

Five Years after the Fukushima Daiichi Accident



Nuclear Safety Improvements and Lessons Learnt

Five Years after the Fukushima Daiichi Accident: Nuclear Safety Improvements and Lessons Learnt

Executive Summary

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Executive summary

Since the Fukushima Daiichi nuclear power plant accident, the principal NEA standing technical committees with responsibilities in the areas of regulatory oversight, nuclear safety, radiological protection and public health, and nuclear liability – the Committee on Nuclear Regulatory Activities (CNRA), the Committee on the Safety of Nuclear Installations (CSNI), the Committee on Radiation Protection and Public Health (CRPPH) and the Nuclear Law Committee (NLC) – have been closely co-ordinating their activities in these areas. As part of these efforts, a report entitled *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt* was published (NEA, 2013c), detailing the immediate response of the NEA and its member countries to the accident. Among the key findings, the 2013 report underlined that member countries had performed focused safety reviews of their operating reactors and had determined that they were safe to continue operations while more comprehensive safety reviews were conducted to identify work needed to further improve safety.

Five Years after the Fukushima Daiichi Accident: Nuclear Safety Improvements and Lessons Learnt provides an update on these activities and lessons learnt, including: i) activities undertaken by regulatory authorities in NEA member countries which have led to the establishment of new requirements resulting in specific nuclear power plant improvements in multiple areas; ii) activities to improve the regulatory framework in member countries; iii) research activities to acquire additional knowledge and understanding of the accident itself; iv) activities implemented to improve emergency preparedness and radiological protection; and v) legal improvements, including those in the area of liability law. The report focuses on actions taken by the NEA and its member countries, and as such, is complementary to reports produced by other international organisations, including the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO).



TEPCO, Japan.

Recent photo of the Fukushima Daiichi nuclear power plant.

Since the previous report, regulatory authorities in NEA member countries have performed diverse activities that have led to the establishment of new requirements. The potential impact of external hazards has been the focus of such requirements, as has plant improvements related to the diversity of equipment, enhancements in the robustness of safety functions and continuing efforts to improve organisational behaviours. Actions undertaken in these areas have led to: i) a re-examination of external hazards; ii) an improvement of the robustness of the electrical systems; iii) an enhancement of the robustness of the ultimate heat sink (UHS); iv) protection of the reactor containment system; v) protection of spent fuel in storage pools; vi) reinforced capability to rapidly provide diverse equipment and assistance from on-site or off-site emergency preparedness facilities; vii) a reinforcement of safety culture, including human and organisational factors in decision making during emergencies; and viii) continued safety research. Although the objective of enhancing safety is shared around the world, countries have addressed these issues with different approaches. Since national standards or safety requirements are country-specific and relate to specific threats and hazards in each country, member countries are not necessarily starting from the same point of departure. Some improvements have already been implemented, some are in the process of being completed and still others are being planned and will be implemented at nuclear power plants (NPPs) in the coming years. In several countries, governments have also taken action to reinforce the independence of their regulatory bodies.

Safety is a process that evolves as we learn through research and the evaluation of operating experience. As was the case with the Three Mile Island and Chernobyl accidents, the implementation of lessons learnt from the Fukushima Daiichi accident and the continuation of related research activities are long-term actions that will further develop into the future as regulators and the nuclear industry learn from the accident.

An important need identified by the NEA and its member countries was that of better developing and enhancing the approach taken to the evaluation and inclusion of external hazards in the safety analysis. It was generally concluded that there has traditionally been a more thorough and detailed inclusion and consideration of internal hazards in safety analyses and safety cases. As a consequence, member countries have re-examined the response of their NPPs to external hazards, including those of higher magnitude than have previously been considered, and have used the latest data technology to identify and consider plausible combinations of sequential and consequential events.

In many countries, the focus has remained on the robustness of electrical systems. As a result, NPPs in these countries are in the process of upgrading the capability of the existing direct current power sources as well as installing new, dedicated equipment to ensure redundant and diverse sources of alternating current electrical power, which would be available following a significant event. Measures have included new or improved fixed installations, as well as additional mobile power sources.

Ensuring that heat can be removed from the core in the event of an extreme natural event has led other countries to consider bunkered safety systems, designed to resist extreme natural events. Many countries have now installed or are considering strategic placement of portable equipment that can be quickly positioned and provide emergency cooling. Some countries have enhanced the decay heat removal function by providing an alternate path for cooling water supply, arranging for passive cooling or identifying an alternate heat sink.

The Fukushima Daiichi accident demonstrated that the ability of NPPs to maintain containment integrity could be challenged by severe natural hazards. In response, some NEA member countries have refocused their efforts on upgrading NPP abilities with respect to containment venting and hydrogen mitigation. In other countries, new or improved filtered vents or filtering strategies are being implemented or considered for use during venting to limit containment pressure. Some countries are introducing a different hydrogen mitigation strategy or improving the existing one. The ability to continuously cool the containment during beyond-design-basis events (also called design extension conditions) has been evaluated and modifications are being planned and implemented.

The ability of spent fuel pools (SFPs) to cool and protect spent nuclear fuel was also a challenge during the Fukushima Daiichi accident. Although no damage occurred to any of the SFPs or to the spent fuel at the Fukushima Daiichi nuclear power plant, NEA member countries have taken actions to

improve the protection of the SFPs in their countries. For example, protection of SFPs against external events has been reassessed in some countries, and has led to the installation of redundant SFP level and temperature indications, as well as diverse cooling water supplies.

Some countries have required that portable safety equipment be stored in a protected manner at the site, to provide redundancy and diversity of equipment during a significant event. Another approach implemented in countries is to establish off-site equipment storage facilities, which can transport various types of equipment to a facility within hours or days of an event. These facilities can provide a full range of equipment in an emergency, including portable electrical generators, pumps, hoses, ventilation equipment, diesel fuel storage and transport vehicles, as well as fire trucks. The facilities are located far enough away from the existing NPP that a natural disaster at the NPP would not affect the off-site facility.

Several NEA member countries have adopted a broad consideration of safety culture characteristics, including human and organisational factors, which include specific safety culture programmes that focus on attitudes towards safety, organisational capability, decision-making processes and the commitment to learn from experience.

The Fukushima Daiichi accident clearly illustrated the **challenges that operations and emergency response staff can face** when dealing with a major nuclear accident, thus emphasising **the importance of reliable human performance under extreme conditions.**

Following implementation of actions resulting from reviews and self-assessments, member countries have found that, in general, nuclear safety, emergency preparedness and response arrangements have improved. They have also acknowledged that more remains to be done.

National safety frameworks are being further improved with steps taken to establish or reinforce the effective independence of regulatory bodies and to update regulations. International co-operation is also increasing with greater participation in peer

reviews and exchanges of information. These actions are reinforcing the global characteristics of nuclear safety, and international collaboration is growing as a result.

While many activities and improvements are in progress, it must be noted that the safety improvements being made at nuclear power plants as a result of the Fukushima Daiichi accident are part of a long-term effort that will continue to evolve as countries continue to share information and learning.

In addition to what has been carried out directly by member countries, this report presents the high-priority follow-on items that NEA committees identified to assist countries in benchmarking and continuously improving their nuclear safety practices.

The CNRA, for example, has considered relevant topics and reached consensus on a variety of reports and documents providing best practices and guidance in the areas of accident management, crisis communication, precursor events, defence in depth (DiD), regulatory effectiveness, safety culture and the regulation of new reactors. Such guidance and best practices are designed for countries with existing, mature regulators and can be used for improving policies and practices, benchmarking and training staff. They can also be useful for new entrant countries in the process of developing and maintaining an effective nuclear safety regulator.

The NEA regulatory guidance booklet on *Implementation of Defence in Depth at Nuclear Power Plants: Lessons Learnt from the Fukushima Daiichi Accident* examines and provides advice on the implementation of DiD. A key observation is that the use of the DiD concept remains valid after the Fukushima Daiichi accident. Indeed, lessons learnt from the accident, and the accident's impact on the use of DiD, have reinforced the fundamental importance of DiD in ensuring adequate safety.

In follow-up to the Fukushima Daiichi accident and in agreement with the CNRA, the CSNI decided to launch several high-priority activities. Topics were selected on the basis of high safety significance, where more detailed technical information and common approaches were needed. The approach taken was to attempt to clarify the status of implementation, discuss national requirements, consider the advantages and disadvantages of different options, identify potential room for improvement from

an accident management perspective and determine overall strategies going forward. Topics covered include probabilistic safety assessment (PSA) for external events, filtered containment venting, hydrogen management, spent fuel pools, fission product release, human performance, electrical systems and components under seismic load.

The CSNI also launched a series of joint safety research projects in support of accident analysis and management to conduct benchmark studies of the Fukushima Daiichi accident, and to investigate technical phenomena such as hydrogen behaviour, containment response and system thermal-hydraulics under beyond-design-basis accident conditions.

The CRPPH, for its part, has been actively involved in the improvement of many aspects of international and national emergency management preparation and implementation. Two reports were published on the post-accident management of food from affected areas, including the presentation of a framework for national and international food management, and an overview of the framework's impact on international food trade. The committee has continued to work on approaches to and lessons from stakeholder involvement, in particular with the International Commission on Radiological Protection (ICRP). Lessons from the Japanese experience that are applicable internationally have been gathered by the CRPPH and will be used to guide further work in this important area. The CRPPH has also developed a detailed report on the state of the art in radiological protection science, and another report on the management of occupational exposure in the event of severe accidents.

The NEA Nuclear Law Committee (NLC) has been examining the Fukushima Daiichi accident from a legal perspective. Its activities have focused on the legal framework established in Japan to compensate victims of nuclear accidents (i.e. the nuclear liability scheme) and its implementation with regard to the victims of the Fukushima Daiichi accident, in order to draw lessons for the benefit of the larger international community. A report was published in 2012 entitled *Japan's Compensation System for Nuclear Damage: As Related to the TEPCO Fukushima Daiichi Nuclear Accident*, and an update of this report is under preparation.

Research and development efforts to date have already significantly enhanced the understanding of phenomena in relation to the Fukushima Daiichi accident. Many NEA member countries are involved in two key research projects: the **NEA Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant (BSAF)** and the **NEA Senior Expert Group on Safety Research Opportunities Post-Fukushima (SAREF)**.

Conclusions from the report

Continuing enhancement of safety

Since the publication of *The Fukushima Daiichi Nuclear Power Plant Accident: OECD/NEA Nuclear Safety Response and Lessons Learnt* (NEA, 2013c), member countries have continued to seek lessons from the accident at the Fukushima Daiichi NPP. The report examined prompt actions and analyses at national levels, as well as international engagement to ensure safety. NEA member countries have continued to take appropriate actions to maintain and enhance the level of safety at their nuclear facilities, and thus nuclear power plants are safer now because of actions taken since the accident.

Ensuring safety is a continual process, which evolves as we learn through operating experience and research. Safety is the prime responsibility of the operator, with the regulator's goal to ensure that operators continuously improve and make NPPs safer. The continued operation of nuclear power plants requires that their robustness to extreme situations be reinforced beyond-design-basis safety margins, and many of these improvements have been implemented or are in the process of being implemented. While an external event (an earthquake-induced tsunami) caused the Fukushima Daiichi accident, the actions that have been taken around the world to make NPPs safer are applicable to any type of event, man-induced or naturally occurring.

Effective implementation of safety improvements

While NEA member countries have been able to discuss the same lessons learnt from the Fukushima Daiichi accident and the outcomes sought are very similar, there are nonetheless different avenues being taken to achieve the goal of enhancing safety, and preventing and mitigating potential accidents.

Unique natural conditions exist in member countries, in particular with regard to potentially extreme natural events; different national regulatory requirements, for example, for the prevention and mitigation of severe accidents; various approaches to and applications of periodic safety reviews in order to continuously improve safety; and different types and generations of NPPs. Since national standards or safety requirements, as well as those safety measures actually implemented, are country-specific and reflect operating experience from the particular country or regulatory practices within the country, member countries are not necessarily starting from the same point of departure. Differences in the priorities and implementation of schedules for safety improvements exist among member countries.

Using operating experience and risk insights

Lessons learnt concerning operating experience have been disseminated internationally, particularly in relation to the main initiators and conditions that have been observed during the Fukushima Daiichi accident. The accident did not reveal any unknown initiators, sequences or consequences. However, the combination and the severity of initiating events had never occurred before, and the evolution of the accident in three different units simultaneously was also new.

The accident at the Fukushima Daiichi site demonstrated that while existing operating experience feedback systems provide a good tool to provide lessons learnt and help prevent the recurrence of events, operating experience combined with risk insights can provide an even greater source of potential improvement as demonstrated in the course of real events.

The timely implementation of NPP operating experience is a continuous challenge for both regulators and operators. The challenge is to identify precursor events and the subsequent lessons learnt, and then to implement the related actions to enhance plant safety and prevent recurrence.

The **NEA Working Group on Operating Experience** has found that more efforts are needed to ensure timely and full implementation of lessons learnt from precursor events. It has also found that combining the use of risk insights with operating experience may drive plant changes that would effectively reduce risk.

Strengthening regulatory frameworks

National safety frameworks have been and are being further strengthened to enhance governmental frameworks and update regulations, including through reinforcing the independence of regulatory bodies. The principle of regulatory independence, in particular the effective separation between the functions of the regulatory body and those of any other body or organisation concerned with the promotion or use of nuclear energy, is fundamental and requires vigilance to ensure it is maintained.

Some member countries have reviewed, and other member countries are in the process of reviewing, their regulatory frameworks and are making changes as appropriate to update their legislation so as to reflect lessons learnt from the Fukushima Daiichi accident. One example is the emphasis on ensuring that a clear and comprehensive legal framework exists to allow the operator of a nuclear installation – and its government, if necessary – to quickly react and adapt to the specific circumstances of an event in order to ensure timely and financially adequate compensation to victims.

Much has been done by member countries in benchmarking and continuously improving their nuclear safety frameworks and regulations: this has included activities on accident management, crisis communication, precursor events, defence in depth, regulatory effectiveness, safety culture and regulation of new reactors. International co-operation is also increasing with greater participation in benchmarking of effective regulatory practices and exchanges of information.

A long-term learning process supported by safety research

As was the case with the Three Mile Island and Chernobyl accidents, implementation of lessons learnt from the Fukushima Daiichi accident and the continuation of related research activities are long-term actions that will evolve into the future as regulators and the nuclear industry continue to learn from the accident.

While near-term, higher priority lessons learnt are currently being addressed, our knowledge will expand as the Fukushima Daiichi units are decommissioned. Efforts such as the NEA Senior Expert Group on Safety Research Opportunities Post-Fukushima (SAREF) and the NEA Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Station (BSAF) have already provided invaluable insights concerning severe accident progression and the current status of reactors in all three units that experienced core melt. Research continues into accident progression, recovery and the human factors involved in severe accident response. Important information is emerging from post-accident recovery efforts at the Fukushima Daiichi nuclear power plant.

The human element as an essential aspect of safety

Human and organisational factors and safety culture are essential to all aspects of nuclear safety, from design, construction and operation to the response to potential events or accidents. Both licensees and regulatory bodies identified these as relevant issues to be addressed in the post-Fukushima Daiichi accident assessment. The human element has a considerable impact on all levels of the defence-in-depth concept.

Work carried out by the NEA and its member countries on both the characteristics of an effective nuclear regulator and on regulatory safety culture have been recommended for benchmarking, peer review, and for training and development of regulatory staff.

Several NEA member countries have initiated a broad consideration of safety culture characteristics, including human and organisational factors. These initiatives include specific safety culture programmes that focus on attitudes towards safety, organisational capability, decision-making processes and the commitment to learn from experience. Going forward, the NEA and its member countries recognise that nuclear safety will benefit from continuing work in areas such as safety culture, and human and organisational factors.

Although the **prime responsibility for the safety of a nuclear installation** is with the licensee or plant operator, the regulatory body itself has an important responsibility in ensuring the safety of nuclear installations. The NEA guidance booklet on *The Safety Culture of an Effective Nuclear Regulatory Body* identifies five principles that support the safety culture of an effective nuclear regulatory body. These principles concern leadership for safety, individual responsibility and accountability, co-operation and open communication, a holistic approach, and continuous improvement, learning and self-assessment.

Emergency management and the long-term commitment of resources

The accident at the Fukushima Daiichi site demonstrated the challenges involved when managing the consequences of a large-scale accident. As time progressed, radiological and social consequences became increasingly evident, while decisional responsibilities were shifting from central government to regional and local governments, and to affected individuals. Approaches to address the complexity generated by such long-lasting circumstances needs to be considered and included in national planning.

Moreover, the resources needed to manage an emergency on the scale of the accident at the Fukushima Daiichi nuclear power plant have proven to be considerable. Non-accident countries, even those not directly affected, expended significant resources on understanding the rapidly evolving situation so as to support recommendations on how to best protect expatriate populations in Japan, to address issues of people and cargo arriving from Japan and to manage food emanating from Japan. The Japanese government was challenged by the need to expend significant resources to address the accident situation, and simultaneously dedicate resources to formally and informally address

questions from other countries and from international organisations. Emergency management planning should thus take into account the Japanese experience in terms of the training and resources required to be appropriately prepared to manage the collection and flow of information.

Enhancing stakeholder involvement and public communication

Involvement of stakeholders (local authorities, industry, non-governmental organisations, government officials and the public) in decision making is appropriate and advisable to enhance the credibility, legitimacy, sustainability and final quality of regulatory and off-site emergency management decisions. In addition, proactive outreach to stakeholders in regular communications (i.e. in non-accident situations) is highly desirable to improve their understanding in times of crisis.

Some member countries have further developed their policies on transparency, openness and involvement of stakeholders in the regulatory process, providing a window into the regulatory decision-making process. Different country-specific practices and regulatory requirements reflect more general practices within each individual country.

Experience during the Fukushima Daiichi NPP accident highlighted the need to reconsider approaches to information sharing and assessment, both domestically and internationally. The experience reaffirmed that regulators and governments should be effectively communicating with their stakeholders to ensure that all aspects of safety in relation to nuclear facilities are understood. To achieve this goal, regulators need to continue improving their communication strategies, as well as the implementation of such strategies.

International co-operation as a key factor in continuous safety enhancement

International co-operation provides a forum for regulators to work together to share and analyse data and experiences, gain consensus and develop approaches that can be applied within each country's regulatory process. International co-operation also provides a platform for peer regulators to encourage vigilance in ensuring NPP safety and avoiding the complacency that contributed to the accident at Fukushima Daiichi. Regulatory authorities from NEA member countries are working together internationally to share information and actions taken in order to improve their regulatory frameworks and NPP safety. The NEA provides an effective forum for co-operation on both medium- and longer-term issues in its specific task groups, working parties and expert groups, as well as through joint international safety research projects.

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Five Years after the Fukushima Daiichi Accident: Nuclear Safety Improvements and Lessons Learnt

Countries around the world continue to implement safety improvements and corrective actions based on lessons learnt from the 11 March 2011 accident at the Fukushima Daiichi nuclear power plant. This report provides a high-level summary and update on these activities, and outlines further lessons learnt and challenges identified for future consideration. It focuses on actions taken by NEA committees and NEA member countries, and as such is complementary to reports produced by other international organisations.

It is in a spirit of openness and transparency that NEA member countries share this information to illustrate that appropriate actions are being taken to maintain and enhance the level of safety at their nuclear facilities. Nuclear power plants are safer today because of these actions. High-priority follow-on items identified by NEA committees are provided to assist countries in continuously benchmarking and improving their nuclear safety practices.