

The Fukushima Daiichi Nuclear Power Plant Accident



OECD/NEA Nuclear Safety Response and Lessons Learnt



**The Fukushima Daiichi
Nuclear Power Plant Accident:
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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Foreword from the NEA Director-General

On 11 March 2011, Japan endured one of the worst combined natural disasters in its history when a massive earthquake struck its eastern coast and was followed by a tsunami which led to the loss of thousands of lives. These combined natural disasters were also at the origin of the Fukushima Daiichi nuclear power plant accident due to the prolonged loss of electric power supply and ultimate heat sink required for cooling. While the accident itself was not responsible for any casualties, it has affected the lives of tens of thousands of displaced Japanese citizens, resulted in very large economic costs and caused considerable environmental damage in the surrounding area.

As part of the NEA's activities to maintain and further develop the scientific, technological and legal bases for the safe use of nuclear energy, and as a contribution to the OECD mission to foster "better policies for better lives", the Agency has worked closely with its member and partner countries to examine the causes of the accident and to identify lessons learnt with a view to the appropriate follow-up actions being taken at the national and international levels. Much has already been accomplished, and further studies and research will be carried out.

While for most this accident has not called into question the use of nuclear power as such, it has reminded us all that nuclear energy requires the highest standards of safety which need to be reviewed and improved on a regular basis, and that there can be absolutely no complacency in this regard.

The Fukushima Daiichi nuclear power plant accident marks a turning point in terms of reviewing how nuclear safety is evaluated and ensured. It has triggered a closer examination of specific site locations and designs associated with those sites. It has also compelled nuclear safety experts to confirm that the principles upon which nuclear safety has been built remain valid, notably the defence-in-depth concept, but that more needs to be done to ensure their effective implementation in all countries and all circumstances. A strong safety culture, maintaining a questioning attitude and learning from one another will help us accomplish this together. The work of the NEA described in this report constitutes an important contribution to the safety of both today's and tomorrow's nuclear reactors.

Luis E. Echávarri
NEA Director-General



Foreword from the Chairman of the NEA Committee on Nuclear Regulatory Activities (CNRA)

The NEA member countries, standing technical committees and secretariat took prompt action following the Fukushima Daiichi nuclear power plant accident to review the safety of nuclear power reactors in operation. In parallel, they also extended offers of direct assistance to the Japanese authorities to help them face the various challenges presented by the accident and the evacuation of the population in the surrounding areas.

The NEA actions taken in response to the accident are described in the pages that follow. They have primarily been led by the three NEA committees concerned with nuclear and radiation safety issues – the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI) and the Committee on Radiation Protection and Public Health (CRPPH) – but also involved the NEA as a whole.

The CNRA, in its capacity as the NEA regulatory committee, has ensured that member countries share their experiences and results from national safety reviews, decisions taken to improve safety and changes being considered to their regulatory frameworks. In addition, the committee established the means and procedures needed to achieve results consistent with the importance of the issues at hand. External events, accident management, emergency response and crisis communication, human and organisational factors, and robustness of plant safety systems are a few examples of the priorities set by the committee.

The NEA standing technical committees and secretariat played an essential role in bringing together the top regulators and experts to discuss issues of common interest in a collegial, open-minded approach in the NEA fora for international co-operation. The results of their efforts thus far in addressing the Fukushima Daiichi nuclear power plant accident are offered herein for the benefit of all interested parties and stakeholders.

The lessons learnt from the accident will continue to be identified and developed over the long term. To date, a considerable amount of work has been completed, but more remains to be done. To meet our objectives, a consistent international effort is necessary and the CNRA will continue to play a key role in ensuring the appropriate regulatory response to the accident.



Jean-Christophe Niel, CNRA Chairman
Director-General of the French Nuclear Safety Authority (ASN)

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Executive summary

The Fukushima Daiichi nuclear power plant (NPP) accident that occurred on 11 March 2011 following a massive earthquake and tsunami was one of the most severe accidents ever experienced at a nuclear power plant and will have to be dealt with for many years by those in charge of nuclear safety (operators, safety bodies). Following the accident, nuclear regulatory authorities, governments and international organisations around the world took immediate actions to support Japan in its response. Under the control of nuclear regulatory authorities, operators began undertaking a series of analyses and follow-up measures to ensure the safety of all nuclear facilities. This report outlines the actions taken by the OECD Nuclear Energy Agency (NEA) and its member countries. Key messages and their implications for ensuring high levels of nuclear safety are also summarised.

At the national level, all NEA member countries with nuclear power plants took early action to ensure and confirm the continued safety of their operating NPPs and the protection of the public. After these preliminary safety reviews, all countries with nuclear facilities carried out comprehensive safety reviews, often referred to as “stress tests”. These comprehensive safety reviews reassessed the safety margins of nuclear facilities with a primary focus on challenges related to conditions experienced at the Fukushima Daiichi NPP, for example extreme external events and the loss of safety functions, or capabilities to cope with severe accidents. The reviews examined the adequacy of design-basis assumptions as well as provisions for beyond-design-basis events.

NEA member countries with nuclear power plants evaluated, and when warranted, took actions to improve the safety of the plants. They also undertook to upgrade existing safety systems or to install additional equipment and instrumentation so as to enhance the ability of each plant to withstand a natural event that disrupts access to the electrical power grid and/or ultimate heat sink for an extended period, including events that affect all the reactors at a single site simultaneously (multi-unit events).

In the weeks following the accident, the NEA already began establishing expert groups in the nuclear safety and radiological protection areas as well as contributing to



TEPCO, Japan.

information exchange with the Japanese authorities and other international organisations. It promptly provided a forum for high-level decision makers and regulators within the G8-G20 frameworks.

Effective implementation is being sought of actions aimed at making it extremely unlikely that an accident similar to that of the Fukushima Daiichi NPP accident

Key messages

- NEA member countries implemented focused safety reviews of their operating reactors and determined that they were safe to continue operation. Additional safety enhancements that will help to better cope with external events and severe accidents have been identified and are being implemented.

Key messages

- *Nuclear safety professionals have a responsibility to hold each other accountable to effectively implement nuclear safety practices and concepts.*
- *The primary responsibility for nuclear safety remains with the operators of the NPPs, and regulatory authorities have the responsibility to ensure that the public and the environment are protected.*

could occur in the future. The main focus is on enhanced application of the defence-in-depth concept to ensure robustness against external threats and on accident management practices to face loss of safety functions. In addition, countries are improving their knowledge of the behaviour of spent fuel pools (SFPs) under accident conditions; gaining better understanding of staff performance under stressful conditions through human performance/factors analysis; and reviewing and improving crisis communication, emergency procedures and guidance. Actions are also being undertaken to improve the effectiveness of emergency plans, in particular in situations with severe damage to the local, national or regional infrastructure that could be caused by an external initiating event. Research and development programmes related to severe accidents and probabilistic safety assessments (PSAs) considering natural hazards are being conducted as well.

In addition to revising regulatory requirements to better cope with external hazards and severe accidents, many countries, and the international radiological protection community in general, are revisiting approaches to emergency management and recovery in order to be better prepared nationally for accident situations. This includes reviewing national preparations for post-accident recovery and for transition from the emergency to the recovery phase. Improvements in international communications and exchange of information and expertise among regulatory authorities, their technical crisis centres and relevant international organisations are also being studied and implemented.

Two years after the accident, the NEA continues to assist the Japanese authorities in dealing with their recovery efforts, associated challenges and research plans. Current issues include more comprehensive safety reviews, decontamination, radiological protection and stakeholder dialogue. The NEA is also supporting research programmes designed to improve understanding of how the accident progressed as well as to obtain safety-related information during decommissioning and dismantling.

Based on experience from the Three Mile Island and Chernobyl accidents, a full analysis of the Fukushima Daiichi NPP accident will take many years. The NEA is working with the Japanese authorities on the development of the research plans to collect the information needed to better understand what happened as the accident progressed at each of the units. Associated activities will continue for several years and new activities may also be needed in the future.

The key messages and conclusions drawn from the post-accident activities and the implications they have on ensuring that high levels of nuclear safety are continuously maintained and improved internationally are outlined below.

First among these is that NEA member countries using nuclear power promptly implemented focused safety reviews of their operating reactors, considering such impacts as those related to extreme external events, and determined that they were safe to continue operation while more comprehensive safety reviews were conducted. Additional safety enhancements that will help to better cope with external events and severe accidents have been identified and are being implemented in NEA member countries.

Key messages

- *There is no room for complacency in the implementation of nuclear safety practices and concepts.*
- *The Fukushima Daiichi NPP accident identified significant human, organisational and cultural challenges, which include ensuring the independence, technical capability and transparency of the regulatory authority.*

A fundamental message from the accident is that there is no room for complacency in the implementation of nuclear safety practices and concepts.

The existing national and international requirements already in place provide an effective framework for accidents within the design basis, and efforts are underway to enhance these frameworks to better address accidents that, although unlikely, could result in catastrophic consequences if unmitigated.

Nuclear safety professionals have a responsibility to hold each other accountable to effectively implement nuclear safety practices and concepts. Recognising that the primary responsibility for nuclear safety remains with the operators of the NPPs, regulatory authorities have the responsibility to ensure that the public and the environment are protected from the harmful effects of radiation.

Although the accident at the Fukushima Daiichi NPP overwhelmed essentially all the engineering and procedural barriers to the offsite release of radioactive material, the fundamental concepts of defence-in-depth still remain valid and continue to be shared by those in charge of nuclear safety. Where there is higher uncertainty, as in the case of external hazards, effective implementation of the defence-in-depth concept requires additional measures to address these uncertainties to maintain adequate safety margins.

There are lessons being learnt, analyses being conducted, and information being collected to support safety enhancements to cope with events that go beyond the design basis. This report has shown that there would be benefit from having guidance from regulatory authorities in each country on the application of DiD in such areas as: a) prevention and mitigation at each level¹ of DiD, b) to ensure that actions taken and resources relied upon at one level of DiD can be made independent from the other levels, and c) to minimise the potential for common-cause failures propagating from one level to another.

The Fukushima Daiichi NPP accident identified significant human, organisational and cultural challenges that need to be addressed. Such challenges include ensuring the independence, technical capability and transparency of the regulatory authority.

The diversity of national recommendations during emergencies, and in particular the differences between Japanese protection recommendations and those of foreign governments for their own citizens in Japan, suggests that mechanisms to share technical information among governments should be improved.

It has been recognised that significant improvements are needed in national and international communications and information exchange among national regulatory organisations and their crisis response centres. The international information exchange aspects of nuclear emergencies are also being reviewed internationally in a drive to improve all communication aspects among countries that could be directly or indirectly affected by nuclear emergencies.

The NEA International Nuclear Emergency Exercises (INEX) have focused on this issue, and will continue to study national approaches to making related decisions. In addition, should a large accident occur, there could be a need for urgent actions in countries adjacent to the accident state.

Key messages

- *The fundamental concepts of defence-in-depth remain valid and continue to be shared by those in charge of nuclear safety.*

Key messages

- *Since an accident can never be completely ruled out, the necessary provisions for dealing with and managing a radiological emergency situation, onsite and offsite, must be planned, tested and regularly reviewed.*

1. See Table page 25.

Key messages

- *Ensuring safety is a national responsibility but poses a global concern due to potentially far-reaching accident consequences.*
- *Complete experience feedback from the Fukushima Daiichi nuclear power plant accident will take many years.*
- *A questioning and learning attitude is essential to continue improving the high level of safety standards and their effective implementation.*

The implementation of protective measures remains problematic, in particular as the situation transitions to longer-term recovery, and those evacuated wish to return to their normal lives. This transition requires significant resources and efforts to effectively engage with stakeholders so as to understand and appropriately address their concerns. This is particularly complex in a post-accident situation where public trust may often be low.

To date, a considerable amount of work has been completed to gather in-depth experience and feedback from the Fukushima accident, but much more remains to be done by the whole nuclear community. As the accident-recovery process continues to evolve and reach specific conclusions, the latter could have an

effect on the long-term recommendations for research and development. Such work could be included in NEA ongoing research, with the goal of developing enhanced analysis methods for those areas that were found to require increased scrutiny following the preliminary safety assessments and technical evaluations carried out after the accident (i.e. severe accidents, external hazards assessments). These and other activities, some to be identified, will continue for several years to come.

For medium- and longer-term actions to address lessons learnt, international co-operation provides a forum for collecting, sharing and analysing data to develop consistent approaches that can be applied within the national regulatory framework. This international co-operation also provides a forum in which peer regulators can actively encourage each other to remain vigilant in ensuring the safety of their nuclear power plants and help avoid the complacency that contributed to the accident at the Fukushima Daiichi NPP.

Since an accident can never be completely ruled out, the necessary provisions for dealing with and managing a radiological emergency situation, onsite and offsite, must be planned, tested and regularly reviewed in order to integrate experience feedback from drills and from the management of real-life situations. As a complement to these safety provisions, the NEA will continue working on appropriate communication of nuclear risks.

Following the large societal, economic and psychological impacts of the accident, the nuclear safety organisations considered that provisions should be identified to prevent and mitigate the potential for severe accidents with long-term, offsite consequences.

To conclude, it is the collective responsibility of nuclear safety professionals to ensure that there is no complacency in the effective implementation of the practices and approaches that have been developed over decades of use of nuclear power to protect the public and the environment from the harmful effects of radiation. A questioning and learning attitude is essential to continue improving the high level of safety standards and their effective implementation.

Ensuring safety is a national responsibility but poses a global concern due to potentially far-reaching accident consequences. Within this context, international co-operation is important for identifying commendable practices to ensure that nuclear safety is effectively addressed within the national regulatory framework of countries with nuclear power programmes. The NEA provides an effective forum for this international co-operation.

Working together through international co-operation, regulatory authorities can identify commendable practices that will support national programmes as they develop and implement the medium- and longer-term actions in response to the lessons learnt from the accident.

Introduction

The first phases of the Fukushima Daiichi nuclear power plant accident began shortly after the 11 March 2011 Tohoku earthquake and tsunami struck, but continued to evolve in the weeks and months that followed. By 30 March 2011, the NEA Committee on Nuclear Regulatory Activities (CNRA) had established a Senior-level Task Group on Impacts of the Fukushima Daiichi NPP Accident (STG-FUKU). This group was initially requested to co-ordinate the response of the CNRA, to exchange information on national activities and to examine generic implications and lessons learnt from the event. A request was also made to identify areas where in-depth evaluations would be of benefit at the international level, and to define the activities that could be undertaken by the new task groups of the CNRA or the NEA Committee on the Safety of Nuclear Installations (CSNI) in order to address gaps that were not addressed within the scope of an existing group.

At about the same time, the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPF) was established by the NEA Committee on Radiation Protection and Public Health (CRPPH) as a focal point for Fukushima activities, with support from the CRPPH Working Party on Nuclear Emergency Matters (WPNEM), on radiological protection and emergency management issues. Each of the committees has also been working in co-operation with all relevant international organisations, in particular the International Atomic Energy Agency (IAEA) and the European Commission (EC).

In June 2011, the NEA organised, in co-operation with the French Presidency of the G8, an international ministerial meeting and a regulatory forum. At these meetings, the accident at Fukushima Daiichi NPP and the lessons learnt were discussed, and the issues identified are now being addressed by the CNRA, the CSNI and the CRPPH. Feedback from the ministerial meeting and the regulatory forum focused on priority areas for NEA activities including: extreme external natural events and resilience to external impacts (e.g. combined risks); plant design and the ability of safety systems and accident management measures to withstand severe accidents; emergency response and management capabilities; crisis communication; and site recovery plans and their implementation. The need to improve collaboration, communication and transparency, especially during a crisis, was also identified as an important area of focus for lessons learnt. Further, it was considered important to assure the international community that the regulatory authorities in NEA and associated countries are sharing information and working together to ensure the continued safe operation of nuclear power plants today and into the future. In addition, it is expected that they will work towards improving their practices and the international nuclear safety framework as required, in order to implement lessons learnt, further improve NPP safety and prevent complacency.



During its October 2011 meeting, the NEA Steering Committee for Nuclear Energy held a policy debate on the Fukushima Daiichi NPP accident, which focused on NEA and member countries' responses. During the debate, it was recalled that the accident was due to the combined effects of a very strong earthquake and an exceptionally high tsunami, which has led nuclear safety authorities worldwide to conduct safety evaluations for beyond-design-basis events and multiple risks. Further, the Steering Committee stressed the importance of defence-in-depth and a strong safety culture. It noted the importance of maintaining good communication and co-operation among regulatory bodies, industry and international organisations in order to maximise the exchange of key information. The Steering Committee acknowledged that the operator is responsible for the safety of its plant(s), while the regulator is responsible for protecting public health and seeing that the proper regulations and system of verification are in place to ensure that the operator is meeting its responsibilities in this area.

To ensure that the NEA facilitated an effective and efficient exchange of information and response to the Fukushima Daiichi NPP accident, a meeting was organised in December 2011 among the bureaus of the three principal standing technical committees with responsibilities in the areas of regulatory oversight, nuclear safety and radiation protection and public health (the CNRA, the CSNI and the CRPPH) to discuss how best to co-ordinate and co-operate in responding to the accident. All three committees had begun to consider and, in some cases, to initiate tasks to address some of the lessons being learnt from the accident. The meeting participants agreed on how to implement an integrated response process whereby the CNRA would assume overall co-ordination of the NEA integrated response and that the STG-FUKU would assume the role of programme/oversight official and co-ordinator. In addition, the CSNI extended the scope of its Programme Review Group (PRG) to address cross-cutting activities related to the Fukushima Daiichi NPP accident. The three committees were clear in their expectations: that highly important, urgent tasks were to produce draft results within one year, and that lower-importance and/or lower-urgency tasks were to be completed within a two- to three-year time period.

The CNRA, taking into account the report from the STG-FUKU, also considered and set out its regulatory priorities for scientific and technical tasks that the CSNI had identified, and has given strong support to the high-priority tasks proposed by the CSNI. In addition, and again based on the STG-FUKU report, the CNRA identified and requested areas for new CSNI tasks – for example on the robustness of electrical systems. The CSNI has responded positively to these requests and a series of existing, new or modified international scientific and technical research tasks are underway with the objective of strengthening the various layers of the defence-in-depth (DiD) concept.

The CSNI highlighted technical priorities at an early stage in a working document (“Considerations and Approaches for Post-Fukushima Daiichi Follow-Up Activities”) that identified concepts to be considered in response to the accident. The working document looked at, among other issues, external and internal hazards, plant robustness, safety management, emergency preparedness and safety research more generally. It also noted that focus should be given to strengthening and improving the implementation of the DiD concept. The underlying technical phenomena associated with the Fukushima Daiichi NPP accident, including such matters as fuel and system performance, hydrogen generation and behaviour of the spent fuel pools, was identified as a focus of future research programmes. One important conclusion reached by the CSNI is that the local, site- and reactor-specific conditions that led to the accident and its consequences will not be fully described and understood for some time. The CSNI also concluded that a major lesson to be drawn from this accident is that current practices may not fully consider the safety impact of low probability, but nevertheless physically possible external initiating events.

From the very early phases of the Fukushima Daiichi NPP accident, the CRPPH and the NEA Secretariat were very active in following the situation and in addressing members'

needs. The CRPPH also conducted extensive work to identify the emergency management and recovery lessons from the accident. As a founding member of the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE), which was created to co-ordinate relevant emergency management planning and response work by international organisations, the NEA participated in the activities of IACRNE during the accident. The IAEA, Chair of the IACRNE, held a series of teleconferences with member organisations immediately following the accident to share information and to co-ordinate response activities. While the NEA has no statutory responsibilities for nuclear emergency management, the Secretariat offered its services to collect national decisions and recommendations with regard to the Fukushima Daiichi NPP accident, and to survey the development of frequently asked questions (FAQs) by IACRNE member organisations so as to ensure consistency and coherence. It also surveyed IACRNE member organisations' public web pages, in particular those of the IAEA, the World Health Organization (WHO), and the World Meteorological Organization (WMO), and reported back to the IACRNE that public messages being sent by relevant international organisations were very consistent.



On 17 March 2011, the NEA also began collecting information on governmental decisions that was then posted on the IAEA's ENAC (Emergency Notification and Assistance Conventions) secure website, in accordance with the NEA offer to provide this service to the IACRNE. The NEA developed and sent out a short survey to obtain information on the types of governmental decisions and recommendations being made, and asked governments to keep the NEA Secretariat informed of updates. The questions asked addressed recommendations for foreign nationals in Japan; for monitoring passengers, crew and transport returning from Japan; for importing food or goods from Japan; and for potassium iodide (KI) distribution to foreign nationals in Japan. A total of 34 governmental organisations responded, including 8 non-OECD member countries, and several organisations from the Global Health Security Initiative (GHSI) member countries (the G8 plus Mexico). Information collection and updating of responses on the IAEA secure website continued until 21 April 2011, at which point it was suspended because the governmental decisions and recommendations collected represented an incomplete snapshot of a time when decisions were being taken based on specific circumstances, and for which concrete conclusions or lessons could not be drawn. However, this large number of decisions and recommendations was useful for identifying patterns regarding the subjects of decisions, and suggested mechanisms or approaches that could improve responses to an accident situation. Identified patterns included national decision consistency, national philosophy for addressing emerging issues, and national conduct of technical assessments in uncertain circumstances. The results are provided in "Patterns in Governmental Decisions and Recommendations (GDR) Information Exchange during the Fukushima NPP Accident" [NEA/CRPPH(2012)3].

Immediate response by NEA member countries

Prompt actions to ensure safety

All NEA member countries took early action to ensure and confirm the continued safety of their existing and planned nuclear power plants and the protection of people from the hazards of exposure to radiation. Preliminary safety reviews represented an essential part of these actions. The reviews concluded that there was no technical basis for requiring the currently operating plants to shut down. The reviews found that short-term actions taken by licensees (if necessary) provided assurance of the continued safe operation of the plants while more thorough evaluations of the accident and the impact on continued safe operation were performed. The licensees have reported that they will continue to take actions as appropriate as more lessons are learnt nationally and internationally. Subsequent to these reviews and as expressed at the Ministerial Seminar on Nuclear Safety organised by the NEA and the French Presidency of the G8 on 7 June 2011, regarding the reduction of nuclear risks, the participating countries largely agreed that all countries with nuclear facilities should carry out comprehensive safety reviews. These comprehensive reviews, based directly on the first elements of immediate feedback from the Fukushima Daiichi NPP accident, would enable an evaluation of NPP safety and robustness, and would test their capacity to withstand major incidents beyond the existing design-basis capabilities for external hazards.

Comprehensive safety reviews or “stress tests”

NEA member countries have conducted the comprehensive safety reviews, discussed during the 7 June 2011 Ministerial meeting, of the design and safety analysis of their nuclear power plants with respect to protection of the facilities from extreme natural hazards. These targeted reviews have generally been based on existing and new safety studies and on engineering judgment to evaluate the behaviour of an NPP when facing a set of challenging situations. This work by member countries has generally included reviewing and challenging the adequacy of design-basis accidents, and has concentrated on beyond-design-basis situations, including extreme natural hazards.

Each NEA member country has used its own approach and methods for these reviews, although some also conducted reviews within a regional framework, for example the European Stress Test Programme. The reviews generally covered similar initiating events (e.g. earthquake, flooding and other extreme natural conditions challenging the specific site) and consequent or postulated loss of safety function (e.g. loss of electrical power, including station blackout [SBO]; loss of ultimate heat sink [UHS]; or a combination of both), as well as capability to cope with severe accidents. Although different approaches and methods were used, individual NEA member countries reached similar conclusions. This has led to a fairly high level of commonality in the safety improvement and enhancement programmes of member countries.

Activities to enhance safety

NEA member countries continue to look at what lessons they can learn from the accident at the Fukushima Daiichi NPP, to take appropriate action to maintain and enhance the level of safety at their own nuclear facilities and to share those lessons and actions with other countries. Provided below is a summary of the type of measures that have been adopted, or are currently in progress within NEA member and associated countries,

organised in accordance with the main topics that were identified as relevant by most of the concerned organisations: the hazards due to initiating events of a magnitude beyond the expected values in the plants' design bases; generalised loss of safety functions and accident management, including severe accident prevention and mitigation; emergency preparedness and planning; radiological protection and health physics and regulatory infrastructure. In addition, information on other relevant aspects such as defence-in-depth, post-accident recovery and clean-up, and other work that the NEA should consider in these areas has been included.

Initiating events

Extreme external events such as earthquakes, flooding and other external hazards

Significant activities and actions have been taken by NEA member countries with the objective of reviewing the capability of the NPPs in their respective countries to withstand conditions similar to those that triggered the Fukushima Daiichi NPP accident. More specifically, NEA member countries examined the response of NPPs to external events of higher magnitude than have previously been considered. The focus was on the need to re-evaluate, through new and targeted safety assessments, the hazards posed by external events – such as earthquakes, floods and extreme weather conditions, including in combination – and review the adequacy of associated design-basis assumptions. Plausible combinations of sequential events (earthquake and tsunami, hurricane and flooding); and consequential events (e.g. earthquake that causes fire or a pipe rupture with a loss-of-coolant accident) have also been included in the assessments.

In all NEA member countries, licensees were requested to examine their capability to respond to extreme natural events that are beyond the current design basis such as earthquakes, flooding and other external hazards (i.e. tornadoes or hurricanes) that may cause a prolonged loss of electrical power and/or cooling to the reactors. In response, the nuclear industry is developing and implementing enhancements to mitigate high-consequence, low-frequency hazards. Even though methodologies varied among member countries, the results were similar in terms of implementation of design upgrades and improvements of regulatory requirements to existing NPPs as well as requirements for new NPP construction. While the details of how these upgrades were achieved may be different, the end goals were similar. NEA member countries concluded that the review scopes were comprehensive and compare favourably.

Changes to regulatory frameworks for rare initiating events

Changes and/or enhancements are being made or planned to regulatory requirements in order to address rare initiating events that may lead to common-cause failures, cliff-edge effects and consequential hazards. These changes are being driven by the safety assessments performed by licensees as requested by regulatory bodies following the Fukushima Daiichi NPP accident. In some cases, changes to regulations and new design requirements were commonly based upon the results of these self-assessments after being reviewed by the regulator.

The general approach adopted by NEA member countries when requesting that their licensees reassess extreme external events is through:

- re-evaluation of existing methodologies that had been used in the design-basis and beyond-design-basis analyses of the external hazards; and
- reassessment of site-specific external hazards and plant margins (e.g. new events, enhanced basis for existing events and combinations of events) previously conducted in combination with periodic safety reviews.



In general, the NEA member countries' reviews of licensees' assessments yielded new regulations or requirements to be considered in order to address cliff-edge effects for extreme natural hazards in the following major areas:

- extended station blackout (loss of all the plant's alternating current sources, which could be induced by external hazards) or loss of the UHS;
- design-basis flooding and extreme flooding conditions beyond design-basis;
- increased survivability of instrumentation and equipment including the systems, structures and components needed to respond to design extension conditions, in effect applying the concept of robustness in that different types of equipment will likely be required to survive in plant states caused by the external initiator; and
- procurement of equipment that can survive beyond-design-basis conditions to provide basic safety functions (power, heat sinks, water supplies).

Many countries are considering beyond-design-basis accidents (BDBA) within their regulatory frameworks, for example the French concept of hardened core.

Also, due to different situations in the countries related to NPP design and site locations, or differences in views on the issues, some countries are taking additional actions associated with changes to the regulatory framework for external events, and in response to the Fukushima Daiichi NPP accident, including by:

- requiring upgrades of containment venting to withstand external events;
- requiring site re-evaluations for external hazards for existing and new NPPs – including imposing criteria around a combination of events that could affect the facility;
- providing a clear distinction between design-basis hazard (internal or external initiating conditions or situations that the plant needs to be protected from) and design-basis accident (accidents for which measures have been established in the design to prevent the accident from occurring or to mitigate the consequences of an accident once it begins);
- developing and defining the differences in the design and analysis aspects for new plants versus existing plants; and
- implementing safety requirement harmonisation processes by regional organisations, like WENRA, related to better protection against extreme natural hazards.

Long-term enhancements with supporting analyses being developed by the nuclear power industry to protect nuclear power plants against severe external hazards with high consequences

In NEA member countries, licensees are carrying out a number of common analyses to re-evaluate nuclear power plants against extreme external hazards with potential high consequences, including:

- level 1 and 2 PSA – identification of hazards and their consequences, for example through the development of a state-of-the art methodology for assessment of seismic risks, flooding, high winds or a combination of hazards;
- installation and use of monitoring systems or early warning systems (meteorological systems, seismic monitoring, tsunami warning, etc.) for external hazards;
- re-analysis of a plant's safety margins based on re-analysis of external hazards; and
- use of periodic reassessments for improvements and provisions for continuous improvement in protection of essential safety equipment through station walkdowns.

In addition, in some countries the nuclear power industry's actions include:

- use of automatic plant trips for external hazards (i.e. seismic risks or tsunami trips); and
- use of reinforcements to increase the protection of essential equipment from harsh environmental conditions associated with extreme external hazards and beyond-design-basis accidents.

Loss of safety functions

Regulatory authorities in NEA member countries are performing a number of common activities to establish requirements for long-term loss of electrical power and/or the loss of cooling water supplies. In response, the nuclear industry is carrying out safety assessments and investigations to prevent, mitigate and arrest the progression of severe accidents in the event of the long-term loss of electrical power, SBO and/or the loss of cooling water supplies and the ultimate heat sink. As a result of these assessments, and as appropriate, actions are being taken to upgrade existing safety systems or install additional equipment and instrumentation to enhance the ability of each nuclear power plant to withstand a natural event (or events in combination) without access to the electrical power grid (including in multi-unit events) for an extended period.

Changes currently being made to regulatory frameworks to enhance safety support systems

Generally, member countries are considering the establishment of requirements for the following major safety support systems.

Electrical supply systems:

- provisions for increased electrical capability after the loss of the grid connection, including additional fixed generators such as diesels, enhanced offsite power supplies, mobile electrical equipment, enhanced batteries, recharging of batteries;
- extended SBO – requiring enhanced capability to cope with a prolonged SBO (coping duration);

- improved robustness of emergency equipment beyond current design conditions for external hazards (seismic risks, flooding, high winds, weather-generated missile impacts); and
- improved connection capabilities for mobile or alternative electrical supplies to power equipment and instrumentation essential for fulfilling the vital safety functions.

I&C systems:

- enhancement of equipment functionality to remain capable of monitoring plant conditions under extreme environmental conditions associated with severe accident – monitoring instrumentation for essential plant parameters;
- installation of enhanced equipment for monitoring water levels and temperatures in the plant's SFP;
- provision of alternative power supplies for essential instrumentation (supplies and connection capability); and
- development of operator training to address plant monitoring during degraded plant conditions with questionable instrumentation or readings.

Approaches to provide core, spent fuel pool and containment cooling:

- enhance SFP cooling capability (alternative connections and sources of water supply, procedures to implement alternative methods, etc.) considering extreme weather and severe accident conditions;
- increase capability to provide make-up to core considering extreme weather and severe accident conditions;
- provide alternative capability to discharge heat to the existing ultimate heat sink; and
- improve robustness of emergency equipment considering severe external hazards (seismic risks, flooding, high winds, weather-generated missile impacts) – beyond current design conditions.



Alternatives to the ultimate heat sink:

- verify robustness of ultimate heat sinks – additional evidence (e.g. test results) that provides confidence in the existing UHS capability.

In addition, some countries are also considering the establishment of requirements to demonstrate long-term heat removal capability in the event of loss of the UHS, in the following areas:

- use of sprinkler systems as an alternative for cooling in the spent fuel pool, especially for situations with large losses of pool water inventory;
- requirements for alternative containment cooling systems for boiling water reactor (BWR) plants for drywell and wet well cooling;
- use of air cooling systems as an alternative to the existing ultimate heat sink;
- consideration of alternative water sources (wells, ponds) in which to discharge heat; and
- reinforcement of systems capable of removing decay heat over the long term, such as systems and components able to maintain the capacity of the steam generators (PWR) to remove heat to the atmosphere: feedwater systems and relief valves.

Long-term enhancements being developed by the nuclear industry to improve the robustness of safety support systems

In parallel, the nuclear industry in member countries is developing long-term enhancements to the aforementioned safety support systems, notably in the areas listed below.

Electrical supply systems:

- procuring portable [battery recharging, instrumentation and controls (I&C) supplies, etc. – spot power] and mobile (larger electricity demands) generators for enhanced electrical supplies;
- enhancing offsite power supplies by providing additional sources and improved grid reliability – improving the independence of offsite power supplies;
- implementing formal protocols (including staff availability, training, etc.) to guarantee that NPPs are the first “consumer” to have electrical supply restored from the national or regional grid;
- ensuring increased capacity and discharge times for direct current (DC) batteries, with the capability to recharge the batteries;
- enhancing DC power supply system robustness;
- improving the functional capability of existing electrical equipment under extreme environmental conditions caused by external hazards;
- providing procedures and training on the use of electrical equipment – including usage under harsh environmental conditions during severe accidents;
- enhancing the capability to connect electrical power supplies to essential equipment and instrumentation upon the loss of fixed equipment;
- providing enhanced protection to fixed electrical (I&C) equipment from external hazards and internal events to withstand harsh conditions during severe accident conditions (e.g. fire barriers, waterproofing of electrical switchgears); and
- ensuring the capability of the electrical alternating current (AC) power supplies to function for an extended period (i.e. a minimum of 72 hours without replenishment).

I&C systems:

- providing alternative power supplies for essential instrumentation;
- shedding loads from batteries to extend the time that emergency instrumentation remains functional to monitor conditions in the core, spent fuel pools, containment and other areas of the plant required to remain habitable during severe accidents;
- providing alternative motive force for equipment (valves and dampers) to implement actions in response to severe accidents;
- developing a better understanding of the limitations of I&C equipment to remain functional beyond its design specifications;
- enhancing the robustness of I&C systems for hydrogen control systems;
- improving instrumentation survivability to support actions implemented under severe accident management guidelines (SAMGs), SBO and other extreme conditions for core, spent fuel pool and containment cooling;
- providing additional and/or improving the robustness of existing instrumentation for monitoring and controlling the temperature and water level in the spent fuel pool considering the conditions that may exist during beyond-design-basis events; and
- providing additional, or improving existing, radiation monitoring equipment for monitoring conditions onsite during severe accidents.

Approaches to provide core, spent fuel pool and containment cooling:

- using mobile pumping equipment (e.g. fire trucks, diesel driven pumps) for alternative sources of water; diversifying backup in case the existing fixed equipment fails;
- protecting existing equipment by providing barriers for flooding, placing the pumps at higher elevations within the plant – enhanced protection;
- enhancing capability and mission time of existing fixed equipment;
- using easily accessible quick-connection equipment (piping, etc.) to provide alternative sources of cooling water to the core, the spent fuel pool and the containment without the need to enter areas where personnel would be endangered by radiation, debris, high temperatures or steam; and
- installing permanent cooling systems designed for extended external hazards.

Alternatives to the ultimate heat sink:

- installation of alternative pathways to the existing ultimate heat sinks;
- installation of a diverse heat sink; and
- use of other heat sinks, such as alternative sources of water bodies (ponds, rivers, water tables).

Protection of containment under severe accident conditions:

- venting of containment (filtered versus unfiltered), for example installation of venting systems to maintain containment integrity, provide for alternative containment heat removal and prevent or mitigate core damage in the event of a severe accident;

- improvement of capacities for containment flooding to mitigate the consequences of molten corium poured into the reactor cavity/pedestal; and
- for new reactors, use of core-catchers for protecting the containments.

Combustible gas control:

- installing passive autocatalytic hydrogen recombiners (PARs) in containments and other locations in the plant where combustible gases may accumulate, and/or justifying that additional measures for hydrogen build-up are not needed; and
- developing the basis for deciding the amount and location of hydrogen mitigation equipment (PARS, igniters).

Other enhancements:

Due to different situations in the countries or different views on the issues, some licensees are in the process of implementing additional analyses and enhancements such as:

- consideration of the effect of water quality used to provide alternative sources of cooling water during a severe accident;
- enhancement of the leak-tightness of reactor coolant pressure boundary systems and components (reactor coolant pump seals);
- implementation of heat removal from the wetwell (BWR) by filtered venting (Japan);
- initiation of joint research to develop new ways to monitor reactor vessel water level during severe accident conditions (Japan);
- use of air cooling as an alternative heat sink, for instance:
 - Finland will use the atmosphere for decay heat removal to reach safe shutdown;
 - India is using evaporative cooling consistent with existing designs;
 - the Russian Federation is also considering evaporative cooling for some types of reactors (RBMK);
- use of venting which can also serve as a heat sink by releasing steam into the atmosphere (Sweden); however, its efficiency for long-term application has not been analysed (water balance, decontamination factor decreases over time);
- use of thermo-siphoning in CANDU plants (previously demonstrated before the accident at Fukushima Daiichi NPP);
- use of an alternative containment spray system (Belgium), closely associated with filtered venting system;
- study of water injection (make-up) into the reactor pit to minimise the corium-concrete interaction that would limit the generation of non-condensable gases and therefore reduce the risk of containment over-pressurisation (Belgium, with something similar being considered in Canada, the Netherlands and Spain);
- study of how to improve robustness of existing venting systems (seismic qualification) and efficiency of filters (France);
- enhancement of the robustness (seismic and other adverse conditions) of equipment and I&C that are relied upon for severe accident management

- strategies (Japan, Belgium) broadly applied to all equipment including containment venting systems;
- improvement of back-up power supplies to existing (containment) hydrogen igniters;
 - analysis of hydrogen hazards in other buildings surrounding the containment (Spain, Sweden, Belgium), generation and build-up of hydrogen at locations (pockets) outside the containment;
 - use of video monitoring systems to assess the conditions of the spent fuel pool during some beyond-design-basis conditions (Japan);
 - use of monitoring equipment in the reactor pit to detect core melt through and in the containment to detect hydrogen even with total loss of electrical power (France);
 - filtering of other buildings surrounding the containment; and
 - implementation of severe accident management guidelines (SAMGs), including increased scope such as shutdown conditions or spent fuel pools.

Accident management

Licensees with regulatory oversight of NEA member countries are carrying out a number of common activities to improve their understanding of accident prevention, management and mitigation. For example, a review is being undertaken of the guidance that is to be used by the operator on site to manage emergency situations resulting from accidents, including severe accidents, caused by rare and potentially extreme events, or a combination of events. Other activities include initiation of research and development (R&D) programmes related to severe accidents and development of Level 2 PSAs. These licensees are also participating in international co-operation in this area, including with the NEA (CNRA, CSNI and CRPPH), WENRA, the European Nuclear Safety Regulators Group (ENSREG) and the IAEA to improve knowledge and understanding.

Additionally, and as a consequence of the lessons learnt from the accident, countries are working on other relevant areas such as:

- improving their knowledge of the behaviour of SFP under accident conditions;
- gaining a better understanding of staff performance under stressful conditions through human performance/factors analysis and work; and
- reviewing and improving accident management procedures and guidance.

Changes to regulatory frameworks

To ensure that licensees have established effective accident management approaches to respond to transients, accidents and severe accidents in an integrated manner, countries are requiring new or updated procedures (e.g. emergency operating procedures [EOPs], SAMGs and extended damage mitigation guidelines) for all plant states, including the shutdown state, as well as accidents in SFPs and multiple units. Finally, protocols are being developed to support centralised offsite crisis centres. Training issues are being addressed to properly implement those procedures. Most countries are reviewing their human resources for accident response in all affected organisations.

Discussions within member countries continue with the goal of identifying the best or optimum use of PSA in accident management. Some countries are incorporating a new requirement to have full scope Level 1 PSA; this issue is under discussion in other countries and also at regional levels.

Also, some countries have introduced additional requirements for prevention and mitigation of severe accidents, while others are considering the options available over and above those that are already in place.

Long-term enhancements being developed by the nuclear power industry to improve the capability to support the onsite response of the licensees

In some countries, the industry is pursuing long-term enhancements to improve the capability to support the onsite response. For example, the industry has established central support centres with mobile equipment and other resources (including human resources) where appropriate. This action is very dependent on the distribution of facilities within a country. Processes for the deployment are being fully integrated into plant procedures. Moreover, the industry (vendors and licensees) in the different countries are generally developing or updating their SAMGs.

All the operators are acquiring mobile electric power supplies and pumps, as appropriate. This new equipment is stored and located in a safe place so that it is available in the event of severe conditions on the site. Commonality of connections, hook ups and procedures are being considered, and the maintenance, inspection and testing of this equipment is being addressed. Further, sufficient equipment is being procured to support response at each of the units separately, without relying on the equipment for a co-located unit.

Long-term plans for addressing the human and organisational challenges of accident management

Countries are pursuing long-term plans for addressing the human and organisational challenges of accident management under harsh environmental conditions that may be encountered simultaneously with response to a severe accident. Common actions addressed by the countries include:

- training and exercises for implementing mitigation strategies during single and multi-unit events;
- improvement of capacity to communicate both internally (onsite) and externally (offsite); and
- re-evaluation of staffing levels for extended and multi-unit events, for example assessing the number of qualified workers necessary for the emergency response organisation.

In addition, several countries are developing site-specific alternative emergency management centres (or enhancing the existing facilities) to support emergency workers' duties, including improving protection of equipment, tools and procedures for emergency workers.

Some countries are investigating the impact of stress on staff behaviours including emotional, psychological and cultural aspects associated with emergency response, and reviewing associated training and support.

Some countries are evaluating the qualifications of emergency staff for their duties, and attempting to determine whether human actions are achievable during multi-unit events with extreme external conditions.

Defence-in-depth

The general approach adopted by NEA member countries relies on all relevant aspects of the implementation of DiD in the form of a series of design and procedure provisions to prevent and mitigate incidents and accidents that could lead to a large and early radioactive release. This concept is supported by emphasis on the inherent safety

characteristics of the reactor, and insights from deterministic and probabilistic safety analyses to evaluate and optimise the overall plant design. During its October 2012 meeting, the NEA Steering Committee held a policy debate on nuclear safety defence-in-depth. Participants in the debate recognised that the concept of defence-in-depth is valid, but that issues have been raised post-Fukushima regarding its implementation that need to be further reviewed and improved. They stressed that responsibility for safety lies with the operator, but that the regulator has an important role to play in ensuring that the barriers in place to protect the public and the environment remain effective.

Changes to the regulatory framework to encourage enhanced implementation of defence-in-depth, including during the design, siting, construction and operation of nuclear facilities

In light of the Fukushima Daiichi NPP accident, NEA member countries are adopting the following measures to enhance application of defence-in-depth during the design, siting, construction and operation of nuclear facilities.

- Many NEA members within the European Union are incorporating the WENRA reference levels as they relate to DiD implementation during design, siting, construction and operation. Hence, the use of the WENRA technical report is considered in the implementation of the safety objectives.
- While conceptually DiD will remain the same, its application is evolving to increase the emphasis on mitigation in addition to primarily relying on prevention. In addition, low-probability but high-consequence internal and external hazards that could lead to simultaneous breaching at all levels of DiD should be taken into consideration.
- Despite existing regulatory frameworks incorporating the concepts of DiD, guidance for its application could be provided in some instances.
- Consideration should be given to expansion of DiD to include actions to minimise to the extent practical large or early offsite releases and mitigating equipment to arrest the progression to a severe accident condition.
- Enhancing the independence between the actions and equipment used to respond to escalating accident conditions at different DiD levels will also be necessary. Nevertheless, in some instances, resources and equipment that may be used to mitigate an accident may also be used to prevent it.

Levels of defence-in-depth

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 onsite emergency
5	Significant offsite release of radioactivity	Mitigation of radiological consequences of significant releases of radioactive materials	Accident management and offsite emergency response

Source: adapted from INSAG-10, *Defence-in-Depth in Nuclear Safety: A Report by the International Safety Advisory Group*, IAEA, 1996.

- Recognition that through Level 3 of DiD, design aspects and operator actions are primarily considered for responding to escalating accident conditions. As the accident progresses beyond Level 3, the importance of accident management with support from offsite agencies (government and other responsible authorities) for onsite accident response increases, as does that of engaging offsite response authorities.

Ensuing DiD discussions between member countries centred on the following differences/issues:

- Providing clarity between the regulatory framework and the concept of DiD. As an example, clarity could be provided in the application of the concept of DiD to the existing regulatory frameworks for screening of internal and external hazards and plant states that are included as a design-basis initiating event (a screening criteria that is often used is if the probability of an initiator is less than 10^{-7} , it is not considered credible and so is excluded from consideration in the design). However, where a certain initiator is excluded should not only depend on a probabilistic indicator but also on the severity of the potential consequences.
- Incorporating DiD into the regulations by specifying more detailed requirements on diversity, independence or separation in regulations (Sweden, Germany).
- Using failsafe or single-use components (rupture discs) – those that are fail safe for design-basis events – versus passive systems used for design-basis events that may hamper severe accident response.
- Incorporating the defence-in-depth concept to include the mitigation and prevention aspects in the redevelopment of its regulatory requirements (Japan) such as expanding the scope of the regulatory framework to encompass Level 4 (mitigation of severe accidents).
- Increasing transparency in industry-led peer reviews – operating experience – to enhance the understanding of the effectiveness of DiD implementation.
- Considering organisational factors and management system tools when implementing the defence-in-depth concept (i.e. better implementation of independent reviews during design, construction, maintenance and operation).

Impact of changes related to societal acceptance of the risks of nuclear power in the end goal of the defence-in-depth principle within the regulatory framework

In general, NEA member countries indicated that the social acceptance of the risks of nuclear power has not altered but reinforced the end goal of the defence-in-depth logic as implemented within the existing regulatory framework. However, in some countries, the nuclear accident at Fukushima Daiichi NPP has altered the public perception of nuclear energy to the point that a strict phase-out strategy has been enacted. The decision to phase out nuclear power in these countries is based upon societal, political or legal considerations rather than strictly technical or safety factors.

In fact, there has been a continuing shift that started before the Fukushima Daiichi NPP accident (since Chernobyl) towards minimising, and if possible eliminating, offsite releases by enhancing design and safety systems for new reactors. The Fukushima Daiichi NPP accident emphasised or reinforced the wide application of this concept to existing reactors; in other words, that the prevention of releases should be applied to existing plants by adopting new safety requirements and modern standards for these plants.

Emergency preparedness and planning

Following the Fukushima Daiichi NPP accident, NEA member countries reviewed and updated national, regional, provincial, municipal and local emergency plans and guidance. This included, in some countries, conducting local and national exercises to identify possible areas for improvements in emergency arrangements, particularly in the co-ordination among the different national organisations involved. Further, many countries began to upgrade their national, regional, offsite and onsite emergency response centres.

Changes to the regulatory framework

Member countries are implementing regulatory changes to improve the effectiveness of the emergency plans for situations with severe damage to the local, national or regional infrastructure that could be caused by an external initiating event. The adoption of the improvements is based on the specific assignment of emergency duties in each country (responsibility for the onsite actions is always that of the nuclear operator but the offsite plans are in general the duty of the local or national organisations). Relevant actions related to this issue are:

- increasing the training and exercising of the emergency plan(s), including a clear intention to extend the type of scenarios to be exercised beyond the current international practices;
- assessing new staffing and communications needs for severe conditions, specifically for multi-unit and prolonged SBOs and other long-lasting events;
- enhancing existing Emergency Control Centres and/or building new ones with reinforced resistance to external events and to high radiation conditions at the site, and reassessing the internal and external communications capabilities;
- assessing capabilities to receive assistance from outside after events affecting the existing infrastructures, with both the impact on the onsite emergency response teams and the local offsite responders being considered; and
- enhancing the onsite, offsite and national radiological monitoring capability; according to the national regulation, this could be the responsibility of nuclear operators or public organisations (regulator and/or local or central authorities).



AFP Image Forum.

Enhancement of communication systems

Most countries have initiated activities to reassess the robustness of the communication systems between onsite and offsite emergency response organisations, especially during extended blackout conditions. Different improvements have been identified and are being implemented. Some countries are looking at diverse means of communication – for

example, satellite communications for onsite to offsite, as well as hard-wired data transfer from the plant to offsite emergency centres.

It has also been recognised that significant improvements are needed for international communications and information exchange among national regulatory organisations and their crisis response centres. As such, the international information exchange aspects of nuclear emergencies are also being reviewed in order to improve capabilities to communicate reliable data, information and decisions quickly and effectively among national authorities and their emergency and technical crisis centres from all countries affected, directly or indirectly, during nuclear emergencies.

Long-term enhancements being developed by the nuclear industry, responsible government agencies, and local responders to enhance emergency planning and preparedness

One important lesson learnt after the Fukushima Daiichi NPP accident is the need for strengthening the roles and training of the local emergency response organisations to help co-ordinate actions in the event of an emergency. To fully validate the current situation, a review of existing emergency exercises (in terms of frequency and scope) involving local and national responding organisations, with the focus on the implementation of the appropriate enhancements, is being carried out by different countries.

Some member countries are reviewing their emergency planning philosophy to ensure that it is appropriate to address the challenges posed by the Fukushima Daiichi NPP accident. Such aspects as long-term sheltering and distribution of stable iodine are key considerations, as are the criteria and approaches for instigating and terminating countermeasures. As part of this assessment, some member countries are also looking at re-evaluating the size and nature of their emergency planning zones. It is worth noting that the practicality of extending existing detailed emergency planning zones beyond current levels and potentially into high population urban areas is a constraint, so each country is taking the appropriate actions based on the current situation of the NPP sites. The use of various types and sizes of emergency planning zones (e.g. for evacuation, sheltering, food restrictions, reassurance measurements) is also under consideration. An activity that had been previously undertaken by many countries, but that is now a higher priority after the Fukushima Daiichi NPP accident is to try to enhance co-operation with neighbouring countries in emergency situations, including through participation in co-ordinated drills and exercises.

Radiological protection

Changes to the regulatory framework

In general, most of the member countries believe their current regulations are sufficient to ensure that the operators have the resources and procedures for protecting workers from high levels of radiation when responding to a severe accident. However, some countries are considering improvements in this area. Different actions are being considered and in some cases implemented:

- increasing readily available resources for protecting people, including personal protective equipment for onsite workers, and also for new workers and support arriving at the site;
- analysing the human and material resources needed for radiological protection in case of severe accident;
- stockpiling equipment (new logistical centres being created, in some cases on site, and in other cases remote from the sites), while other countries are looking for long-term gaps;

- re-evaluating the dose limits for emergency workers based on international experience and taking into account the lessons learnt from the Fukushima Daiichi NPP accident; and
- implementing emergency workers training, guidance and information.

Enhancements for public protection

Many countries, and the international radiological protection community in general, are revisiting approaches to emergency management and recovery in order to be better prepared for accident situations. Enhancements include such things as consideration of the need for long-term sheltering and possible alternatives, and the need to focus more resources on recovery planning and preparation. The need for stakeholder involvement in planning and preparation activities has been reinforced by the Fukushima accident, and remains a challenge, in particular in clean-up and recovery activities.

Enhancements for worker protection being developed and implemented by the nuclear power industry

In some countries, the industry is developing enhancements for worker protection during severe accident conditions. For example, some licensees or operators (the United Kingdom, the United States) are currently conducting further studies surrounding issues such as managing the traumatic, psychological, stress and family effects that staff and other responders may encounter during a severe and prolonged nuclear emergency. In Spain, the licensees are considering implementing additional actions to maintain the habitability of the control facilities (e.g., main and secondary control rooms) and onsite emergency centre during a prolonged station blackout.

Enhancements to onsite and offsite radiological monitoring

In general, member countries are reviewing their existing capacities in relation to monitoring capabilities, taking into account the assigned responsibilities of the different parties for real-time monitoring (operator, regulator, others). These reviews include an examination of the effectiveness and efficiency of existing capacities and, where appropriate, the identification of possible enhancements. Some actions are being taken to enhance the onsite and offsite monitoring of radioactive releases during accidents, and determine source terms to support recommendations related to offsite protective measures. Additionally, inverse source term estimation approaches (based on monitor readings) are being considered and analysed.

Post-accident recovery and clean-up

Although recovery issues did not emerge in the early period of the accident, many countries began assessments to determine whether national plans for transition from the emergency to recovery, and for long-term recovery actions, need to evolve to appropriately address lessons from the Fukushima accident. Assessments are taking into account the latest international recommendations and guidance, notably from the International Commission on Radiological Protection (ICRP) and the IAEA.

Post-accident recovery is an inherently complex situation, and many aspects cannot be planned in detail because post-accident conditions will strongly depend on the accident scenario details. Recognising this, many countries are reviewing their national preparations for post-accident recovery, and for transition from the emergency to recovery. In general, it is felt that recovery preparation will require at least as much effort and as many resources as emergency management preparation. In this context, many countries are looking at the latest international recommendations and guidance from the ICRP and the IAEA, comparing this to experience from the Fukushima Daiichi NPP accident response, and assessing their own programmes against this benchmark.

Improvements to this area can be gained through continued international co-operation, involvement and lessons learnt – some of which were underway before the Fukushima Daiichi NPP accident. In some member countries, the responsibility for this area rests outside the remit of the nuclear safety regulator.

Regulatory infrastructure

Many of the regulatory authorities and their oversight organisations in NEA member countries undertook a review and, when appropriate, a revision of their legislative framework for nuclear safety regulation and implemented changes to the functions and responsibilities of the regulatory body, particularly in the areas of independence and competence.

In addition, many NEA member countries reported that they strengthened bilateral and regional collaboration, will host or are planning to host international peer review missions, and are participating in other relevant international activities.

Changes to regulatory infrastructure to enhance independence and technical competence

Some countries are confident of the level of independence of their regulators. This situation has been reached in many cases by national initiative, but the international processes and fora, notably the Convention on Nuclear Safety (CNS), the International Nuclear Safety Advisory Group (INSAG, and in particular its INSAG-17 report on *Independence in Regulatory Decision Making*), as well as the IAEA Integrated Regulatory Review Service (IRRS) missions, have played an important role in the improvement of this relevant aspect. Also, some countries are now revising the legislation for the nuclear safety authority to enhance the level of independence and technical competence of the regulatory body. Many member countries are using the conclusions of IRRS missions to ensure adequate independence and competence and identify any shortfalls and areas for improvement. Financial capability and existence of technical safety expertise are also being evaluated by member countries to ensure that the independence and technical capability is maintained *de facto* as well as *de jure*. Where applicable, research programmes are being reviewed for their adequacy in supporting current and future technical capability and competence. International co-operation of regulators and technical safety organisations is seen as an important aspect of maintaining and enhancing these capabilities.

Changes to enhance openness and transparency

Many countries believe they currently have a robust and proactive policy of openness and transparency in their decision-making processes, where many of their decisions and decision-making documents are open to the public. Also, member countries are striving to increase the level of openness and transparency for all their regulatory activities, as encouraged by IRRS recommendations and NEA guidance.

Changes to improve communication during a crisis

All countries are conducting activities to improve the capabilities of the regulatory body to effectively communicate with internal and external stakeholders during a crisis. Many countries are reviewing and updating their crisis communication plans and exploring the use of the internet and social media during crisis situations. For example, they are improving the reliability of websites, and developing robust websites for crisis situations. In addition, crisis communication teams are being trained for emergency situations. During a crisis, web pages may be changed to focus on information to the public which is specific to the crisis.

NEA initial considerations and approach

Following the Fukushima Daiichi NPP accident, the NEA standing technical committees with safety mandates (the CNRA, the CSNI and the CRPPH) each developed specific issues and ideas for moving forward.

Preliminary issues identified for follow-up by the CNRA included:

- the exchange of information on the national safety reviews;
- lessons learnt from the accident in each country;
- decisions made in each country to improve the safety of the NPPs;
- changes being proposed to regulatory requirements and regulatory programmes; and
- Fukushima-related activities of the Working Group on the Regulation of New Reactors (WGRNR), the Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC), the Working Group on Operating Experience (WGOE), the Working Group on Inspection Practices (WGIP) and the STG-FUKU.



In addition, the CNRA invited the CSNI to support work that included:

- reassessment of defence-in-depth considerations;
- reassessment of accident management issues;
- development of a thorough understanding of the accident progression; and
- review of pre-cursor events.

The CSNI developed a concept paper, including a list of preliminary activities for possible NEA work that included:

- review of approaches to considering internal and external hazards;
- review of plant robustness and defence-in-depth considerations;
- safety management (human and organisational performance issues) technical studies;
- review of emergency preparedness approaches;
- review of containment response under severe accident conditions; and
- research on severe accidents and other technical matters.

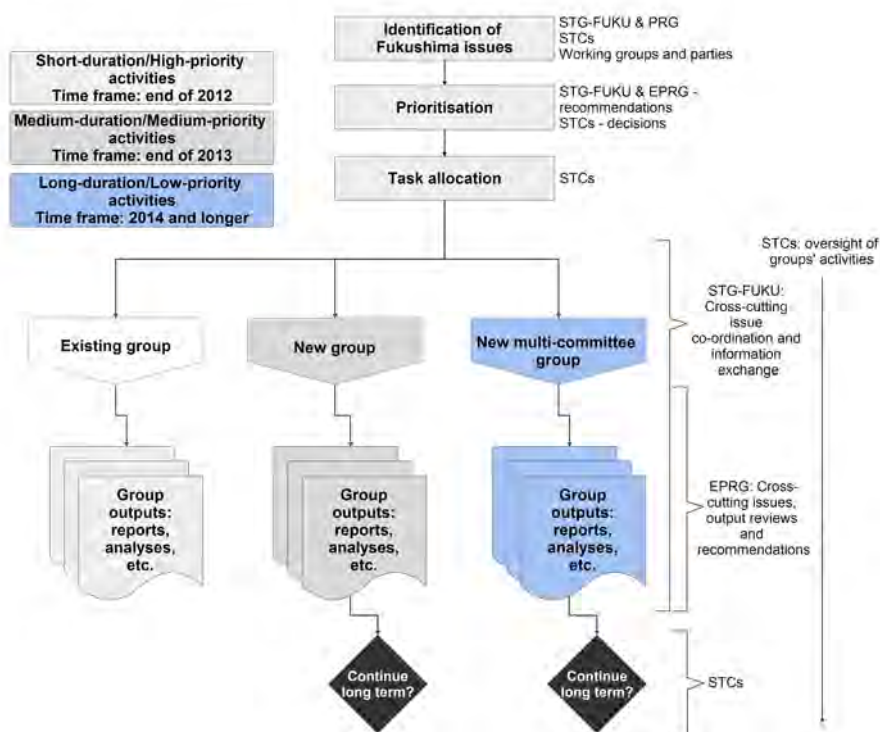
The CRPPH had two main objectives following the accident: 1) learning from the experience and improving for the future, and 2) making the expertise of the CRPPH available to the Japanese authorities and stakeholders. To address these issues the CRPPH:

- shared and assessed national lessons learnt and how countries reacted to the accident;

- addressed questions and shared experience with the Japanese by involving key NEA stakeholders in consequence management – advice on practical questions;
- co-sponsored the International Symposium on Decontamination: Towards the Recovery of the Environment held in Fukushima in October 2011;
- co-sponsored and participated in a series of five ICRP dialogue initiative meetings (November 2011, February 2012, July 2012, November 2012 and March 2013) with residents from affected areas; and
- assisted with the organisation of the ISTC/STCU Symposium and Workshop: The Experience and Technology of Russia, Ukraine and Other Countries on Remediation and Restoration of Environments held in Tokyo and Fukushima City in February 2012.

Recognising the need to co-ordinate the activities of these three committees, the CNRA requested that a joint bureau discussion be held to establish a means for the three committees to work efficiently together to serve the member countries in each of their respective areas of expertise. At the December 2011 tri-bureau meeting, the process that was agreed to (outlined in Figure 1) started by identifying the ongoing and proposed issues and activities of the NEA related to the accident. Once the list of activities was completed, it was reviewed by the STG-FUKU and the CSNI Programme Review Group (PRG), with participation by STG-FUKU and CRPPH representatives. They then identified cross-committee issues and developed recommendations on priorities and significance for the NEA response. The process included consideration of radiological protection and emergency management issues within the mandate of the CRPPH by the participation of a representative from the CRPPH EGRPF at both the STG-FUKU and EPRG meetings.

Figure 1: NEA tri-committee co-ordination process



For the identified cross-committee activities, the proposals were updated with input from the STG-FUKU and the EPRG for consideration by the standing technical committees following their existing processes for review and approval of new work. The committees gave consideration to the information and priorities provided by the process as they developed and updated their programmes of work.

The implementation of this process identified the following areas for NEA work:

- accident management and progression including procedural transition, human performance and improved offsite emergency preparedness;
- crisis or emergency communications with the public, among regulatory authorities in different countries, between onsite and offsite emergency responders, and the role of international organisations;
- reassessment of DiD including the balance of deterministic and probabilistic approaches to regulatory decision making;
- evaluation of the methodologies for defining and assessing initiating internal and external events, including coupled, as well as methodologies for defining the design-basis criteria;
- reassessment of operating experience and prior opportunities to identify or address conditions that could challenge nuclear safety (precursor events);
- regulatory infrastructure;
- radiological protection; and
- decontamination and recovery.

These areas represent the scope of safety- and regulatory-related work ongoing or planned at the NEA, based on the lessons learnt from the Fukushima Daiichi NPP accident as of the time of this report.

Transition of Fukushima-related activities into the long-term strategic plans

In immediate follow-up to the accident, the STG-FUKU was instrumental in sharing information among participating countries and organisations and identifying the priority safety and regulatory policy work on which the NEA should focus. The NEA has now integrated the ongoing Fukushima-related activities into the normal working processes of the Agency and is ensuring that such activities are being assigned to the responsible working group, task group or working party within one of the standing technical committees. They have been included in the operating plans and programmes of work of these committees which have been updated to reflect both the ongoing and planned Fukushima-related work. From a longer-term perspective, the strategic planning documents for the standing technical committees were also updated as appropriate to reflect the integration of the lessons learnt from the Fukushima Daiichi NPP accident into the main challenges being faced and how the overall NEA strategy is being met.

The sharing of information and the co-ordination of activities among the working groups, task groups and working parties of the three main committees involved in Fukushima-related work has been established through the participation of representatives from the CRPPH, the CNRA and the CSNI in these groups when appropriate, or through status briefings by the NEA staff or representatives from other NEA groups. The CRPPH and the CNRA will continue to participate in the meetings of the CSNI Programme Review Group to encourage communication and co-ordination. In addition, future tri-bureau meetings will be held as appropriate to ensure that the needs of the NEA member countries continue to be met as related to the overall response to the lessons learnt from the accident.

Moving forward, NEA staff will take on the role that the STG-FUKU currently has of keeping the standing technical committees and NEA members informed of the status of ongoing Fukushima-related activities. Recognising that new areas of work will be identified where the NEA can effectively respond to lessons learnt as the accident clean-up and recovery continue, the CNRA Bureau intends to take on the role of assessing the new work and providing feedback on whether the work is within the mandate of the NEA. If this is the case, the CNRA will decide what priority the work should be given, and recommend which committee should be asked to take on the work. With this feedback, each committee will then review the new work to determine whether and how best to proceed following its normal business processes.

During its December 2012 meeting, the CNRA acknowledged that NEA Fukushima-related activities were effectively being integrated into the normal processes, stressed the enhanced co-ordination that was occurring between the standing technical committees and noted that the work and roles of the STG-FUKU were nearing completion as it approached the end of its mandate in June 2013. This provided time for the senior-level task group to finalise its ongoing work in the area of defence-in-depth and to complete its final report.

NEA actions in follow-up to the Fukushima Daiichi accident

The Fukushima Daiichi NPP accident has raised important issues which are applicable to power reactor design, including those related to unfavourable natural and human-induced external events and their possible combination. As was learnt from experience with the Three Mile Island and Chernobyl accidents, full analysis of the Fukushima Daiichi NPP accident could take several years. Therefore, NEA member countries have agreed that they should continue to consider what has been learnt from the Fukushima Daiichi NPP accident over the next several years and possibly decades. The NEA is working with the Japanese authorities in the development of the research plans to collect information needed to better understand what happened to the plants as the accident progressed at each of the units. Recognising these facts, the NEA standing technical committees have planned, and in some cases begun, activities that will continue well beyond the end of 2013 into 2014, more than three years after the accident. For each of the committees, this work was proposed, reviewed and approved following their existing working methods. Using the information to support the review and approval of these activities, a brief overview of the ongoing and planned work of the NEA that will continue into the near future is provided below.

Nuclear regulation

Activities dealing with regulatory matters are dealt with by the CNRA. Ongoing and planned activities are described hereunder.

Accident management

The CNRA established a Task Group on Accident Management (TGAM) to review accident management practices in light of the Fukushima Daiichi NPP accident. The TGAM has a three-year mandate to assess member country needs and challenges from a regulatory point of view. The objectives of the task group include identifying measures that should be considered to enhance the regulations and regulatory guidance for operators' accident management activities. The task group will:

- act as a focal point for the timely and efficient exchange of information on the activities of national regulatory authorities related to changes to onsite accident management requirements, regulatory guidance and oversight activities;
- identify commendable practices that are being implemented to address lessons learnt as a result of the Fukushima Daiichi NPP accident in the area of accident management;
- identify areas and issues, and associated priorities that would benefit from in-depth evaluation or research; and
- identify short-term and long-term follow-on activities, and associated priorities for the task group, and make recommendations for activities that may be better conducted under the mandate of current CNRA, CSNI and CRPPH working groups.

Topics for the task group include:

- enhancements of onsite accident management procedures based on lessons learnt from the Fukushima Daiichi NPP accident;
- decision-making and guiding principles in emergency situations;
- guidance for instrumentation, equipment and supplies for addressing long-term aspects of accident management; and
- guidance and implementation when taking extreme measures for accident management.

Membership in the task group includes representatives of the regulatory authorities or their technical support organisations from Belgium, Canada, Finland, France, Germany, Japan, the Republic of Korea, the Netherlands, the Russian Federation, Slovenia, Spain, the United Kingdom and the United States. Also participating are the European Commission and the CSNI.

The task group will co-ordinate with the CSNI and the CRPPH on issues of mutual interest. The group met in October 2012, February 2013 and May 2013. The initial report is expected to be submitted to the CNRA for review and approval during its December 2013 meeting. This report will include an overview of guiding principles for accident management and commendable practices in the areas of procedures and guidance; equipment, infrastructure and instrumentation; and human and organisational resources. Longer-term activities of the TGAM will focus on developing guidance for use in enhancing the regulatory framework for onsite accident management procedures that includes decision making in emergency situations and for taking extreme measures.

Defence-in-depth (DiD) concept and implementation

All NEA member countries agree that the implementation of safety improvements are important, especially in the case of those safety improvements concerned with the prevention, management and mitigation of severe accidents. This includes the strengthening and implementation of the concept of DiD that has been developed and refined by those in charge of nuclear safety over many years.

As mentioned earlier, during its October 2012 meeting, the NEA Steering Committee held a policy debate on DiD. Participants in the debate recognised that the concept of DiD is valid, but that issues have been raised regarding its implementation that need to be further reviewed and improved. They stressed that responsibility for safety lies with the operator, but that the regulator has an important role to play in ensuring that the barriers in place (DiD) to protect the public and the environment remain effective.

One implication of the accident is that DiD and its implementation may have been applied and worked well with the design and operation of a plant against internal events, but it worked less well against external hazards related to site aspects. As a consequence, the CNRA and the CSNI held a Joint CNRA/CSNI Workshop on Challenges and Enhancements to DiD in Light of the Fukushima Daiichi Accident for NEA member countries at the OECD Conference Centre in Paris on 5 June 2013. This joint workshop focused, among other things, on the issue of implementing DiD for rare and extreme external and internal hazards – such as tsunamis – and how they can be evaluated and considered, including in combination.



Review of precursor events

The Working Group on Operating Experience (WGOE) is actively working on a task focusing on pre-cursor events to evaluate various initiators and situations for new lessons that may be drawn from these events in light of the Fukushima Daiichi NPP accident and improvements in implementing lessons learnt. This task report will have an input from the CSNI Working Group on Risk Assessment (WGRISK). The Chair of the WGOE is scheduled to present the final draft report for approval at the December 2013 CNRA meeting.

Regulation of nuclear site selection

In May 2010, the Working Group on the Regulation of New Reactors (WGRNR) issued a report on siting practices associated with the members considering new plant construction. Upon issuance of the report, the WGRNR identified several follow-up activities in the area of siting, including assessing impacts of multi-unit sites, or determining how regulators should assess the specific design features of the NPP against the fixed site parameters. The objective of this activity is to prepare a supplemental report, complementing the “CNRA Working Group on the Regulation of New Reactors: Report on the Survey on Regulation of Site Selection and Preparation” [NEA/CNRA/R(2010)3] to address additional issues and obtain more details on regulatory approaches for new reactor siting, including changes or enhancements as a result of the Fukushima Daiichi NPP accident.

A detailed survey was prepared covering siting topics including: multi-unit sites, site layout considerations, consideration of external hazards and combinations of hazards, population density (land use planning control), emergency preparedness integration activities with siting, social acceptability (extent of public consultation), and assessments to examine the nuclear power plant design parameters and how they are affected by the site characteristics. The activity is led by the Canadian Nuclear Safety Commission (CNSC) and it is expected that the report will be provided to the CNRA for approval during its December 2013 meeting.

Crisis communication

Regulatory bodies were subjected to an enormous amount of pressure following the accident. The main challenge faced by communicators for regulatory bodies was finding a balance between information sharing in a timely manner and the reliability of data when details were difficult to obtain. Also, it was important to make sure that information given by other countries was not detrimental to the affected country.

In early March 2011, the CNRA Working Group on Public Communication of Nuclear Regulatory Organisations (WGPC) was in the final stages of preparing its “Road Map for Crisis Communication of Nuclear Regulatory Organisations – National Aspects” [NEA/CNRA/R(2011)11] when the Fukushima Daiichi NPP accident occurred. Not only did the Fukushima Daiichi NPP accident highlight the importance of crisis communication, it also prompted the CNRA to organise an international workshop on the topic. The workshop, entitled *Crisis Communication: Facing the Challenges*, was held on 9-10 May 2012 in Madrid, Spain. It was organised under the CNRA in collaboration with the Spanish *Consejo de Seguridad Nuclear* (CSN). Over 180 experts attended the workshop, including 11 heads of nuclear regulatory organisations, from 27 countries and 6 international organisations. Representatives from the media (TV, radio and newspapers) took part in the workshop, which also included stakeholders from industry, local authorities, media representatives and environmental organisations. The workshop was also webcast live. Recommendations for enhancing crisis communication during events at nuclear facilities identified during this workshop are being incorporated into the Road Map on Crisis Communication for Nuclear Regulatory Organisations – National Aspects by the WGPC as it implements its programme of work.

One of the main findings identified during and after the Fukushima Daiichi NPP accident was the importance of social media. It was highly recognised as a new tool of communication with the public. After launching the new “Social Media” task in late September 2011, led by the NRC, the WGPC has continued its work by exchanging information on how to develop and use the social media platforms more effectively and how to control any possible harm or risks from the misuse or misinformation distributed by social media. The WGPC will look for case studies so that member countries can benefit from good experience and trial errors. In addition, the WGPC is carrying out a task on “Nuclear Regulatory Organisations Communication Plans and Routine Communication” in order to take into account all lessons learnt from the Fukushima Daiichi NPP accident.

Nuclear safety

In follow-up to the Fukushima Daiichi NPP accident and in agreement with the CNRA, the CSNI decided to launch several high priority activities.

Human performance under extreme conditions

The main objectives of this study being conducted by the Working Group on Human and Organisational Factors (WGHOFF) are to share experience and develop knowledge about human and organisational factors (HOF) shaping human intervention and performance under extreme conditions; identifying specific, currently applied HOF design principles in the nuclear industry and comparing them with available knowledge; and providing a basis for improvements and necessary research for taking into account HOF issues in the design and use of measures for achieving the best level of human and organisational performance as possible under extreme conditions. The outcome of this study will be a report that identifies HOF challenges during extreme event conditions; sets out HOF good practices and knowledge gaps; and proposes HOF principles to support human intervention and performance under extreme conditions. The report is expected to be used by licensees that are working to improve design aspects of such interventions, regulatory authorities reviewing proposed design improvements, and research organisations that are still defining necessary research projects in this regard. The GRS (Germany) has the lead for this activity with other participants including Bel V (Belgium), VTT (Finland), IRSN (France), JNES (Japan), the ONR (United Kingdom), the NRC (United States) and OECD/Halden (Norway). The plan is to provide the report for CSNI approval during its June 2014 meeting.

Filtered containment venting

The main objectives of the status report of the Working Group on Analysis and Management of Accidents (WGAMA) are to compile the status on the implementation of filtered containment venting for pressurised water, heavy water and boiling water reactors, including systems already installed and contemplated; to describe the national requirements on the implementation of venting systems and the filter performance; to briefly describe the different systems available as well as their demonstrated or expected performance; to discuss possible disadvantages of containment venting, for example inadvertent opening, risk of under-pressure; to identify, from an accident management perspective, if there is room for improvement both for the hardware and the qualification of the systems; and to summarise the status of containment venting strategies as currently implemented, especially the strategies that require interfacing with decision-making processes to actuate containment venting. The report is expected to be used by decision makers in regulatory authorities, technical support organisations, research institutes and utilities as a comprehensive summary of the current status of the technology and venting strategies, as well as the developments required for possible improvements to filtration technologies. The effort is being led by the *Institut de radioprotection et de sûreté nucléaire* (IRSN) (France) with support from the Atomic Energy of

Canada Limited (AECL) (Canada), and includes participation from the European Commission Joint Research Centre (EC-JRC) (European Union), *Électricité de France S.A.* (EDF) (France), AREVA NP, the *Gesellschaft für Anlagen- und Reaktorsicherheit* (GRS) mbH (Germany), the Nuclear Power Corporation of India Limited (NPCIL) (India), the Nuclear Energy Safety Organization (JNES) (Japan), the *Comisión Nacional de Seguridad Nuclear y Salvaguardias* (CNSNS) (Mexico), the Korea Atomic Energy Research Institute (KAERI) (Republic of Korea), the *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas* (CIEMAT) (Spain), the *Consejo de Seguridad Nuclear* (CSN) (Spain), the Swedish Radiation Safety Authority (SSM) (Sweden) and the Paul Scherrer Institute (PSI) (Switzerland). The report should be completed and provided to the CSNI for approval in 2014.

Hydrogen management

The main objectives of the WGAMA status paper are to review the approaches to hydrogen risk in the member countries (safety requirements, mitigation systems and their implementation, code validation, accident management strategies) and to identify the advantages and drawbacks of the various approaches. The paper is expected to give a comprehensive summary of the current status of the technology and hydrogen risk management strategies. This activity is being led by the AECL (Canada) with support from the IRSN (France) and participation from the EC-JRC (European Union), the *Valtion Teknillinen Tutkimuskeskus* (VTT) (Finland), the *Commissariat à l'énergie atomique et aux énergies alternatives* (CEA) (France), EDF (France), AREVA NP GmbH, the GRS (Germany), the Jülich Research Centre (JÜLICH) (Germany), the Karlsruhe Institute of Technology (KIT) (Germany), the JNES (Japan), the Nuclear Research and Consultancy Group (NRG) (Netherlands), KAERI (Republic of Korea), the CIEMAT (Spain), the PSI (Switzerland) and the NRC (United States). The report is expected to be used by decision makers of the safety authorities, technical support organisations, research institutes and utilities. The plan is to provide the report to the CSNI for approval during its June 2014 meeting.

Robustness of electrical systems

The CSNI agreed to review the robustness of electrical systems in view of the Fukushima Daiichi accident. A task group was established for that purpose (ROBELSYS), and during the first meeting they proposed to the CSNI to hold a workshop. The objectives of the workshop are to identify and discuss the lessons learnt from the Fukushima Daiichi NPP accident related to the electrical systems and the provisions taken by various countries in terms of requirements and design in order to enhance the robustness of these electrical systems, especially with regard to protection against extreme external hazards. Items to be addressed in the workshop are the review of the lessons learnt from the Fukushima Daiichi NPP accident as concerns the robustness of electrical systems; a review of the provisions already taken or planned in each participating country after the Fukushima Daiichi NPP accident, regarding the sources, the distribution systems and the loads, and documenting the technical basis for these improvements; a review of the possibilities to connect sources very close to the loads; and a review of the protection of distribution systems against external hazards. The expected result of this workshop will be the publication of the proceedings that will include findings related to means to further strengthen the robustness of electrical systems in the aftermath of the Fukushima Daiichi NPP accident. The expectation is that this will be used by decision makers of the regulatory authorities, designers and operators responsible for assessing the implementation of enhancements to the protection of electrical systems at nuclear power plants. Leading this activity is the IRSN (France) with participation from the SSM (Sweden), Vattenfall AB (Sweden), EDF (France), STUK (Finland), the GRS (Germany), the NRC (United States) and the ENSI (Switzerland). Also, contributions are being sought from grid operators, electrical equipment suppliers and standards organisations. The workshop is in preparation, with the proceedings scheduled to be provided to the CSNI for approval during its June 2014 meeting.

Spent fuel pool accident conditions

The main objectives of the CSNI status report being prepared jointly by the WGAMA and the Working Group on Fuel Safety (WGFS) are to produce a brief summary of the status of spent fuel pool accident and mitigation strategies to better contribute to the post-Fukushima Daiichi NPP accident decision-making process; to provide a brief assessment of current experimental and analytical knowledge about loss of cooling accidents in SFPs and their associated mitigation strategies; to briefly describe the strengths and weaknesses of analytical methods used in codes to predict spent fuel pool accident evolution and assess the efficiency of different cooling mechanisms for mitigation of such accidents; and to identify and list additional research activities required to address gaps in the understanding of relevant phenomenological processes, to identify where analytical tool deficiencies exist, and to reduce the uncertainties in this understanding. This activity is being led by the IRSN (France) with participation from Bel V (Belgium), the CNSC (Canada), Ústav Jaderného Výzkumu Řež, a.s. (ÚJV) (Czech Republic), the European Union (with the Severe Accident Research Network [SARNET] working groups examining related issues), the Hungarian Academy of Sciences Centre for Energy Research (MTA EK) (Hungary), the University of Pisa (UNIPI) (Italy), the JNES (Japan), KAERI and KINS (Republic of Korea), the CIEMAT and the CSN (Spain), the SSM (Sweden) and the PSI (Switzerland), and it is expected to be used as a guide for further research activities in this area by regulatory authorities, technical support organisations, reactor designers, research institutes, vendors and utilities. The report is expected to be provided to the CSNI by December 2014.

Risk analysis for natural external hazards

The CSNI agreed to discuss the use of risk methodologies (PSA) for assessment of natural external hazards and a workshop was organised to initiate the task. The objectives of the workshop jointly held by the WGRISK and the WGIAGE were to support an assessment of the current state of PSAs for natural external hazards; to support the re-evaluation of PSAs for natural external hazards, in part as a tool to address the lessons learnt from the Fukushima Daiichi NPP accident; to evaluate the use of PSAs in the identification and justification of appropriate mitigation and accident management measures following the completion of comprehensive safety review programmes; to share methods and good practices and experiences in member countries on PSA analysis for natural external hazards; and to identify potential new work in this area. The expected outcome is a task report including the workshop proceedings and a summary of the commendable practices and experience gathered during the workshop. The report is expected to be used by decision makers of regulatory authorities, industry and utilities, NEA working groups, PSA practitioners and external hazards analysts as a tool to address the application of PSA to the assessment of external natural events. The workshop was hosted by the ÚJV (Czech Republic) with support for workshop co-ordination and task report preparation from Säteilyturvakeskus (STUK) (Finland), the IRSN (France), the GRS (Germany), Nukleáris Biztonsági Kutatóintézet (NUBIKI) (Hungary), the JNES (Japan) and the NRC (United States). Others participating institutions included the Institute of Nuclear Energy Research (INER) (Chinese Taipei), the CNSNS (Mexico), the Swiss Federal Nuclear Safety Inspectorate (ENSI) (Switzerland) and the ONR (United Kingdom). The workshop took place on 17-19 June 2013, with the task report tentatively scheduled to be provided to the CSNI for approval during its June 2014 meeting.

High seismic loads on metallic components

The objectives of the MECOS project under the Working Group on Integrity of Components and Structures (WGIAGE) are to quantify the existing design margins in the seismic analysis of safety-class components for high seismic loads, while also considering the effects of plant ageing. Plant ageing can result in degraded material properties as well as cracking or loss of material through ageing mechanisms. After

assessing the existing design practices and associated margins, the project will recommend, as needed, additional research and development in order to elaborate more realistic analysis methods for high seismic loads. The summary of existing design practices is also intended to transfer knowledge to young engineers. The project is aimed at assessing the consequences of the external hazard from a seismic event on plant safety. The outcome of the MECOS project is expected to be a global set of recommendations for seismic assessment of components under high seismic loads. The project is being led by EDF (France) with the support of the WGIAGE members of the seismic and metal subgroups. The report is planned to be provided to the CSNI for approval during its June 2014 meeting.

Software tools for the estimation of fission product releases

The CSNI approved the proposal from the WGAMA to perform a benchmark of fast-running software tools used to estimate fission product releases during accidents in nuclear power plants. The WGAMA agreed to perform this benchmark in co-operation with the CRPPH Working Party on Nuclear Emergency Matters (WPNEM). The objective of this proposed activity is to benchmark software tools used to estimate accidental radioactive material releases inside and outside the containment boundary and public doses during accident conditions or emergencies in nuclear facilities such as power reactors research reactors and fuel reprocessing facilities. The benchmarking is intended to identify the strengths and weaknesses of the tools used for source term prediction and identify the knowledge gaps, as well as to propose improvements to modelling capabilities. The proposed activity and the follow-up are expected to augment the predictive capability of national regulatory authorities to rapidly respond to short-term protective measures effectively during nuclear emergencies. The benchmarking does not include the in-depth analysis codes (such as MAAP and MELCOR) that may not be suitable for use during emergencies due to their runtime limitations and time required to set up input files.

The final deliverable will be a state-of-the art report summarising the benchmark study. The report will cover the software examined, scenarios used for benchmarking, results of benchmark exercises, comparisons of the candidate tools, capabilities of the software tools and areas for improvement in modelling and software capabilities.

A secondary deliverable is a database/matrix documenting the various reactor accident software programmes and their advantages and disadvantages. This will include comparisons of the various software tools and their ability to estimate source terms, to model dose and to simulate accident scenarios, as well as their versatility (i.e. the ability to model different reactor types), accuracy and speed of calculation. The summary document will also provide a best software practice guideline for the completed comparisons. Recommendations by the project team based upon the findings of the benchmarking will be provided in the state-of-the-art report.

The results of this benchmarking will be of use to code developers, allowing them to identify areas for improving existing codes. The results will also benefit nuclear regulators, international organisations, operators and research institutes and emergency management organisations by allowing them to compare the various options available for assessing a nuclear emergency and to determine which one best suits their needs to accurately assess and confidently deal with a nuclear accident. In addition, the results will provide regulators with an understanding of accident simulations and interpretations as performed by organisations participating in the benchmark study in the state-of-the-art report. Thus different modelling abilities and techniques will be comparable among different jurisdictions.

This project is being led by the CNSC (Canada) with participation from BEL V (Belgium), the AECL (Canada), the Danish Emergency Management Agency (DEMA) (Denmark), the CEA and the IRSN (France), the GRS (Germany), the NPCIL (India), the

ENEA (Italy), the NCBJ (Poland), KAERI (Republic of Korea), ABMerit (Slovak Republic), the SSM (Sweden), AREVA (France) and the IAEA. The final report is expected to be provided to the CSNI for approval during its December 2014 meeting.

In addition to the activities described above, in December 2012, the CNRA requested that the CSNI consider taking on a new activity to look at the lessons being learnt in relation to the contribution that Japanese culture played in the accident, specifically as it related to safety culture. This issue was raised in the report issued by the Commission established by the Japanese Diet to investigate the causes of the accident at the Fukushima Daiichi NPP. It is being considered by the CSNI WGHOFF to determine whether the activity is within the scope of its mandate and if so, to develop a proposal of activities and outcomes to address this issue. The CSNI will review and approve this new proposal following its normal business process.

Joint research projects

The NEA has provided a platform for over 30 years to enable interested countries, on a cost-sharing basis, to pursue research or share data with respect to particular nuclear safety areas or issues that would otherwise be difficult to deliver on a national basis. Such joint projects, of which there have been over 30, have generated significant knowledge that has helped both to resolve many specific safety issues and to better understand the safety envelope within which nuclear reactors and their associated processes operate.

The NEA conducted a review of the joint research projects and prepared a report entitled *Main Benefits from 30 Years of Joint Projects in Nuclear Safety* (ISBN 978-92-64-99171-2, available at www.oecd-nea.org/nsd/reports/2012/nea7073-30-years-joint-safety-projects.pdf). This report highlighted the added value of international co-operation for maintaining unique experimental infrastructures, preserving skills and generating new knowledge.

The report also flagged those ongoing NEA joint research projects that had work of direct significance to the understanding of the accident and its outcomes. Full details of their relationship to the accident may be found in the report, but the NEA recognises that as further information is collected during the recovery and decontamination efforts at the Fukushima Daiichi NPP, there may be further insights identified for consideration within these joint research projects.

The ongoing joint research projects are listed below. General information on the projects can be found on the NEA website (www.oecd-nea.org/jointproj/).

Ongoing OECD/NEA safety experimental projects:

- Behaviour of Iodine Project (BIP-2) (project period: 2011-2014);
- CABRI Water Loop Project (project period: 2005-2015);
- Fire Propagation in Elementary, Multi-room Scenarios (PRISME-2) Project (project period: 2011-2016);
- Halden Reactor Project (current project period: 2012-2014);
- Loss of Forced Cooling (LOFC) Project (project period: 2011-2014);
- Primary Coolant Loop Test Facility (PKL-3) Project (project period: 2011-2015);
- Rig-of-safety Assessment (ROSA-2) Project (project period: 2009-2013);
- Sandia Fuel Project (SFP) (project period: 2009-2013);
- Source Term Evaluation and Mitigation (STEM) Project (project period: 2011-2015);
- Studsvik Cladding Integrity Project (SCIP-2) (project period: 2009-2014);

- Thermal-hydraulics, Hydrogen, Aerosols and Iodine (THAI-2) Project (project period: 2011-2014).

Ongoing OECD/NEA database projects:

- Cable Ageing Data and Knowledge (CADAK) Project (current project period: 2012-2015);
- Component Operational Experience, Degradation and Ageing Programme (CODAP) (project period: 2011-2015);
- Fire Incidents Records Exchange (FIRE) Project (project period: 2006-2013);
- International Common-cause Data Exchange (ICDE) Project (phase 6 project period: 2011-2014).

Following the accident, and based on a proposal from Japan, the NEA has initiated a benchmark to reproduce the Fukushima Daiichi NNP accident evolution and identify improvements needed in severe accident tools. In addition, the NEA safety committees initiated three new joint projects based on existing research facilities which address safety issues related to the accident.

Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant (BSAF)

This benchmark study on the accident, which is being led by the Japan Atomic Energy Agency (JAEA), has an initial phase that is projected to be implemented between November 2012 and March 2014. The project has two main objectives:

- to analyse and evaluate the accident progression and current status within the reactor pressure vessel (RPV) and primary containment vessel (PCV) of Fukushima Daiichi NPP units 1 through 3 to assist with future investigation and ultimately with fuel removal at those units; and
- to improve the methods and models of computer codes in use by each participating country and organisation, to reduce uncertainties in severe accidents (SA) analysis and validate SA codes using actual data available from Fukushima Daiichi NPP units 1 through 3.

The operating agent is the JAEA with participants from several organisations in France, Germany, Japan, the Republic of Korea, the Russian Federation, Spain, Switzerland and the United States.

The project will take the available data from the Fukushima Daiichi NPP accident and share it with the participants who will use it with their own predictive methods and codes. The outcomes of the various analyses will then be discussed and shared via the NEA to promote improved understanding of the abilities and limitations of existing methods and codes. The current target for this last stage is March 2014.

Hydrogen Mitigation Experiments for Reactor Safety (HYMERES)

Using the existing PANDA (operated by PSI, Zurich, Switzerland) and MISTRA (operated by the CEA, Saclay, France) test facilities, the main objective of the HYMERES project is to improve the understanding of the hydrogen risk phenomenology in the containment in order to enhance the quality of hydrogen behaviour modelling in safety assessments that will be performed for current and new nuclear power plants.

The HYMERES project introduces three new elements with respect to previous projects related to hydrogen risk. It will examine:

- Firstly, realistic flow conditions within the reactor containment. This will provide crucial information in the evaluation of the basic computational and modelling requirements needed to analyse a real nuclear power plant.

- Secondly, tests addressing the interaction of different combinations of safety components operating simultaneously will be performed (e.g. the thermal effects created by two passive autocatalytic recombiners [PARs], spray and cooler, spray and opening hatches). These combinations will be defined by the participants.
- Thirdly, the system behaviour for selected cases will be addressed (e.g. the differences in hydrogen concentration build-up between reactor types including BWR, PWR or PHWR designs), recognising that the hydrogen concentration build-up in the containment depends on the responses of different components in the system.

The project findings will include:

- detailed reports for the tests in each facility with the rationale for the test matrix and the specified test conditions, data interpretation and application with a discussion of the results' relevance for code validation, significance for nuclear plant safety issues and their applicability to real plants; and
- a joint PANDA-MISTRA final report at the end of the project, summarising the test results and assessing the conclusions drawn from the test series with respect to applicability to real nuclear power plants.

PWR transient tests under postulated accident scenarios (PKL phase 3)

Based on an extension of the current experimental programme of the NEA joint projects at the PKL test facility in Erlangen, Germany (operated by AREVA, France), the PKL phase 3 tests will investigate safety issues relevant for current PWR plants as well as for new PWR design concepts by means of transient tests under postulated accident scenarios and systematic parameter studies on thermal-hydraulic phenomena. It is important to point out that findings from the previous NEA joint project test programmes (PKL and PKL-2) on thermal-hydraulic phenomena will be available to allow comparison with the transients test from PKL-3.

The first category of tests addresses current safety issues related to beyond-design-basis accident transients with significant core heat-up (i.e. station blackout scenarios or loss-of-coolant accidents in connection with failure of safety systems). In the tests, the efficiency of very late initiated accident management measures will be demonstrated and the safety margins thereby explored, including the initiation of accident management measures involving emergency operating procedures and/or severe accident management measures.

The second category of tests addresses some subjects already investigated in the former PKL projects but varies the parameters either to provide an extension to already existing databases on cool-down procedures or to determine the sensitivity of boron precipitation in the core following a large-break LOCA.

Finally, three test subjects remain open, to be defined by the participants following the results of the preceding experiments.

Participants in PKL-3 include: Belgium, China, the Czech Republic, Finland, France, Germany, Hungary, Japan, the Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland and the United States.

The PKL-3 project schedule is from April 2012 through to the end of December 2015. Deliverables for the project include:

- detailed test reports, data interpretation and a discussion of the results' relevance for code validation, significance for PWR safety issues and their applicability to real PWRs; and

- a final report, supplied at the end of the project, summarising the test results and assessing the conclusions drawn from the test series with respect to applicability to real PWRs.

Advanced Thermal-hydraulic Test Loop for Accident Simulation (ATLAS)

ATLAS, operated by KAERI (Republic of Korea), is a large-scale thermal-hydraulic test facility for an APR1400 that can simulate the thermal-hydraulic behaviour of major systems and components during transient and accident conditions at full pressure and temperature conditions.

The NEA joint project at this facility is scheduled to take place from March 2014 to February 2017. It is the intent that the work will relatively rapidly offer the ability to reconsider events that have an extremely low occurring frequency but result in a high core damage frequency, such as that found at the Fukushima Daiichi NPP where the accident attracted international attention due to multiple high-risk failures.

The project will, via experiment:

- investigate design extension conditions (DEC), such as an SBO, a reactor vessel rupture or a total loss of feed water, to identify the major thermal-hydraulic scenarios to be addressed in the design and to further contribute to safety analysis technology of nuclear power plants;
- produce clearer knowledge of the current phenomena involved in these accidents such that the ability of currently proposed passive safety systems to mitigate them – the key new features of advanced light water reactors being implemented to reinforce safety as well as to improve nuclear power plants' economic competitiveness – may be tested, and provide enhanced guidelines for accident management;
- improve the knowledge of two-phase multi-dimensional natural circulation phenomena involved in passive cooling systems to overcome limitations in modelling within current system-scale safety analysis codes by having realistic physical models to compare against. Such work will furthermore assist in quantifying the prediction accuracy to determine the area where model development is required; and
- assist in developing risk-informed requirements in rulemaking; for instance, the intent is to experimentally investigate and characterise major thermal-hydraulic behaviour following a medium-break loss-of-coolant accident (LOCA) to support the rule-making development of 10 CFR Part 50 on emergency core cooling systems.

New reactors

In addition to the activities performed by the CNRA on new reactors, the NEA performs the technical secretariat function for the Multinational Design Evaluation Programme (MDEP), which is a multinational initiative that develops innovative approaches to leverage the resources and knowledge of national regulatory authorities who are, or will shortly be, undertaking the review of new reactor power plant designs. Twelve regulatory bodies currently participate, along with one associate member. The IAEA also takes part in some of the MDEP work. The MDEP carries out a broad range of activities including enhancing multilateral co-operation within existing regulatory frameworks, and increasing multinational convergence of codes, standards, guides and safety goals. The MDEP design-specific working groups engaged in regulatory reviews of new reactor designs such as the EPR, AP1000 and APR1400 are currently evaluating the lessons learnt from the accident at the Fukushima Daiichi NPP in close collaboration with stakeholders. Once their evaluations are completed, the working groups will document their findings in

a technical report that includes common conclusions that each of the working group members have reached.

To date, the EPR working group has produced a draft common position on the lessons learnt from the accident at the Fukushima Daiichi NPP. The draft common position addresses five review areas: external hazards, reliability of safety functions, accidents with core melt, spent fuel pools and emergency preparedness in design. The draft common position confirmed the relevance of the general safety objectives that have been considered for Generation III reactors (e.g. the EPR), such as limitation of the probability of core melt, limitation of significant releases offsite, and management of severe accident situations, in particular as related to the lessons learnt from the Fukushima Daiichi NPP accident. As compared to most current operating reactors, the EPR contains additional safety measures and margin. For example, there are four redundant and independent trains of safety systems, including an emergency diesel generator in each of the trains, and additionally, two diverse station blackout diesel generators. There are also systems to provide for severe accident management and protection against external events such as earthquakes and flooding. The total loss of the main heat sink is also one of the design bases of the plant. Nevertheless, it has been observed to date, from regulators who have completed their safety reviews of their EPR design applications, that the EPRs could suffer cliff-edge effects after a few hours in the most severe accident situations, particularly those involving a common-cause failure that results in long-term loss of electrical power and cooling. Safety improvements have been proposed to address those situations.

Radiological protection

The CRPPH continues to consider that the implications of the Fukushima Daiichi NPP accident on radiological protection policy, regulation and application are significant and need to be studied. With time, issues and lessons are becoming clearer, and national regulatory authorities are working to assess impacts on national programmes and to implement any necessary changes. In this context, the CRPPH continues to follow the situation closely, and will adjust its programme of work accordingly as new aspects emerge.

In addition, the CRPPH continues its close co-operation with the Japanese government in order to best support its need for international experience, and to best allow the CRPPH community access to Japanese experience in dealing with the aftermath of this tragic accident. The CRPPH has focused in particular on the areas of offsite decontamination, the Fukushima Medical Health Survey, emergency response planning and stakeholder involvement.

Radiological protection aspects of the Fukushima Daiichi NPP accident

In order to ensure that its Fukushima Daiichi NPP accident-related work was appropriately co-ordinated within the CRPPH programme of work with the Fukushima-related work of other NEA standing technical committees, and with relevant international organisations, the CRPPH created the Expert Group on Radiological Protection Aspects of the Fukushima Accident (EGRPF) during its March 2011 meeting. The EGRPF was charged with identifying and addressing those issues arising from the accident that could reasonably be acted on in the context of the NEA's competencies and mandate, and in co-ordination with other international organisations, in particular the IAEA.

The first task undertaken by the group was to discuss the issues that arose regarding international trade in food and goods coming from contaminated areas in Japan. This work was performed by an EGRPF subgroup that included observers from the IAEA and the EC, and its results were forwarded to the IAEA and the Food and Agriculture Organization (FAO) for use in their standard development activities. The EGRPF subgroup developed a framework approach in which criteria for trade in contaminated food and

goods could be defined. The central themes of the framework are that accidents requiring trade criteria to be established will be rare and distinct; the accident country will quickly stop trade until the situation is in hand and contamination is characterised; and the accident country will then develop criteria for the protection of its own population in contaminated areas, also to be applied to food and goods used elsewhere in the accident country and to food and goods leaving the country. These accident-specific national criteria should drive international, accident-related criteria.

The second task undertaken by the group addressed issues and lessons emerging as the accident's impacts have become more fully understood in NEA member countries. Approximately two years after the accident, the EGRPF developed a survey of emerging issues and lessons and sent this to NEA members. It enquired about any post-Fukushima Daiichi NPP accident national policy modifications foreseen or being implemented to address the return to evacuated areas; clean-up criteria; management of decontamination waste; communications issues; and education and development of a radiological protection culture. The results of this survey were discussed at the 71st meeting of the CRPPH (May 2013) during a topical session on recovery management, and will be included in a summary report on this important issue.

The final major task undertaken thus far by the EGRPF was the development of the 3rd Science and Values Workshop, held in Japan in November 2012. The CRPPH has, since the early 1990s, studied issues of stakeholder involvement in radiological protection decision making. The committee's most recent work in this area has focused on understanding how radiological protection science and social values contribute to the development of sustainable, accepted decisions. Following two workshops on this topic (2008 in Finland, 2009 in France) the CRPPH agreed to hold the 3rd Science and Values Workshop in Japan, with the objective to better understand how science and values may influence the evolution of the system of radiological protection, and to better understand how science and values should be included and transparently articulated in radiological protection decision making. Taking into account the Fukushima Daiichi NPP accident experience, the dimensions of science and values were addressed by Asian and international delegates through three key topics of relevance to the Fukushima Daiichi NPP accident: assessment and management of low-dose exposures and public health; protection of children and self-help behaviour approaches; and non-cancer effects. The summary of the workshop's results will be published. The CRPPH will continue its work on science and values through the EGRPF, with the organisation of an Asian regional workshop in Tokyo during the first half of 2014.

The CRPPH will also support, through the EGRPF, a workshop on decontamination and stakeholder involvement to be held in Japan during the first half of 2014 as well. This workshop will focus on the technical results of decontamination of different areas (forests, agricultural fields, urban areas, houses), providing details on Japanese experience at reducing dose rates and population annual doses. Approaches to involving stakeholders in planning and objective setting will also be addressed.

The EGRPF will, as a result of discussions at the 71st CRPPH meeting in May 2013, continue its work on post-Fukushima Daiichi NPP accident radiological protection issues.

Nuclear emergencies

The CRPPH has been contributing actively to the area of nuclear emergency matters since just after the Chernobyl accident in 1986. Following the Fukushima Daiichi NPP accident, the Working Party on Nuclear Emergency Matters (WPNEM) significantly adjusted its programme of work to identify and address emerging issues. In particular, work already underway in two areas was modified to include Fukushima Daiichi NPP accident issues, and a new project on issues and lessons was initiated.

Following the issuing of new ICRP recommendations on emergency management (ICRP publication 109), the WPNEM undertook a survey of members asking how the new

recommendations were interpreted and implemented in national approaches to emergency management. After the Fukushima Daiichi NPP accident, national reactions to post-Fukushima Daiichi NPP accident implications were explicitly taken into account in the report. The final report on this topic will be published.

The above-mentioned work on ICRP recommendations stimulated the WPNEM to consider national approaches to short-term countermeasures in the context of emergency management. As a result, the WPNEM agreed to perform an update study of its 2003 report on this topic. Following the Fukushima Daiichi NPP accident, the working party agreed to include the influence of the Fukushima Daiichi NPP accident on national approaches in short-term countermeasures, and as such the final report is due to be issued in the second half of 2013.

Similar to the work of the EGRPF, the WPNEM considered that it would take some time after the Fukushima Daiichi NPP accident for national authorities for nuclear emergency management to fully understand and develop approaches to post-Fukushima Daiichi NPP accident issues and lessons. As such, the WPNEM recently developed a short survey were to identify issues and lessons in the areas of emergency communications, dealing with incoming trade and technical assessments of accident situations. The results of this survey were discussed at the 71st meeting of the CRPPH (May 2013) during a topical session on emergency management, and will be included in a summary report on this important issue.

In the mid-1990s, the WPNEM worked with the EC and the IAEA to develop an inter-comparison of computer codes assessing the impact of large-scale nuclear accidents. Following the Fukushima Daiichi NPP accident, there has been an increased interest in assessing the cost of nuclear accidents, both from the perspective of internalising accident costs and of understanding the deterministic magnitude of large-scale accident costs. As such, the NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) has initiated a project to undertake such a cost analysis. The WPNEM will participate in this work, providing the project with its expertise in accident impacts and response.

Since 1992, the WPNEM has developed, implemented and assessed international nuclear emergency exercises through the INEX series. These ground-breaking exercises have assisted NEA member countries to better understand and prepare for the international aspects of nuclear emergencies. The INEX-4 exercise had originally been scheduled to be performed in 2011, but with the onset of the Fukushima Daiichi NPP accident, some countries chose to postpone their exercises and thus the schedule for submission of national exercise results was modified. An INEX-4 summary report has been prepared, and national exercise results were presented and discussed in a topical session during the 71st meeting of the CRPPH (May 2013). Although this exercise assessed national preparedness for addressing the consequences of a radiological dispersion device in an urban environment, it was agreed that the relevant Fukushima Daiichi NPP accident-related issues should be addressed in the exercise summary report, which will be published in mid-2013. The WPNEM will begin planning for the INEX-5 exercise in 2013, and will fully take into account the implications of the Fukushima Daiichi NPP accident in formulating the objectives for this exercise, which will most likely be planned for the 2014 or 2015 time frame.

Information System on Occupational Exposure (ISOE)

The ISOE programme was created in 1992 as a forum for the exchange of practical occupational exposure management experience among nuclear operators. Following the Fukushima Daiichi NPP accident, ISOE members quickly agreed that their experience in the area of occupational exposure management in high radiation areas and for severe accident management



TEPCO, Japan.

should be collected and reported. The ISOE Expert Group on Occupational Radiation Protection in Severe Accident Management and Post-accident Recovery (EG-SAM) was thus created, and is scheduled to finalise its report in late 2013, and to organise a workshop on this topic in late 2014. The report will include an assessment of radiation protection management and organisation; radiation protection training and exercises related to severe accident management; facility configuration and readiness; worker protection; radioactive materials and contamination controls; logistics and lessons learnt.

Support for the ICRP dialogue initiative

The CRPPH has been actively involved in an initiative organised by the ICRP, called the ICRP Fukushima dialogue initiative. Since November 2011, the ICRP has organised, with support from the NEA Secretariat, five dialogue meetings (November 2011, February 2012, July 2012, November 2012 and March 2013). These two-day meetings provide a forum for affected stakeholders to share their concerns, experience and actions in order to better understand how to proceed. The NEA will continue to support and participate in these activities, and is preparing a report summarising the process and procedures that have been used to organise these conferences.

Legal framework and liabilities

The NEA Nuclear Law Committee (NLC) has been focusing on the legal framework and implementation of Japan's compensation scheme for victims of the Fukushima Daiichi NPP accident. Against the framework of the Japanese Act on Compensation for Nuclear Damage (originally enacted in 1961), Japan has adopted additional legislation and guidance and has implemented mechanisms designed to facilitate the implementation of the compensation scheme. Although Japan does not presently adhere to one of the international nuclear liability conventions, its legislation conforms to the guiding principles of the international third party nuclear liability regime, and it is one of the few countries that have opted for unlimited liability of the operator.

The NLC has received briefings on the compensation scheme at each of its meetings since the accident. During the March 2012 NLC meeting, a special session was dedicated to the Japanese nuclear third party liability regime in light of the Fukushima Daiichi NPP accident. Detailed reports were provided by Japanese experts from the Nuclear Liability Office, Research and Development Bureau at the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Cabinet Secretariat of the Government of Japan (Nuclear Power Plant Accidents Economic Response Office) and the Dispute Reconciliation Committee for Nuclear Damage Compensation (the Reconciliation Committee). These reports outlined progress in the compensation process of victims of the accident, the nuclear liability system and the Nuclear Damage Compensation Facilitation Corporation that was established by the Japanese government in order to financially assist nuclear operators in meeting their obligations to pay compensation to victims in the case of a nuclear accident. The presentations also included a description of the guidelines which have been adopted by the Reconciliation Committee in its effort to clarify the types of damage to be compensated by TEPCO and the method of calculating the amount of damages.

Because of the interest in the Japanese compensation scheme, the NEA Secretariat, in co-operation with the Permanent Delegation of Japan to the OECD, prepared the publication *Japan's Compensation System for Nuclear Damage: As Related to the TEPCO Fukushima Daiichi Nuclear Accident* [ISBN 978-92-64-99200-9, available at www.oecd-nea.org/law/fukushima/7089-fukushima-compensation-system-pp.pdf]. The publication gathers in one volume the translations in English of the major statutes, ordinances and guidelines issued in Japan for the establishment and implementation of the compensation scheme in response to the Fukushima Daiichi NPP accident. The publication also includes several commentaries on third party nuclear liability by

Japanese experts who are currently actively involved in the implementation of the compensation scheme.

The publication furthers the goals of the NEA in the nuclear law area, which is to help create sound national and international legal regimes required for the peaceful uses of nuclear energy and to serve as a centre for nuclear law information and education. The publication should provide useful insights to national authorities and legal experts as they reflect on potential improvements in their national regimes and in the international framework for nuclear liability.

Direct support to Japan by the NEA

Since the Fukushima Daiichi NPP accident, the NEA has helped establish or carry out a number of activities aimed at assisting Japan in its recovery efforts and challenges.

In October 2011, with the support of the CRPPH, the NEA assisted the Japanese government in organising the International Symposium on Decontamination: Towards the Recovery of the Environment, held in Fukushima City. The meeting was opened by the Japanese Minister of the Environment, at that time Mr. Goushi Hosono, by the NEA Director-General, Mr. Luis Echávarri, and by a video message from the IAEA Director-General, Mr. Yukiya Amano. The meeting addressed technical and stakeholder involvement issues in recovery, and its results were presented to the CRPPH at its March 2012 meeting. Conference results are available on the NEA website (www.oecd-nea.org/press/2011/NEWS-07.html).

In the area of nuclear safety, and with regard to the second phase of safety reviews of the Japanese fleet of nuclear reactors (commonly called “Japanese stress tests”), an NEA team of international experts met in Tokyo on 16-18 November 2011 with the Nuclear and Industrial Safety Agency (NISA) of Japan and the Japan Nuclear Energy Safety Organization (JNES). The goal of this event was to allow NISA and JNES to acquire better understanding of other NEA member countries’ post-Fukushima national comprehensive safety reviews, international guidance and review methodologies. The mission included a technical experts’ meeting for sharing information on national comprehensive safety reviews, an international seminar with the Japanese nuclear industry and public, and a meeting with an advisory committee supporting the regulatory reviews of licensee analyses as part of the Japanese stress tests. The NEA team included experts from Finland, France, the Republic of Korea, the United Kingdom and the United States. The IAEA also participated in the meetings.

In addition, the NEA has supported with CRPPH involvement a Stakeholder dialogue initiative in Fukushima City (in November 2011, February 2012, July 2012, November 2012 and March 2013) and in Date City (in February 2012), initiated by the ICRP and providing a platform for discussions amongst local officials, residents, businesses, farmers and non-governmental organisations. The NEA provided technical advice and background information regarding rehabilitation of living conditions in the affected areas. The NEA is continuing to support these efforts in order to further encourage dialogue and to build stakeholder trust.



In the area of nuclear regulation, on 17-18 January 2012, an NEA team of international experts met in Tokyo with members of the Japanese Advisory Committee for Prevention of Nuclear Accidents and the special Japanese Task Force for the Reform of Nuclear Safety Regulations and Organisations to foster increased understanding of various

national regulatory organisations and their approaches to the regulatory oversight of nuclear power plants. Participants discussed different approaches to reforming areas recommended by the advisory committee, such as those concerning independence, regulatory oversight, crisis management, human resources and development, new safety regulations, transparency and international aspects for regulatory organisations. The NEA team included experts from France, the Republic of Korea, the United Kingdom and the United States. The IAEA also participated in the meeting.

In February 2012, the CRPPH assisted the Japanese government in organising a two-part conference in Tokyo and in Fukushima, again addressing both the technical and stakeholder involvement aspects of recovery. In Tokyo, the workshop on the Experience and Technology of Russia, Ukraine and Other Commonwealth of Independent States (CIS) Countries on Remediation and Restoration of Environments primarily addressed the post-Chernobyl recovery experience. This session was mainly organised by the International Science Technology Centre/Science and Technology Centre in Ukraine (ISTC/STCU). In Fukushima, the Seminar for the Restoration of Fukushima was opened by the Japanese Minister of the Environment, at that time Mr. Goushi Hosono, and by the Governor of Fukushima Prefecture, at that time Mr. Yuhei Sato. The conference addressed decontamination, health and agriculture, education and stakeholder involvement issues, and was organised by the CRPPH. Conference results are available on the NEA website (www.oecd-nea.org/rp/meetings/ISTC-STCU/).

In March 2012, the NEA, in co-operation with the IAEA, helped the Japanese government to organise an international experts' workshop in Tokyo on the Japanese government and TEPCO Council's mid- to long-term plan for decommissioning the Fukushima Daiichi nuclear power plant. It was followed by a public symposium on the same subject. The workshop and symposium provided a forum for discussion and exchange of information among invited technical experts from Japanese utilities, research and design organisations, regulatory bodies, manufacturing and service companies and other international experts on decommissioning, radioactive waste management and robotics.

Key messages

Assurance of safety

Shortly after the Fukushima Daiichi nuclear power plant accident, NEA member and associated countries using nuclear power implemented focused safety reviews of their operating reactors and determined that they were safe to continue operation considering such impacts as those of extreme earthquakes and tsunami-induced flooding while more comprehensive safety reviews were conducted. These countries subsequently conducted these reviews in light of the accident and lessons learnt. The scope of the comprehensive safety reviews were broader than just the conditions experienced in Fukushima and included confirming that existing design bases provided assurance of safety. Building on these reviews and with regulatory oversight, operators in NEA member countries have implemented or are planning to implement safety enhancements that better prepare the NPP operators to respond to extreme initiating events, such as the prolonged loss of electric supply and loss of ultimate heat sink, as experienced at the Fukushima Daiichi NPP. These enhancements, when effectively implemented, are aimed at making it extremely unlikely that another Fukushima Daiichi NPP-type accident or other accident due to multiple failures of safety systems would occur in the future. The enhancements, many of which go beyond the existing licensing basis for the NPP, provide for increased capability to provide electrical power and cooling water to the equipment needed to prevent an accident from escalating, and would help to mitigate an accident should it progress to significant core damage (severe accident).

Ensuring safety is a national responsibility but poses a global concern due to the potentially far-reaching accident consequences. In this context, international co-operation is important in identifying commendable practices to ensure that nuclear safety is effectively addressed within the national regulatory framework of countries with nuclear power programmes. The NEA provides an effective forum for this international co-operation and has supported its members in developing safety enhancements in areas such as defence-in-depth, accident management, human and organisational factors, joint research projects, radiological protection, crisis communication and emergency management.

Shared responsibilities

Recognising that the primary responsibility for nuclear safety remains with the NPP operators, regulatory authorities have responsibility to ensure that the public and the environment are protected from the harmful effects of radiation. The operator's responsibilities include ensuring that organisations that support it – such as designers, construction organisations, vendors and their suppliers – understand their roles and responsibilities for nuclear safety. Through the implementation of their oversight role, regulators supported by their technical support organisations have the responsibility of ensuring that the plants are designed, constructed, operated and maintained consistent with well-established technical and regulatory requirements aimed at the protection of the public and the environment. In the case of an accident, emergency management organisations share responsibilities with regulators and operators to effectively exchange and utilise information for public and environmental protection. Collectively, each individual working in the nuclear industry – operator, vendor, designer, constructor,

technical safety expert and regulator – has a shared responsibility to hold each other accountable for the development and effective implementation of nuclear safety principles.

Human and organisational factors

A fundamental key message from the Fukushima Daiichi NPP accident is that there is no room for complacency in the implementation of nuclear safety practices and concepts. While there are lessons being learnt, analyses being conducted and information being collected to support safety enhancements to cope with events that go beyond the design basis, at the conceptual level, nuclear safety practices and approaches do not require significant changes based on what has been learnt from the accident. Existing national and international requirements provide a framework that, when effectively implemented, could have prevented this accident from occurring. The measures that countries are implementing now, after the accident in Japan, could have been implemented before the accident occurred and are aimed at increasing the robustness of nuclear reactors against extreme hazards and plant states.

The regulators and licensees have focused significant efforts on the design and technical safety aspects that can be improved to enhance safety. However, the Fukushima Daiichi NPP accident identified significant and new human, organisational and cultural challenges that also need to be addressed. The accident revealed the importance of applying existing concepts and technical knowledge throughout the decision-making processes for design, operation and accident management. This aspect of the lessons learnt relates to the human and organisation elements in the decision-making processes and to the capability of individuals and organisations to make the required decisions and to take the necessary actions to implement the decisions.

It has been recognised that organisational factors, including the independence, technical capability and transparency of the regulator in Japan, contributed to the accident and emergency response challenges encountered. The accident also revealed that factors contributing to stress in human performance and widely damaged infrastructure need to be considered in the planning and performance of accident management measures.

Defence-in-depth (DiD)

The concepts that form the foundation of nuclear safety principles – such as DiD, diversity, continuous improvement and operational experience feedback – were considered important before the accident, and remain so after the accident. Although the accident at the Fukushima Daiichi NPP overwhelmed essentially all the engineering and procedural barriers to the release of radioactive material offsite, the fundamental concepts of DiD remain valid and continue to be shared by those in charge of nuclear safety (operators, safety bodies). Even though the concepts of DiD are shared, the characteristics as implemented in different regulatory frameworks contribute to the diverging application of these concepts to achieve the end goal of protecting the public, workers and the environment. The DiD concepts provide measures for taking adequate dispositions against different types of risk. The safety requirements to be achieved should be consistent with the safety of the most recent nuclear installations.

A high level of alignment of the concepts underpinning DiD currently exists. Going forward, regulatory authorities in each country should consider including within their guidance both prevention and mitigation measures at each level² of DiD, applying DiD to both the design phase and siting of the NPP. They should also ensure that, to the extent

2. See Table page 25.

practical, actions taken and resources relied upon at one level of DiD are independent from the other levels in order to minimise the potential for common-cause failures propagating from one level to another as occurred at the Fukushima Daiichi NPP. Implicit in considering DiD for the siting of an NPP is the assurance offered that the risks from external hazards are fully considered before the plants are designed and constructed, and unique site features are taken advantage of to minimise common-cause failures of equipment. It is clear then that implementation of DiD would benefit from improved knowledge of and methods for determining the risks from potential external hazards. In the absence of improved knowledge and methods, and where there is higher uncertainty, as in the case of external hazards, effective implementation of the DiD concept requires additional measures to address these uncertainties and the unknown in order to maintain adequate safety margins.

Stakeholder engagement

The last barrier of DiD is the emergency plans and countermeasures implemented to protect the public from the harmful effects of radiation. Current international advice from the ICRP was issued in 2009, and is in the process of being transformed into IAEA requirements for adoption at the national level. As such, the Fukushima Daiichi NPP accident was an extreme test of new advice that had not yet been internationally or nationally implemented. Effective decision making for implementing countermeasures will be enhanced, and decision makers will be better able to respond based on validated facts and informed advice through training and exercises, providing the local, regional and national government officials responsible for offsite emergency preparedness a better understanding of what is happening during an accident, and with whom they will be working should an accident occur.

The implementation of protective measures, however, remains problematic, in particular as the situation transitions to longer-term recovery and those evacuated or sheltered wish to return to their normal lives. This transition requires significant resources and efforts to effectively engage with stakeholders so as to appropriately understand and address their concerns. This is particularly complex in a post-accident situation where public trust may often be low. A significant complicating factor is the lack of conclusive scientific understanding of the levels of risk caused by low-level radiation exposures (i.e. from zero to under a few tens of millisieverts in a year). The CRPPH has assessed relevant recovery management issues and will, in an internationally co-ordinated fashion, work to address such questions while encouraging and promoting stakeholder engagement.

Crisis communication

Regulatory bodies were subjected to an enormous amount of pressure following the accident. The main challenge faced by the communicators for regulatory bodies was finding a balance between the sharing of timely information and the reliability of that information when details were difficult to obtain. Furthermore, it was important to make sure that information provided by other countries was not detrimental to the affected country.

It has been recognised that significant improvements are needed in international communication and information exchange among national regulatory organisations and their crisis response centres. As such, the international information exchange aspects of nuclear emergencies are also being reviewed in order to improve capabilities to communicate reliable data, information and decisions as quickly and effectively as possible among national authorities of all countries and their emergency and technical crisis centres which could be directly or indirectly affected by nuclear emergencies.

In addition, regulatory authorities recognise the need to have effective and tested crisis communication plans available, addressing both national and international needs. The Fukushima experience has clearly underlined the need to be able to communicate consistently and with plain language so that members of the public can understand their safety status. Current communication plans do not adequately address sociological and psychological factors, as well as economic aspects to a lesser degree. The CNRA Working Group on Public Communication of Nuclear Regulatory Organisations has produced very useful reports in the public communication domain and the group should continue supporting member countries in their efforts to upgrade communication plans.

International aspects of emergency preparedness

The Fukushima Daiichi NPP accident showed that countries whose territory would not be directly affected by the accident responded very quickly in collecting information and supplying recommendations to their citizens in Japan. The diversity of national recommendations, and in particular the differences between Japanese protection recommendations and those of foreign governments for their own citizens in Japan, suggests that mechanisms to share technical information among governments should be improved. The NEA International Nuclear Emergency Exercises (INEX) have focused on this issue, and will continue to study national approaches to making such decisions. Foreign participation in national emergency exercises and common international training should become key elements in improving international emergency preparedness. In addition, should a large accident occur, there could be a need for urgent actions in countries adjacent to the accident state. Many countries, in Europe in particular, have for some time worked bilaterally and regionally to co-ordinate approaches for the implementation of urgent countermeasures. Further discussion on such co-ordination, perhaps in the context of the international notification and assistance conventions, could be of value.

Trade and transport issues

Although international agreements exist concerning post-accident trade in food, these standards were not used, and no standards existed for post-accident trade in goods. International discussions on these issues are ongoing. The NEA has proposed to the IAEA a framework for the development of criteria to manage international trade in food and goods from post-accident, contaminated territories.

Research and development

As the accident-recovery process continues to evolve and specific conclusions are reached, the latter could have an effect on the long-term recommendations for research and development. In addition, there is still significant information being collected as the decontamination and recovery from the accident continues. This process will extend over many years as the dismantling of the damaged reactors progresses and data are collected on the condition of the cores and other features of the plant. After the preliminary safety assessments, technical evaluations were undertaken to respond to the lessons learnt from the accident using the best available methods at the time. Research is ongoing to develop enhanced analysis methods for those areas that were found not to be as mature (i.e. external hazard assessments).

International co-operation and the NEA contribution

Countries are moving forward with the implementation of plans to respond to accidents within their regulatory frameworks by taking actions to improve the safety of nuclear power plants and to enhance emergency preparedness. Short-term issues were generally

dealt with by the national activities and reflected in actions that were taken to address immediate concerns revealed by the Fukushima Daiichi NPP accident.

For medium- and longer-term actions to address lessons learnt, international co-operation provides the best forum for collecting, sharing and analysing data to develop consistent approaches that can be applied within the national regulatory frameworks. This international co-operation also provides a forum in which peer regulators can actively encourage each other to remain vigilant in ensuring nuclear power plant safety to help avoid the complacency that contributed to the accident at the Fukushima Daiichi NPP. The NEA provides a forum for co-operation on both medium-term and longer-term issues in its specific task groups, existing NEA working parties and expert groups, and joint international research projects.

Many countries with mature nuclear power programmes strive to reach and maintain a high level of safety, to apply the principle of continuous safety enhancements that are reasonably achievable, and have used safety reviews to identify measures to enhance safety. These practices should be encouraged and used routinely to update current standards and to identify state-of-the-art practices in light of the lessons learnt from the Fukushima Daiichi NPP accident.

Conclusions

To date, safety reassessments carried out at nuclear power plants around the world have concluded that facilities examined offer **a safety level that is sufficient, and no immediate shutdown has been required**. Nevertheless, continued operation of nuclear power plants requires that their **robustness to extreme situations be increased** beyond the existing safety margins, as soon as possible. It is crucial to continue these reassessments on a periodic basis and to ensure that all safety improvements identified are fully implemented in a timely manner.

Nuclear power plant operators and nuclear activity **licensees have prime responsibility for the safety** of their activity. They cannot delegate this responsibility to others and must assume their responsibility in full and comply with the requirements of the regulations concerning nuclear safety and radiological protection. **Nuclear regulatory authorities play a fundamental role** in ensuring such compliance so that workers, the general public and the environment are protected.

Since **a severe accident can never be completely ruled out**, the necessary provisions for dealing with and managing a radiological emergency situation, onsite and offsite, must be planned, tested and regularly reviewed in order to integrate experience feedback from drills and from the management of real-life situations. The importance of crisis communication, co-ordination and consistency in national and international responses to emergencies has to be emphasised.

As was the case with the accidents at Three Mile Island and Chernobyl, in-depth **experience feedback** from the Fukushima Daiichi accident **will continue over the long term**, up to ten years or more. To date, a considerable amount of work has been completed, but much more remains to be done not only by the licensees but also by national regulators, technical support organisations and international networks and organisations.



To perform this work, a **consistent international effort is necessary**. In addition to the activities carried out under NEA auspices, there are various initiatives that are being co-ordinated at the international level which are in progress. The IAEA Nuclear Safety Action Plan, and national action plans mirroring the IAEA plan, form an important framework in this context. Additional initiatives include the co-ordinated international approach at the European level, implemented under national responsibility in the context of the European Nuclear Safety Regulators Group (ENSREG). Care must be taken to ensure that all international initiatives remain consistent and avoid any duplication of work. Due to the enormous amount of work involved, **attention should first be given to priority**

installations when implementing action plans, due to the potential consequences of an accident at these sites.

The accident at the Fukushima Daiichi nuclear power plant was a tragedy that will continue to be addressed for many years to come. Following the large societal, economic and psychological impacts of the Fukushima accident, the nuclear safety organisations considered that provisions should be identified to prevent and mitigate the potential for severe accidents with long-term, offsite consequences.

To conclude, it is the collective responsibility of the nuclear community to ensure that there is no complacency in the effective implementation of the practices and approaches that have been developed over decades of use of nuclear power to protect the public and the environment from the harmful effects of radiation. A questioning and learning attitude is essential to continue improving the high level of safety standards and their effective implementation.

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List of acronyms and abbreviations

- AC – Alternating current
- AECL – Atomic Energy of Canada Limited, TSO in Canada
- AM – Accident management
- ATF – Accident tolerant fuel
- ATLAS – Advanced Thermal-hydraulic Test Loop for Accident Simulation Project
- BDBA – Beyond-design-basis accident
- BSAF – Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant
- BWR – Boiling water reactor
- CEA – *Commissariat à l'énergie atomique et aux énergies alternatives*, TSO in France
- CIEMAT – *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas*, TSO in Spain
- CRPPH – NEA Committee on Radiation Protection and Public Health
- CNRA – NEA Committee on Nuclear Regulatory Activities
- CNS – Convention on Nuclear Safety
- CNSC – Canadian Nuclear Safety Commission, regulator in Canada
- CNSNS – *Comisión Nacional de Seguridad Nuclear y Salvaguardias*, regulator in Mexico
- CSN – *Consejo de Seguridad Nuclear*, regulator in Spain
- CSNI – NEA Committee on the Safety of Nuclear Installations
- DC – Direct current
- DEC – Design extension conditions
- DEMA – Danish Emergency Management Agency
- DiD – Defence-in-depth
- EC – European Commission
- EC-JRC – European Commission - Joint Research Centre (EC-JRC)
- EDF – *Électricité de France S.A.*
- EG-SAM – IAEA Expert Group on Occupational Radiation Protection in Severe Accident Management and Post-Accident Recovery
- EGRPF – Expert Group on Radiological Protection Aspects of the Fukushima Accident (CRPPH)
- ENAC – Emergency Notification and Assistance Conventions
- ENEA – *Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile*, Italy
- ENSI – Swiss Federal Nuclear Safety Inspectorate, regulator in Switzerland
- ENSREG – European Nuclear Safety Regulators Group

EOP – Emergency operating procedure
EPRG – Extended PRG (CSNI)
FAO – Food and Agriculture Organization
FAQs – Frequently asked questions
GDR – Governmental decisions and recommendations
GHSI – Global Health Security Initiative
GRS – *Gesellschaft für Anlagen- und Reaktorsicherheit* mbH, TSO in Germany
HYMERES – Hydrogen Mitigation Experiments for Reactor Safety Project
IAGRNE – Inter-Agency Committee on Radiological and Nuclear Emergencies
IAEA – International Atomic Energy Agency
I&C – Instrumentation and control
ICRP – International Commission on Radiological Protection
IEA – International Energy Agency
INER – Institute of Nuclear Energy Research, Chinese Taipei
INEX – International nuclear emergency exercises
IRRS – Integrated Regulatory Review Service (IAEA)
IRSN – *L'Institut de radioprotection et de sûreté nucléaire*, TSO in France
ISOE – Information System on Occupational Exposure
JAEA – Japan Atomic Energy Agency
JNES – Japan Nuclear Energy Safety Organization, TSO in Japan
KAERI – Korea Atomic Energy Research Institute
KI – Potassium iodide
KIT – Karlsruhe Institute of Technology, Germany
LOCA – Loss-of-coolant accident
MDEP – Multinational Design Evaluation Programme
MTA-EK – Hungarian Academy of Sciences Centre for Energy Research
NDC – NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (“Nuclear Development Committee”)
NEA – Nuclear Energy Agency
NISA – Nuclear and Industrial Safety Agency, former regulator in Japan
NLC – NEA Nuclear Law Committee
NPCIL – Nuclear Power Corporation of India Limited, TSO in India
NPP – Nuclear power plant
NRC – Nuclear Regulatory Commission, regulator in the United States
NRG – Nuclear Research and Consultancy Group, the Netherlands
NSC – NEA Nuclear Science Committee
NUBIKI – *Nukleáris Biztonsági Kutatóintézet*, TSO in Hungary

OECD – Organisation for Economic Co-operation and Development
ONR – Office of Nuclear Regulation, regulator in the United Kingdom
PAR – Passive autocatalytic hydrogen recombiner
PCV – Primary containment vessel
PHWR – Pressurised heavy water reactor
PRG – CSNI Programme Review Group
PSA – Probabilistic safety assessment
PSI – Paul Scherrer Institute, Switzerland
PWR – Pressurised water reactor
R&D – Research and development
RPV – Reactor pressure vessel
SA – Severe accident
SAMGs – Severe accident management guidelines
SARNET – Severe Accident Research Network
SBO – Station blackout
SC – NEA Steering Committee for Nuclear Energy
SFP – Spent fuel pools
SSM – Swedish Radiation Safety Authority, regulator in Sweden
STC – NEA standing technical committee
STG-FUKU – Senior-level Task Group on Impacts of the Fukushima Accident (CNRA)
STUK – Säteilyturvakeskus, regulator in Finland
TGAM – Task Group on Accident Management (CNRA)
TSO – Technical support organisation
UHS – Ultimate heat sink
ÚJV – Ústav jaderného výzkumu Řež, a.s., TSO in the Czech Republic
UNIPI – University of Pisa, Italy
VTT – Valtion Teknillinen Tutkimuskeskus, TSO in Finland
WENRA – Western European Nuclear Regulators Association
WGAMA – Working Group on Analysis and Management of Accidents (CSNI)
WGFS – Working Group on Fuel Safety (CSNI)
WGHOF – Working Group on Human and Organisational Factors (CSNI)
WGIAGE – Working Group on Integrity of Components and Structures (CSNI)
WGIP – Working Group on Inspection Practices (CNRA)
WGPC – Working Group on Public Communication of Nuclear Regulatory Organisations (CNRA)
WGOE – Working Group on Operating Experience (CNRA)
WGRISK – Working Group on Risk Assessment (CSNI)

WGRNR – Working Group on the Regulation of New Reactors (CNRA)

WHO – World Health Organization

WMO – World Meteorological Organization

WPNEM – Working Party on Nuclear Emergency Matters (CRPPH)

OECD/NEA PUBLISHING, 2 rue André-Pascal, 75775 PARIS CEDEX 16