, Japan).

Seven papers were presented during this session by an operator from Sellafield Ltd. (United Kingdom), by a representative from the Swedish radiation safety authority, by a member of the NEA/CSNI Working group on human and operational factors (WGHOF) and by four representatives from the French technical support organisation (Institute for radiological protection and nuclear safety – IRSN).

- (8) Optimising the Resilience of Nuclear Facilities at Sellafield, *Anita O'Loane; Sellafield Ltd, UK.*
- (15) Post-CSA improvements at La Hague reprocessing site, *Emeline Cluzel, Michel Guillard; Institut de Radioprotection et de Sûreté Nucléaire, France.*
- (16) Improvements following the complementary safety assessments for the French fuel cycle facilities and research laboratories and reactors located in the sites of Cadarache, Marcoule, Romans-sur-Isère, Tricastin and Saclay, *Emeline Cluzel, Michel Guillard; Institut de Radioprotection et de Sûreté Nucléaire, France.*
- (24) Human Performance Under Extreme Conditions With Respect to a Resilient Organisation; *Wolfgang Preischl, NEA/CSNI/WGHOF.*
- (9) Post-Fukushima Improvements: How does the French TSO (IRSN) tackle human and organisational factors in stress tests set up by French Fuel Cycle Facilities? *Beauquier Sophie, Menuet Lise; Institut de Radioprotection et de Sûreté Nucléaire, France.*
- (12) Feedback of Fukushima Accident for Fuel Cycle Facilities Emergency Organisation *Nicolas Sendecki, Emmanuelle Ranc; Institut de Radioprotection et de Sûreté Nucléaire, France.*
- (26) Oversight of emergency planning zones around nuclear fuel cycle facilities and nuclear power plants in Sweden; *Angelica Öhrn; Swedish Radiation Safety Authority.*

Three first presentations highlighted, with detailed information, the Fukushima Daiichi NPS accident response improvements carried out at the Sellafield site (**Anita O'Loane, Sellafield Ltd.),** at the La Hague reprocessing site (**Emeline Cluzel, IRSN)** and at other French FCFs and research reactors and laboratories sites **(Michel Guillard, IRSN),** to enhance sites response to a beyond-design event or severe accident and optimise the resilience of FCFs.

All these sites are multi-facilities sites with plants designed, over several decades, to achieve various functions (e.g. of Sellafield with around 650 buildings, 200 of which with nuclear inventory), with varying level of technology, depending on the time of design, as well as varying operating states (e.g. of La Hague with legacy facilities, facilities under dismantling and reprocessing facilities in operation). Also, some sites are characterised by the predominance of chemical hazards (e.g. of the Tricastin and Romans-sur-Isère sites with UF_6 and HF).

Most of the time, on an FCFs site, due to the diversity of operations across the number of facilities and also to the diversity of radioactive materials and/or chemical products involved in the processes, it is necessary to implement specific solutions as standardised solutions to prevent/mitigate DECs (beyond-design basis accidents) are not usually possible. The presentations illustrated this topic in relation to:

- The equipment able to withstand extreme events, and to perform functions that are vital to the safety of the facilities, implemented/required on the French FCFs sites and associated to the safety requirement level known as “HSC”. The aim is to provide the equipment necessary for controlling the safety functions with protection from hazards greater than those adopted for the general design of the facility (dreaded situations), in order to ensure ultimate protection of the facilities against them over several days (thus enabling off-site resources to intervene). It concerns, for example, the reinforcement of robustness in water supply and capacity to restore the emergency cooling system for spent fuel pools and storage tanks of concentrated fission product for the La Hague site.
- The diversity of operations across the Sellafield nuclear facilities for which it has not been appropriate to implement a “one size fits all” response. This has resulted in a multi-faceted approach, requiring both a range of specific solutions and development of a flexible generic capability. This is a range of equipment which enhances the ability to respond to a severe event; it provides responders with a “toolbox” of equipment from which a flexible accident response can be deployed. This enables response to the wide range of events which could occur at varying levels of event severity on a complex FCF.

Moreover, as part of the presentation regarding the La Hague site, it was pointed out that for some facilities, as a result of the “stress tests”, post-Fukushima improvements should be considered in a particular way if the facilities don’t meet current safety standards nor present any safety margins. For example, for a facility dealing with legacy waste the evacuation of the radioactive material as quickly as possible can be requested.

On the other hand, many necessary improvements regarding human and organisational dimensions have been drawn from lessons learnt from the Fukushima Daiichi NPS accident.

Some of these improvements, implemented or planned by the French FCFs licensees, as well as remaining issues, were presented **(Sophie Beauquier and Lise Menuet, IRSN**) based on an IRSN analysis dedicated to human and organisational factors in the extreme management situation. The most important topics to consider are about:

- Anticipating, as much as possible, the intervention conditions that may be faced by intervening personnel (radiological ambience, possible lack of electricity, heat, equipment and facilities accessibility, availability of necessary information for carrying out a diagnostic of the facilities' status, etc.);
- Arranging a minimum plant staff, especially for the management of the most urgent decisions and actions to be taken at the very beginning of the crisis, waiting (e.g. 48 hours in France) for external resources and reinforcements;
- Providing all the necessary resources with technical skills (including operators of the facilities and, if possible sub-contractors) as well as non-technical skills (regarding managing interactions, as crisis communication, organisational, co-ordination, etc.);
- Organising trainings and preparation measures, in particular to anticipate stress effects and develop organisational resilience.

In addition, the experience gained within the works of the WGHOF on human performance under extreme conditions with respect to a resilient organisation was shared during this Session. Many findings and conclusions were presented **(Wolfgang Preischl, NEA/CSNI/WGHOF**) on:

- Human capabilities to support human performance in critical situations (e.g. stress-management strategies including emotional support);
- Provision of necessary infrastructure to respond to severe accidents including both off-site and on-site capability (e.g. taking into account human factor engineering aspects of technical systems, work aids tools and procedures…) and,
- Organisation to manage for the unexpected and develop resilience (e.g. definition of roles and responsibilities, co-operation and co-ordination, communication…).

For each of these three areas, needs for future researches were suggested; for example, about "Organisation", the transition from compliance to resilience should be studied more deeply.

Furthermore, another illustration of technical and operational solutions, adopted to manage, on FCFs sites, the consequences of long duration accidents from many FCFs due to extreme events was presented in the fifth presentation of session by **Nicolas Sendecki, IRSN**.

These solutions, resulting from discussion between a nuclear operator (AREVA) and the French nuclear safety authority (ASN) and its TSO (IRSN), consist in particular in:

- A new emergency management centre, more robust than those already built, to withstand extreme events and to host emergency team members and allow them to perform their tasks under safe radiological and chemical conditions on-site. The emergency team members must live inside the building independently, as a minimum for 48 hours, and the habitability of the building must be guaranteed that the ventilation system has a constant and reliable power supply. The means implemented to perform diagnosis of the facilities, to insure effective information flow between emergency teams, to collect environmental data…, and the intervention resources must be sufficient and appropriate to accidental situations envisaged on each site. FCFs operators have forecasted commissioning this type of buildings on the FCFs sites in 2017.
- A national task force, composed with AREVA's volunteers (about 1 000 currently), to be deployed on FCFs site in order to assist the local emergency organisation and to manage the damaging effects from extreme natural hazard with complementary human and material resources. FCFs operators would like to have national task force operational from beginning of 2017.

In the last presentation of Session 3, another technical and operational aspect of the use of the Fukushima Daiichi NPS accident lessons learnt was presented by **Sweden (Angelica Öhrn, Swedish radiation safety authority**). It concerns the definition of the emergency preparedness zones around the nuclear sites (regarding, for example, the distribution of iodine tablets (NPPs) or the alert of population and the evacuation plans in case of emergency (NPPs or FCFs)). Indeed, as the current existing zones in Sweden are not enough to handle an accident like the one at the Fukushima Daiichi NPS, an assignment from the Swedish government, for the national radiation safety authority, to perform an oversight of the existing emergency planning zones is going to be published in April 2017. The assignment also includes a change of the zones if necessary.

As a conclusion, in Session 3, many examples regarding the post-Fukushima technical and operational improvements on FCFs sites in various countries were presented, recalling the approaches carried out to draw up beyond-design basis or severe accident scenarios (e.g. graded approach, evaluation of the overall margins for "key" SSC necessary to ensure important safety functions, etc.) and reporting on the equipment, resources and deployment strategies developed and adapted to manage the response to the dreaded situations across the range of FCFs facilities processing with radioactive and/or chemical material.

Outputs and recommendations from these presentations can be stated as follows, as it seems essential to:

- Pay attention to mutual impacts (including domino effects) due to all the facilities located on the site and to the industrial environment. All the combinations of events and interactions due to multi-facilities aspects and, also, aggravating phenomena, like fire, explosions, chemical and/or radioactive releases… due to industrial facilities or NPPs in the vicinity of the FCFs site should be taken into account.
- Implement training and preparation measures, like periodic emergency crisis exercises (including anticipating stress effects, developing organisational resilience, etc.). This notably helps to think about prioritisation of resources and technical means deployment.
- Conduct a strong demonstration and assessment of the robustness of equipment when used for several types of remediation or mitigation actions.
- Identify dreaded situations scenarios and consequences through the use of realistic assumptions, rather than conservative safety case assessment values, to optimise emergency equipment and organisation.

5.5 Session 4 – Post-Fukushima Studies and R&D on Accident Scenarios and Source Terms for FCFs

Fourth session was chaired by Kotaro Tonoike, JAEA and Kenji Mori, S/NRA/R both from Japan.

There were four presentations in this session:

- (5) Behaviour of Volatilised Ru in the Presence of H_2O, HNO_3 and NOx Gases through Leak Path in a Reprocessing Plant; *Yuki Shibata; Japan Nuclear Fuel Limited, Japan.*
- (6) Experiment on airborne release fraction in hydrogen explosion accident at Reprocessing plant; *Takahiro Ishio; Japan Nuclear Fuel Limited, Japan.*
- (20) Development of Standard Procedure for Consequence Analysis of Criticality Accident in Fuel Cycle Facilities; *Yuichi Yamane, Hitoshi Abe; Japan Atomic Energy Agency, Japan.*
- (22) Experimental Evaluation of Release and Transport Behavior of Gaseous Ruthenium under Boiling Accident in Reprocessing Plant; *Naoki Yoshida, Shinsuke Tashiro, Yuki Amano, Kazuo Yoshida, Yuichi Yamane, Hitoshi Abe; Japan Atomic Energy Agency, Japan.*

All presentations of Session 4 were about the behaviour analysis on the source term at the time of the severe accident and/or DEC (or beyond-design basis accident) in FCFs and these were presented by Japan Nuclear Fuel Ltd (JNFL) and Japan Atomic Energy Agency (JAEA).

Two presentations were concerned with experiments about the evaporation to dryness phenomenon in reprocessing facilities. The remaining presentations were concerned with experiments about the hydrogen explosion event in reprocessing facilities and the criticality events in FCFs.

Mr Shibata (JNFL, Japan) had a presentation about experiments on behaviour of volatilised Ruthenium (Ru) in loss of cooling function of High Level Liquid Waste (HLLW) tanks in a reprocessing facility. In the evaporation to dryness of the HLLW due to loss of cooling function, Ru is oxidised and volatilised Ru compound occurs. Leak pass factor (LPF) of volatilised Ru is smaller than that of refractory Ru. According to the presentation, the existence and the residence time of NOx gas would be most significant factor because NOx gas decreases the LPF of Ru.

Mr Ishio (JNFL, Japan) had a presentation about experiments on hydrogen explosion accident at a reprocessing facility. According to this presentation, the airborne release fraction (ARF) of radiation element in hydrogen explosion is very significant but there is little study about this. So, JNFL curried out small scale experiment and annular vessel experiment. JNFL got the useful data for evaluating environment assessment in hydrogen explosion. In future, JNFL continues the research for applying these data to another type vessel.

Mr Yamane (JAEA, Japan) gave a presentation about development of standard procedure for consequence analysis of criticality accident in FCFs. According to this presentation, in JAEA, the application of five component equation to criticality accident as severe accident in FCFs is developed and the remaining issues are explained. The factor is thought to be estimated by this method. So, for the ideal estimation taking into account the temporal change of the factors, calculation models based on more experimental data must be developed.

Mr Yoshida (JAEA, Japan) gave a presentation about experiments on behaviour of gaseous Ruthenium (Ru) under boiling accident in a reprocessing plant. According to this presentation, in JAEA, a study for source term data of Ru at evaporation to dryness due to loss of cooling function has been conducted from the two kinds of experiments. These results suggested that the release and transport behaviour of Ru will gradually change depending on the status of liquid and vapour phase in accident.

Conclusions and recommendations of Session 4 are as follows:

- The estimation and analysis of a source term and the phenomenon in the design extension events are significant for the development of DEC measures for FCFs. More experiments and studies on source term and the analysis of the phenomenon in the design extension events are expected to make these measures more effective.
- There were comments from audiences that commonly pointed to the value of those research and development (R&D) activities and sharing of their results. There is only small amount of published information on experimental results related to releases of DEC of FCFs. Therefore, co-operation in sharing the existing results and in planning new testing is valuable for operators, TSOs, and regulators.

5.6 Final panel discussions and safety assessments

During the Aomori workshop discussions and in the final panel discussion, certain recommended practices and Fukushima lessons learnt for FCFs were presented and the following general topics were discussed:

1. Defence in depth and design-extension conditions.
2. Graded approach and safety classification.
3. Emergency planning, procedures and human factors.
4. Assessment of the chemical hazards.

The Aomori workshop pointed out examples of new requirements, good practices and new research in member countries and applications of these with a graded approach in FCFs. FCFs include large variations of physical and chemical forms of the processed materials, and therefore many presented actions are suitable only for specific facilities. Many operator actions of FCFs are done manually according to written procedures without protection automation; therefore, the work in area of human factors for ensuring the safety of the FCFs is very important.

In the workshop panel, first, summaries of sessions (1 to 4), e.g. outlines of presentations, topics, discussions and proposals from a floor, recommendations of additional works/efforts, insights, perspectives and ideas of WGFCS's works/tasks in the future, were presented by each session chair person. The following sections 5.6.1 to 5.6.4 present the workshop conclusions and recommendations based on the presentation and discussions during the workshop. The recommendations include conclusions which could be drawn based on the discussions and recommendations for future work.

5.6.1 Defence in depth and design extension

The design of FCFs is done according to the list design-basis accidents (DBAs). The design is based on defined limits of key plant parameters and only minor radiological impacts as well as minor chemical

toxicity impacts and reactive chemical impacts, to the personnel and the public are accepted and off-site intervention measures are also minimised. DBA analyses are done with conservative methods.

The Aomori workshop highlighted that, in addition to DBAs, it is necessary to define and justify a selected list of DECs. The set of DECs is usually based on a combination of deterministic and probabilistic assessments as well as engineering judgement of experienced designers. In case of DEC additional measures to bring plant into a controlled state are defined whenever possible and significant releases should be practically eliminated. For those DECs that are not practically eliminated additional design provisions could be necessary to protect the public and limit the impact to the environment.

LEVELS OF DEFENCE IN DEPTH (/2/ *Original source: INSAG-10, Defence in Depth in Nuclear Safety: A Report by the International Safety Advisory Group,* IAEA, 1996)

Levels	Plant status	Objective	Essential means
1	Normal operation	Prevention of abnormal operation and failures by design	Conservative design and high quality construction, operation and maintenance
2	Operational occurrences	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
3	Accidents	Control of accidents within the design basis	Engineered safety features and accident procedures
4	Beyond-design basis accidents	Control of severe plant conditions in which the design basis may be exceeded, including the prevention of fault progression and mitigation of the consequences of severe accidents	Additional measures and procedures to prevent or mitigate fault progression and to manage on-site emergency
5	Significant off-site release of radioactivity	Mitigation of radiological consequences of significant releases of radioactive materials	Accident management and off-site emergency response

The original definition of the recent DiD approach is presented in the table above. The recent terminology includes DEC instead beyond design-basis accident (BDBA). The DEC covers also severe events with releases; and external and internal hazards are taken into account in necessary levels of defence based on their justified probability and possible environmental consequences. The comprehensive application of DiD principle into the design of FCFs needs still more work and comparison of applications in international level.

Based on discussions at the Aomori workshop, the application of DiD for the FCF design is necessary to clarify and assess the adequate level of design of FCFs against external and internal hazards are part of this work. The effects of natural hazards included in the DEC analysis are normally assessed in this work in order to avoid “cliff-edge effects” that would result in loss of a fundamental safety function.

5.6.2 Graded approach and safety classification

The Aomori workshop reiterates the importance of graded approach in applying new requirements into all types and sizes of FCFs with various nuclear risks and chemical hazards, and various amount of radioactivity. A graded approach means that the application of regulatory requirements, used resources and other relevant measures are commensurate with the radiation and chemical risks associated with the exposure situation as well as with the likelihood and magnitude of exposures/3/. The potential hazards of the FCF could be assessed with deterministic or probabilistic tools, or with a combination of them.

To assess and compare level of actions to ensure the safety of the facility, it is possible to grade a facility based on the amount of dangerous materials together with qualitative and/or quantitative risk

assessments of the facility. The assessment of grading includes the scope, extent and details of the analysis, and the required human and financial resources. The provided content and scope and analysis as well as time and resources used may be significantly less for low radioactive inventory FCFs of low complexity (and conventional design) than those required for high inventory FCFs and facilities with complicated chemical processes with high personnel risk /3/. The accident scenarios used for design analysis and design extension assessment should be based on real potential hazard (radioactive inventory and chemical risks) of FCF. The graded approach is also applicable to the selection of site related hazards and to the emergency arrangements to be established based on the potential hazard associated with the FCF, including the emergency equipment and the scope and frequency of the emergency exercises. The resources for performing the safety reassessment and its applications, and the regulatory requirements for a safety reassessment are usually part of a grading process.

The risk-informed approach can be used to define the grading principles and their practical application in FCF. The graded approach was recognised to be useful also in defining resources for actions, levels in the management methods and other organisational factors.

It should be noted that the relatively high age of FCFs and their design standards compared to the NPPs means that ageing risks should be taken into account when reviewing of the design basis of a FCF /3/ and the full scope of ageing management methods should be used when looking at the possibilities to downgrade and limit the actions for safety. The design basis including mitigation of external hazards and ageing risks are key assessment areas in the periodic safety review (PSR) of FCF.

One practical method for grading is the safety classification of SSCs based on the safety functions of facility and relevance of equipment in applying the defence-in-depth concept including DEC events. Functional safety classification of items focuses attention on those items on which safety is most dependent. Safety classification is necessary to ensure that appropriate levels of design standards, surveillance, maintenance, quality and appropriate qualification are employed to ensure reliability and maintainability for these items. The necessary safety functions of FCFs are in general defined on the basis of safety criteria of FCF including radiological safety of personnel, releases and environmental safety of public, and their associated chemical safety.

5.6.3 Emergency planning, procedures and human factors

The set of EOPs of an FCF should include specified provisions for DEC, which means extreme hazards and events developing outside the designed and foreseen situations of facility. The EOPs of facility should describe the provisions for DEC, e.g. actions, equipment and emergency arrangements with the supporting organisational interfaces outside the site. In the event of an accident in a nuclear installation the emergency response is usually based on both an on-site emergency plan that is the responsibility of the licensee, and an off-site emergency plan that is the responsibility of the local, regional and/or national authorities.

In most NEA member states the off-site plan (or plans) will start with the involvement of local or regional authorities and local emergency response services and then extend as necessary to involve national government and national emergency response organisations /2/. Therefore, the periodical training of EOPs supported with training of external actions and co-operation with the external organisations with simulated situations is recommended to be arranged for reducing the stress of personnel in extreme events.

Comprehensive analysis and studies on possible actions, source term, releases to the environment and their trajectories in DEC situations make the measures described in EOPs more effective.

It is obvious that assessment of the DEC situations in the EOPs and their verification and validation processes with mature methods (e.g. verification and validation of operations as well as human factor analysis) as well as the qualification process of equipment and instrumentation should include all facilities in the site. The definition of autonomy requirements for design and operation of FCFs including rare external hazards should be based on a site specific list of hazards and it should be discussed in international

workshops in the future. International operating experiences (e.g. FINAS database events) can be used as a part of this work in international level.

It was also agreed that to confront exceptional – but nonetheless conceivable – extreme natural hazards scenarios, additional on-site safety requirements levels in terms of safety support systems (electrical supply, cooling and heat sink, containment…), instrumentation, control and monitoring systems, human and organisational measures (procedures, training, exercises, communication, maintenance…), emergency organisation and equipment (crisis management centres…) should be adopted. This would guarantee that the vital basic functions of nuclear facilities are sustained over several days, thus enabling off-site resources to intervene.

5.6.4 Assessment of the chemical hazards

Based on discussions at the Aomori workshop the effects of exposure of the various chemical substances and their combination to exposure of radioactive substances during accidents and even during DEC is important for the safety provisions of FCFs. Differences in national legislation and variations in responsibilities of national regulators do not change the responsibility of FCF owner to provide a full list of chemical hazards including the combination of these hazards and nuclear and radioactive risks. This means that all chemical forms and concentrations of radioactive and toxic substances, major physical processes and exposure pathways and their consequences are listed and assessed in a comprehensive safety case of FCF.

In the previous FCF's workshop in Toronto on 2011 /1/ the need for a reference library of chemical hazards related to FCFs was mentioned, however, this subject was not covered in the Aomori workshop. However, the subject could be discussed again during the CSNI workshop on chemical hazards of FCFs, which is planned to be arranged in 2018.

6. CONCLUSIONS AND RECOMMENDATIONS

Remarkable developments on regulations and various technical and operational improvements were presented at the Fukushima Daiichi accident workshop in Aomori. Approaches for DEC and severe accident scenarios included evaluation of the overall margins for "key" SSC necessary to ensure important safety functions as well as new strategies to response to the extreme situations in FCFs with radioactive and chemical material.

Discussions in the Aomori workshop emphasise the applicability and determination of DEC approach (including severe accident management strategies) for all FCFs depending on their safety importance and risk potential. Specifically the criterion used for the determination of the events leading to DEC with releases is important to define and apply. When DEC and external and internal hazards are included in the design it ensures that design scope is comprehensive and any important event is not ruled out. A graded approach and best estimate methods together with probabilistic approach give flexibility and maximise the safety benefits of design taking into account the resource limits.

Other issues under discussion were the criteria used for the likelihood of the events in terms of probabilistic values and resources and training methods to ensure the comprehensiveness of the DEC procedures. A recommended topic for future engagements could be the use of a graded approach for an FCF. In addition, the mutual impact between facilities located on the same site should be assessed and taken into account in design and training of the personnel.

The subjects of emergency planning were discussed during the Aomori workshop, especially in Session 3 as a part of human and organisational factors. It was recognised that the assessment of the management strategies for the DECs, including co-operation with the external organisations, is an important part of EOPs and periodical emergency exercises FCFs. In sessions 2 and 3 it was pointed out that the human factors are key in severe accident situations; these involve responses of individuals and organisations to extreme and potentially unforeseen situations.

The Aomori workshop discussions included the following recommendations:

1. The Defence-in-Depth (DiD) concept applied with grading principle is effective tool for ensuring safety in design and for defining management system, quality methods and working procedures of FCFs. The grading principle could be applied through the functional safety classification of the system and components. The practice can be applied in safety improvements to design, implementation of modifications and in responding proportionately to deviations during the operation.
2. The definition of autonomy requirements for design and operation of FCFs including rare external hazards shall be based on-site specific list of hazards. Autonomy principles should be discussed in the international workshops on future. International operating experiences (e.g. FINAS database events) can be used as a part of this work.
3. The results on the implementation of DiD including DEC (beyond design-basis accident) to FCFs and including realistic and optimised design of equipment used in DEC should be presented at the international level. Examples and lessons learnt in design modification processes of NPPs could be part of this work.

4. All possible, even extremely rare, accidental situations are an important part of emergency exercises of FCFs. These exercises are an important method to test the EOPs, and the analysis basis of the facility states (including accident states) and optimal use of equipment inside them. The lessons learnt from the facility exercises and experience on validation of the procedures of FCFs shall be collected and discussed in an international level activity.
5. The acceptable risk level for external hazards as a part of the whole risk for FCFs should be discussed at the international level. The assessment of combined hazards like earthquakes and tsunamis could be part of such a discussion as well as the mutual impact between facilities located on the same site.

7. REFERENCES

/1/ Workshop on Safety Assessment of FCFs – Regulatory Approaches and Industry Perspectives in Toronto, Canada, September 2011, NEA/CSNI/R(2012)4, July 2013

/2/ *The Fukushima Daiichi Nuclear Power Plant Accident, OECD/NEA Nuclear Safety Response and Lessons Learnt*, 2013; NEA No. 7161, OECD, Paris.

/3/ SRS 90; "Safety Reassessment for Nuclear Fuel Cycle Facilities in Light of the Accident at Fukushima Daiichi Nuclear Power", IAEA; Vienna, 2016

APPENDIX 1 – LIST OF PARTICIPANTS

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APPENDIX 2 – WORKSHOP PROGRAMME

Tuesday, 15 November
Opening- Introduction and Objectives of the workshop

10:00 – 10:45
Chairpersons: K. Mori (S/NRA/R), K. Tonoike (JAEA)

- Opening speech of host organisation – M. Uchida (Director of Division of Research for Nuclear Fuel Cycle and Radioactive Waste, S/NRA/R)
- NEA objectives and goals for the workshop – O. Nevander (NEA)
- Practical arrangements of the workshop – K. Mori (S/NRA/R)

Session 1- Feedback of post-Fukushima safety reviews performed for FCFS

11:10 – 16:20
Chairpersons: J. Marcano (NRC), O. Nevander (NEA)

11:10 – 12:10

- (2) Technical evaluation of modifications to a uranium hexafluoride facility to protect against seismic and tornado missile events
  Jonathan Marcano. Nuclear Regulatory Commission, USA
- (3) Applicability of lessons learnt from the Fukushima Daiichi NPS accident to facilities other than power reactors in the United States
  Margie Kotzalas. Nuclear Regulatory Commission, USA

13:30 – 15:00

- (4) Post-fukushima safety reviews performed at fuel cycle facilities in the United State
  Jonathan Marcano. Nuclear Regulatory Commission, USA
- (7) Evaluating the Resilience of Nuclear Facilities at Sellafield
  Andrew B. Buchan. Sellafield Ltd, UK
- (11) Results and Consequences of Stress Tests Performed for Interim Storage Facilities of Radioactive Material in Germany
  Christian Drobniewski. Bundesamt für Strahlenschutz, Germany

15:20 – 16:20

- (17) Enusa-Juzbado Plant Stress Test Approach and Actions Taken
  Enrique Escandón Ortiz, Luis Blanco Fernández, Óscar Zurrón Cifuentes
  Enusa Industrias Avanzandas, Spain
- (14) Feedback of complementary safety assessments for French fuel cycle facilities and research laboratories and reactors
  Emeline Cluzel, Michel Guillard, Institut de Radioprotection et de Sûreté Nucléaire, France

16:20-16:40
Closing Discussion of first day

Wednesday, 16 November

Session 2- Implementation of post-Fukushima regulatory improvements on FCFS

9:00 – 11:00
Chairpersons: A. Buchan (Sellafield), K. Murthy (CNSC)
9:00 – 11:00

- (1) Current Regulation in Japan and Safety Research in S/NRA/R for Nuclear Fuel Cycle Facilities after the Fukushima Daiichi Nuclear Power Station (1F) Accident
  K. Mori, M. Yokotsuka, M. Takanashi and K. Kubota,. Regulatory Standard and Research Department, Secretariat of Nuclear Regulation Authority (S/NRA/R), Japan
- (23) Implementation of post-Fukushima regulatory improvements on FCFs
  Mickael Gandolin, Autorité de sûreté nucléaire, France
- (19) Canadian Fuel Cycle Facilities: Licensee Responses and Canadian nuclear regulatory framework changes as a result of lessons learnt from the Fukushima Daiichi disaster
  Kavita Murthy, Julian Amalraj and Jocelyn Truong
  Canadian Nuclear Safety Commission, Canada
- (10) The New IAEA Safety Report on Safety Reassessment of Nuclear Fuel Cycle Facilities in Light of the Feedback from the Accident at the Fukushima Daiichi Nuclear Power Plant *Ramon Gater. IAEA*

Session 3 – Implementation of post-Fukushima technical and operational improvements on FCFS

11:20 – 16:30
Chairpersons: V. Lhomme (IRSN), Y. Ueda (S/NRA/R)
11:20 – 12:20

- (8) Optimising the Resilience of Nuclear Facilities at Sellafield disaster
  Anita O'Loane. Sellafield Ltd, UK
- (9) Post-Fukushima Improvements: How does the French TSO (IRSN) tackle human and organisational factors in stress tests set up by French Fuel Cycle Facilities?
  Beauquier Sophie, Menuet Lise
  Institut de Radioprotection et de Sûreté Nucléaire, France

13:40 – 14:40

- (12) Feedback of Fukushima Accident for Fuel Cycle Facilities Emergency Organisation
  Nicolas Sendecki, Emmanuelle Ranc
  Institut de Radioprotection et de Sûreté Nucléaire, France
- (24) Human Performance Under Extreme Conditions With Respect to a Resilient Organisation
  Wolfgang Preischl
  NEA/CSNI/WGHOF

15:00 – 16:30

- (15) Post-CSA improvements at La Hague reprocessing site
  Emeline Cluzel. Michel Guillard, Institut de Radioprotection et de Sûreté Nucléaire, France
- (26) Oversight of emergency planning zones around nuclear fuel cycle facilities and nuclear power plants in Sweden; *Angelica Öhrn, Swedish Radiation Safety Authority*
- (16) Improvements following the complementary safety assessments for the French fuel cycle facilities and research laboratories and reactors located in the sites of Cadarache, Marcoule, Romans-sur-Isère, Tricastin and Saclay
  Emeline Cluzel, Michel Guillard. Institut de Radioprotection et de Sûreté Nucléaire, France

16:30 -16:50
Closing Discussion of second day

Thursday, 17 November

Session 4 – Post-Fukushima Studies and R&D on Accident Scenarios and source terms for FCFs

9:00 – 11:20
Chairpersons: K. Tonoike (JAEA), K. Mori (S/NRA/R)

9:00 – 10:00

- (5) Behaviour of Volatilised Ru in the Presence of H_2O, HNO3 and NOx Gases through Leak Path in a Reprocessing Plant
  Yuki Shibata, Japan Nuclear Fuel Limited, Japan
- (6) Experiment on airborne release fraction in hydrogen explosion accident at Reprocessing plant
  Takahiro Ishio, Japan Nuclear Fuel Limited, Japan

10:20 – 11:20

- (20) Development of Standard Procedure for Consequence Analysis of Criticality Accident in Fuel Cycle Facilities
  Yuichi Yamane, Hitoshi Abe. Japan Atomic Energy Agency, Japan
- (22) Experimental Evaluation of Release and Transport Behaviour of Gaseous Ruthenium under Boiling Accident in Reprocessing Plant
  Naoki Yoshida, Shinsuke Tashiro, Yuki Amano, Kazuo Yoshida, Yuichi Yamane, Hitoshi Abe; Japan Atomic Energy Agency, Japan

13:00 – 14:00 **Closing Panel – Final discussions and recommendations of the workshop**

Chairperson: Y. Ueda (S/NRA/R)
Panellists:
O. Nevander (OECD/NEA)
J. Marcano (NRC)
A. Buchan (Sellafield)
V. Lhomme (IRSN)
K. Tonoike (JAEA)

15:00 – 15:15
Closing remarks and information on technical visit (host organisation)

APPENDIX 3 - CONFERENCE PAPERS

Proceedings of the CSNI Workshop on Developments in Fuel Cycle Facilities (FCFs) after the Fukushima Daiichi Nuclear Power Station (NPS) Accident
Aomori City, Japan
15-17 November 2016