# ONE YEAR AFTER FUKUSHIMA: LESSONS FOR A SAFER NUCLEAR ENERGY

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## Introduction

The accident at Fukushima Daiichi was a wake-up call for many. It reminded that nuclear accidents can happen, they do happen. Our common goal, in the Agency as well as in the wider international community, is that nuclear accidents become less and less likely. Our goal is also that, would an accident happen, all measures for minimizing its consequences would be available, exercised, effective.

Every nuclear incident carries its lessons. These allow for a continuous strengthening of nuclear safety. Unfortunately, the most profound structural or cultural changes need exceptional events to make their way into our minds, into our culture, and into everyday implementation.

On 11 March 2011 a huge earthquake and tsunami left more than 20,000 people dead or missing in eastern Japan. Amidst widespread destruction, the tsunami slammed into Fukushima Daiichi nuclear power plant, disabling cooling systems and leading to fuel meltdowns in three of the six units.

The accident was a jolt to the nuclear industry, regulators and governments. It was triggered by a massive force of nature, but it was existing weaknesses regarding defence against natural hazards, regulatory oversight, accident management and emergency response that allowed it to unfold as it did.

The IAEA responded to the accident by activating its Incident and Emergency Centre and by organizing specialized expert missions to Japan to gain an understanding of the accident and to provide assistance and expert advice. The Ministerial Conference on Nuclear Safety organised by the IAEA in Vienna in June 2011 adopted a Ministerial Declaration which requested the Director General, inter alia, to prepare a draft IAEA Action Plan on Nuclear Safety.

## The IAEA Nuclear Safety Action Plan

Fukushima confirmed that nuclear accidents do not respect borders. The atmospheric releases were detected in both hemispheres. This is a clear demonstration that the primary responsibility of operators and States, enshrined in IAEA safety standards, must be backed by an international approach to safety.

This lesson and the IAEA mandate were the basis for the actions of the Agency during the crisis, leading to the launch of the ambitious Action Plan on Nuclear Safety which was adopted unanimously by our 151 Member States on 22 September 2011. This is the first time in the life of the Agency that all Member States gather, in a comprehensive program, all nuclear safety tools to strengthen the global nuclear safety framework at the national, regional and international levels

This plan requests inter alia the Secretariat to "…organize international experts meetings to analyse all relevant technical aspects and learn the lessons from the Fukushima Daiichi nuclear power station accident". My aim today is to convey some of the lessons that we have learned in the Agency in the 12 months since the accident and address the significant achievements made under the Action Plan to improve nuclear safety worldwide. These lessons, and our achievements, are those of the Agency as a whole, gathering all competencies from the relevant Departments: from the Nuclear Safety and Security Department, but also from the Departments of Nuclear Energy and of Nuclear Sciences and Applications.

**Lessons learned from the accident at Fukushima**

What we have learned first and foremost is that there is a need for a global nuclear safety framework. There is a need to implement effectively the safety standards that are developed in the agency and which provide the basis for a high level of safety. What we have learned also is that nuclear regulators must be strong, they must be independent. We have learned at the same time that it is working together, at the global level, that can help strengthen safety in a continuous way.

The major underlying causes of the Fukushima Daiichi accident have been considered by many national and international organisations over the last 12 months. The outcome of these deliberations has shown that there are a number of common themes emerging. Based on the knowledge obtained up to now, I have grouped the lessons into the following four themes: the regulatory framework, site specific nuclear power plant design vulnerabilities to extreme events, the management of severe accidents, and emergency preparedness and response.

**The Regulatory Framework**

A fundamental prerequisite for an effective nuclear safety regulatory regime is a sound legislative and statutory framework that provides for the effective independence of the regulatory body. The regulatory body should also be effectively separated from the activities associated with the promotion of nuclear energy and should have the necessary authority, competence and resources to discharge its regulatory mandate.

The post-accident reviews raised concerns over the lack of effective independence of the regulatory body that in turn contributed to an insufficiently robust oversight of the operating organisation.

In response to these concerns, some Member States, where such weaknesses had been identified, have already accelerated the implementation of the formal separation of promotion of nuclear energy from the oversight of nuclear installations. This is the case for example for Japan and the Republic of Korea.

A new regulatory system in Japan is being introduced this year, taking into account the separation of regulation and promotion, unifying national regulatory functions, improving crisis management, transparency and training and formulating and updating new regulations and standards. The IAEA provided advice and discussed how Japan could improve and implement its new nuclear safety regulation system.

There was insufficient clarity of roles in the nuclear regulatory framework. An example is the conflicting role of NISA as the regulatory body and of NSC in producing safety guides.

The regulatory requirements in Japan for design and severe accident management were not consistent with the IAEA Safety Standards. The Regulatory Body should focus its efforts on formulating and updating regulatory guidelines and standards, taking into account the latest applicable knowledge. For this purpose, it is essential to ensure sufficient organizational and competence capabilities of regulatory bodies.

The “Intelligent Customer”, regulator and operator alike, should be able to grasp the available relevant scientific knowledge, and apply it in a manner consistent with the IAEA Safety Standards. Fukushima Daiichi accident again demonstrated the crucial truth that a good anchorage of nuclear safety on a sound scientific ground is essential to ensure safety, to draw lessons from the accident, and to build stronger response capabilities.

There was insufficient safety culture within the regulatory body and the operating organization to acknowledge critical safety problems and related international developments and experience. Regulators should ensure that any actions by the licensees that are needed for regulatory decisions are documented and are subjected to follow-up inspection and verification by the licensees and the regulators. Such actions should be mandatory and not rely on a voluntary implementation by the operator.

In October last year, the IAEA has shared with Member States the experience of six years of regulatory peer reviews, highlighting the key lessons learned for an effective regulatory framework. A report on this experience has been prepared and shared with Member States. The Secretariat has also strengthened the Integrated Regulatory Review Service programme to include a more systematic and comprehensive assessment of national regulations and guidance against the IAEA Safety Standards. A specific Fukushima module was incorporated into the scope of IRRS missions to take account of the initial regulatory implications of the accident. These updates are being applied in all IRRS missions as of January 2012. In addition, an international conference on effective regulatory systems will be organised in April 2013 in Canada.

**Site specific design vulnerabilities related to extreme natural hazards**

The initiator for the Fukushima accident was a seismic event of extreme magnitude, the Great East Japan Earthquake, which generated a tsunami beyond the design basis for the Fukushima Daiichi nuclear power plant. In the light of the accident the design basis for a nuclear power plant can no longer be taken for granted. There is a real possibility of occurrence of very large natural events, as a result of an unusual, but credible, combination of smaller events. This was the sequence of events that caused the Great East Japan Earthquake, a sequential rupture of successive fault segments resulting in the massive release of seismic energy.

When the existing nuclear power plants were first designed, tectonic science was in its infancy. The Fukushima accident suggests that sites should be characterized not just by their seismic history or by assuming the most extreme hazards foreseeable, but also by the insights that can be gained from modern tectonics and seismic data bases on a continental scale. Furthermore an investigation of past extreme events for Japan highlights the 896 Jogan earthquake and tsunami. Had a “paleo” investigation been conducted, a different site specific hazard spectrum for Fukushima might have been derived. Thus “paleo” studies of external events should be seriously pursued as a course of investigation in site specific hazard assessments, as requested by the IAEA safety standards.

The IAEA fact finding mission in May 2011 found that:

*“The underestimation of the hazard in the original hazard study for Fukushima NPP, as well as in more recent re-evaluations mainly result from the use of [only] recent historical seismological data in the estimation of the maximum magnitudes”.*

*“[However], Japan has a high level of expertise and experience regarding tsunami hazard and provides leadership in this topic worldwide, and Japanese academic, scientific and technical institutions have a major influence on the international research and development of this topic”.*

These two findings, put together, raise the issue of the close relation that should exist between science, safety assessment, and safety regulation. In the case of Fukushima, it seems that organizational issues have prevented this expertise to be applied to safety regulation.

The accident has raised questions on the level of consideration given to specific safety issues for extreme events, in particular the preparedness for large tsunamis. External events can occur in combination, seismic and coincident massive floods from torrential rains, large dam breaks or tsunamis. These could trigger enduring combined consequences for nuclear power plants such as prolonged station blackout and prolonged total loss of heat sink. These may be compounded by human error and loss of further accident management capability.

Extreme flood conditions have shown that the height of key safety equipment may not be sufficient and hence their protection from flood may have to be made more robust. At Fukushima Daiichi, the plant layout did not provide the appropriate levels of protection for critical safety systems when taking into account the site characteristics. In addition there was a failure to ensure necessary power supplies were able to provide on-going support to key safety functions, including providing the capability for cooling the reactor and spent fuel, for several days.

The current approach to nuclear plant safety for the protection against external natural hazards uses the ‘dry site’ concept where a site remains dry through all the scenarios considered in safety assessment. Site inundation was one of the key drivers in disabling components that could have prevented the rapid degradation of the plant safety functions. Thus as a defence in depth measure, future plant safety assessments should consider scenarios where site flooding is a condition under which severe accident scenarios are enacted. For future plant designs, redundancy could include location at different elevations in the plant layout, instead of in different sectors at the same level, to avoid common cause failure from flooding.

In order for plant operators to face total prolonged station blackout conditions, new “last recourse equipment” such as considerably larger battery capacity, protected air cooled diesels, portable diesel driven pump and heat sink skids, and protected additional water inventories may have to be available.

It was also apparent that there was a lack of reliable essential instrumentation for safety related parameters during the accident. As an example, the reactor temperature and coolant level instrumentation systems installed to provide information following a severe accident failed to meets the operators’ needs during accident and recovery phases. There is a need for updated principles for accident monitoring instrumentation, as a basis for developing national and international standards.

Common cause effects that have been addressed up to now in safety assessments are generally limited only to single nuclear power plant units. However many nuclear power sites have multiple units. Failures from common causes that affect more than one unit, such as that at Fukushima, should be considered. We need to develop a methodology to assess safety margins of multi-unit sites against a common hazard or a combination of hazards.

It is necessary to examine the robustness of Nuclear Power Plants. This means more attention to defence in depth, consideration of low probability, beyond design-basis accidents, consideration of combination of events and common cause failures such as extended loss of ultimate heat sink and loss of essential power supply, and severe accident management issues for multi-unit sites, along with consideration of the safety of spent fuel storage.

The effectiveness of safety improvements by implementation of the upgrades aimed to increase safety margin against seismic and tsunami hazards should be checked by conducting Seismic and Tsunami Probabilistic Safety Assessment using methodologies consistent with IAEA Safety Standards and international practice.

National reviews of the safety of nuclear power plants have been carried out to identify lessons learned from the accident and potential safety improvements. These reviews were carried out by operators to reassess the safety margins of nuclear power plants and reviewed by the national regulators to identify areas that need particular attention in the light of the Fukushima accident.

In response to these lessons and to the action plan, the IAEA has developed a methodology for assessing the safety vulnerabilities of a nuclear power plant, based on the IAEA Safety Standards, and made it available to Member States. An IAEA international expert mission was conducted in Japan from 23 to 31 January 2012 to review Japan's approach for assessing safety at the nation's nuclear power plants.

**The Management of Severe Accidents**

Management of extreme events must involve a switchover from normal operation to an emergency command and control structure with clear leadership and interface requirements well defined at all levels. They should allow for prompt operational decisions, from the field staff to the control room, to internal and external technical support, to corporate emergency structures and to designated government officials.

Severe Accident Management Guides are designed to prevent or mitigate releases, when core damage has occurred, with the aim of returning the core to a controlled, stable state, to maintain or return the containment to a controlled, stable state, and to terminate any fission product release from the plant. In addition Severe Accident Management Guides aim to minimize fission product releases and maximize equipment and monitoring capabilities while achieving the above goals.

At Fukushima Daiichi there was a lack of specific countermeasures to alleviate the severe accident consequences by preparing the plant to respond without significant damage, and there appeared to be inadequate mitigation measures, in particular for preventing hydrogen explosions and assuring operability of the containment venting system, as well as inadequate training and exercises on severe accidents.

In the light of these shortcomings, Severe Accident Management Guides must be enhanced to deal with extreme events in the presence of severely damaged infrastructure. They should assume prolonged mission time of new beyond-design emergency equipment to cover prolonged station blackout and total absence of cooling water inventory. Severe Accident Management Guides for essential personnel in the plant should be integrated with external technical support organizations. They should also cover beyond design basis accidents not only in the reactor, but also in the spent fuel pool, and hydrogen build-up, explosions prevention and mitigation, protective actions of the ground waters against basemat melt-through.

In response to these issues, the IAEA peer review services such as the Operational Safety Review Team and Design Safety Reviews have incorporated the topic of severe accident management programmes, including their comprehensiveness and consistency, regulatory requirements and staff training.

### Emergency Preparedness and Response

Emergency planning and preparedness cannot be left to individual initiatives but must be governed by stringent well-rehearsed legal requirements, involving all relevant stakeholders, support organizations and the Government. Effective emergency response requires appropriate international framework and efficient national emergency management systems that are built on international standards and guidelines.

Universal implementation of the IAEA Safety Standards on emergency preparedness and response at the national level is crucial. It improves preparedness and response, facilitates communication in an emergency and contributes to the harmonization of national criteria for protective actions. Currently Member States are using different - non harmonised - criteria for implementing protective actions and not all Member States have established arrangements for requesting and receiving international assistance.

In addition there is a need for a review of appropriate contingency planning and capacity building in emergency preparedness and response for the impact on food, agriculture, fisheries and forestry to improve quality and comparability of measurement data obtained for environmental samples.

With regard to the implementation of the national emergency preparedness and response arrangements during the Fukushima accident, there appeared to be a lack of clear allocation of responsibilities across the management structures of the operator, the regulator, and the government at central and local levels. In addition there was insufficient communication at local, national and international levels and lack of response to offers of assistance from other countries together with under-utilization of the existing international assistance mechanisms.

At the international level, the Inter-Agency Committee on Radiological and Nuclear Emergencies (IACRNE) and its Joint Radiation Emergency Management Plan of the International Organizations (JPLAN) proved its effectiveness. The inter-agency mechanism for coordination of response in case of severe nuclear or radiological emergency worked in a comprehensive manner, with the IAEA having a central coordinating role. A consistent “one voice message” between international organizations was achieved and proved to have positive impact on public understanding.

However, communication strategies should be strengthened to facilitate national, regional and international coordination and the dissemination of information, including to the agriculture, fisheries and forestry communities.

IAEA’s formal role in sharing of information, as resulted from decisions taken in the wake of the Chernobyl accident, was largely limited to distributing information validated by the State concerned. In an era of instant communication, the Fukushima accident demonstrated the need for a stronger role of the IAEA to meet the expectations of Member States and the Public. The accident demonstrated also the overall importance of the IAEA’s role in response to nuclear emergencies, and the vital need to maintain and further strengthen the IAEA’s Incident and Emergency System, including improvements to the IAEA capability to undertake field missions for environmental sampling and rapid surveys upon request.

The accident showed that the effective implementation of the post Chernobyl Emergency Notification and Assistance Conventions is essential. Expectations and demands of Member

States demonstrated also that an integrated, global, world-wide emergency radiation monitoring display system would be beneficial.

The Incident and Emergency Centre proved to work well overall, demonstrating that the IAEA can respond efficiently around the clock for protracted periods of time. The main issues identified were a need for more staff trained to support operations during long duty periods, to allow performing normal office duties at the same time. Information flow providing prompt, factual, transparent and continuous information was not always adequate.

Experience gained in response to Fukushima accident provides valuable input for enhancing and harmonizing the emergency preparedness and response framework at all levels: facility, local, national, regional and international.

**CONCLUSIONS**

In the first 12 months since the accident at the Fukushima Daiichi nuclear power plant, some lessons have already emerged and have been acted upon, while further lessons still need to be learned.

I have addressed only part of the lessons already learned from the Fukushima Daiichi accident. We recognized that the process will be a long one, but most actors of nuclear energy have acted promptly to draw these lessons, and to strengthen nuclear safety. The IAEA nuclear safety action plan will serve as the thread on this path.

Quite often, I am asked how we can reconcile the terms of the statute of the IAEA: promoting nuclear energy and ensuring safety. The answer is that for those States that decide to use nuclear energy, our job is to help them do it in a safe, secure and sustainable way. Our job is to develop and make available standards and guides whose implementation will allow considering accidents as a remote possibility. Our job is not to forget this remote possibility, but develop and promote standards for preparing and exercising towards this remote possibility.

If the knowledge that such an accident could happen had been available, then the height of the wall to prevent against Tsunami might have been higher. There could have been also water tight doors which would have prevented flooding of the buildings. The diesel generators might have been higher on the hill so that they would not be drowned by the tsunami and, most important also, measures to manage a severe accident would have been foreseen and the staff trained for such a severe accident.

The purpose of the IAEA Action Plan on Nuclear Safety is to define a programme of work to strengthen the global nuclear safety framework. Prompt implementation of the Action Plan by the Secretariat, Member States and other stakeholders will maximise the benefits of the lessons learned from the accident.