The Fukushima Daiichi Accident

Report by the Director General and Technical Volumes

IAEA
International Atomic Energy Agency

“There can be no grounds for complacency about nuclear safety in any country...Safety must always come first...”

“This report is intended to serve as a key reference document on the accident for years to come...”

Yukiya Amano
Director General

This Report presents an assessment of the causes and consequences of the accident at the Fukushima Daiichi nuclear power plant in Japan, which began on 11 March 2011. Caused by a huge tsunami that followed a massive earthquake, it was the worst accident at a nuclear plant since the Chernobyl disaster in 1986.

The Report considers human, organizational and technical factors, and aims to provide an understanding of what happened, and why, so that the necessary lessons learned can be acted upon by governments, regulators and nuclear power plant operators throughout the world. Measures taken in response to the accident, both in Japan and internationally, are also examined.

The immense human impact of the Fukushima Daiichi accident should not be forgotten. More than 100 000 people were evacuated because of the release of radionuclides to the environment. At the time of writing, in 2015, many of them were still unable to return to their homes.

I visited the Fukushima Daiichi plant a few months after the accident and saw for myself the powerful and destructive impact of the tsunami. It was a shocking and sobering experience.

But I was deeply impressed by the courage and dedication of those workers and managers who remained at their posts after the tsunami struck and who struggled, in appalling conditions, to bring the stricken reactors under control. They had to improvise a response in circumstances for which they had not been trained, often lacking appropriate equipment. They deserve our respect and admiration.

A major factor that contributed to the accident was the widespread assumption in Japan that its nuclear power plants were so safe that an accident of this magnitude was simply unthinkable. This assumption was accepted by nuclear plant operators and was not challenged by regulators or by the Government. As a result, Japan was not sufficiently prepared for a severe nuclear accident in March 2011.

The Fukushima Daiichi accident exposed certain weaknesses in Japan’s regulatory framework. Responsibilities were divided among a number of bodies, and it was not always clear where authority lay.

There were also certain weaknesses in plant design, in emergency preparedness and response arrangements and in planning for the management of a severe accident. There was an assumption that there would never be a loss of all electrical power at a nuclear power plant for more than a short period. The possibility of several reactors at the same facility suffering a crisis at the same time was not considered. And insufficient provision was made for the possibility of a nuclear accident occurring at the same time as a major natural disaster.

Since the accident, Japan has reformed its regulatory system to better meet international standards. It gave regulators clearer responsibilities and greater authority. The new regulatory framework will be reviewed by international experts through an IAEA Integrated Regulatory Review Service mission. Emergency preparedness and response arrangements have also been strengthened.

Other countries responded to the accident with measures that included carrying out ‘stress tests’ to reassess the design of nuclear power plants against site specific extreme

MESSAGE FROM THE DIRECTOR GENERAL

natural hazards, installing additional backup sources of electrical power and supplies of water, and strengthening the protection of plants against extreme external events.

Although nuclear safety remains the responsibility of each individual country, nuclear accidents can transcend national borders. The Fukushima Daiichi accident underlined the vital importance of effective international cooperation. The IAEA is where most of that cooperation takes place. Our Member States adopted the IAEA Action Plan on Nuclear Safety a few months after the accident and have been implementing its far reaching provisions to improve global nuclear safety.

The IAEA, which provided technical support and expertise to Japan after the accident and shared information about the unfolding crisis with the world, has reviewed and improved its own arrangements for responding to a nuclear emergency. Our role during a nuclear emergency has been expanded to include providing analysis of its potential consequences and presenting possible scenarios on how a crisis could develop.

IAEA safety standards embody an international consensus on what constitutes a high level of safety. They were reviewed after the accident by the Commission on Safety Standards. A few amendments were proposed and adopted. I encourage all countries to fully implement IAEA safety standards.

IAEA peer reviews have a key role to play in global nuclear safety, enabling countries to benefit from the independent insights of leading international experts, based on the common reference frame of the IAEA safety standards. They address issues such as operational safety at nuclear power plants, the effectiveness of nuclear regulators and the design of nuclear power plant sites against specific hazards. We have strengthened our peer review programme since the accident and will continue to do so.

I am confident that the legacy of the Fukushima Daiichi accident will be a sharper focus on nuclear safety everywhere. I have seen improvements in safety measures and procedures in every nuclear power plant that I have visited. There is widespread recognition that everything humanly possible must be done to ensure that no such accident ever happens again. This is all the more essential as global use of nuclear power is likely to continue to grow in the coming decades.

There can be no grounds for complacency about nuclear safety in any country. Some of the factors that contributed to the Fukushima Daiichi accident were not unique to Japan. Continuous questioning and openness to learning from experience are key to safety culture and are essential for everyone involved in nuclear power. Safety must always come first.

I express my gratitude to the experts from many countries and international organizations who contributed to this Report, and to my colleagues at the IAEA who drafted and reviewed it. I hope that the Report, and the accompanying Technical Volumes, will prove valuable to all countries that use, or plan to use, nuclear power in their continuous efforts to improve safety.

DEPUTY DIRECTOR GENERAL

"Strengthening nuclear safety since the accident has been a top priority of the IAEA and since the adoption of the Action Plan on Nuclear Safety in 2011, much progress has made in this regard. The Report by the Director General and the five technical volumes distil and assemble lessons learned from the Fukushima Daiichi accident, to provide a knowledge base for the future."

Denis Flory
Deputy Director General
Head of the Department of
Nuclear Safety and Security

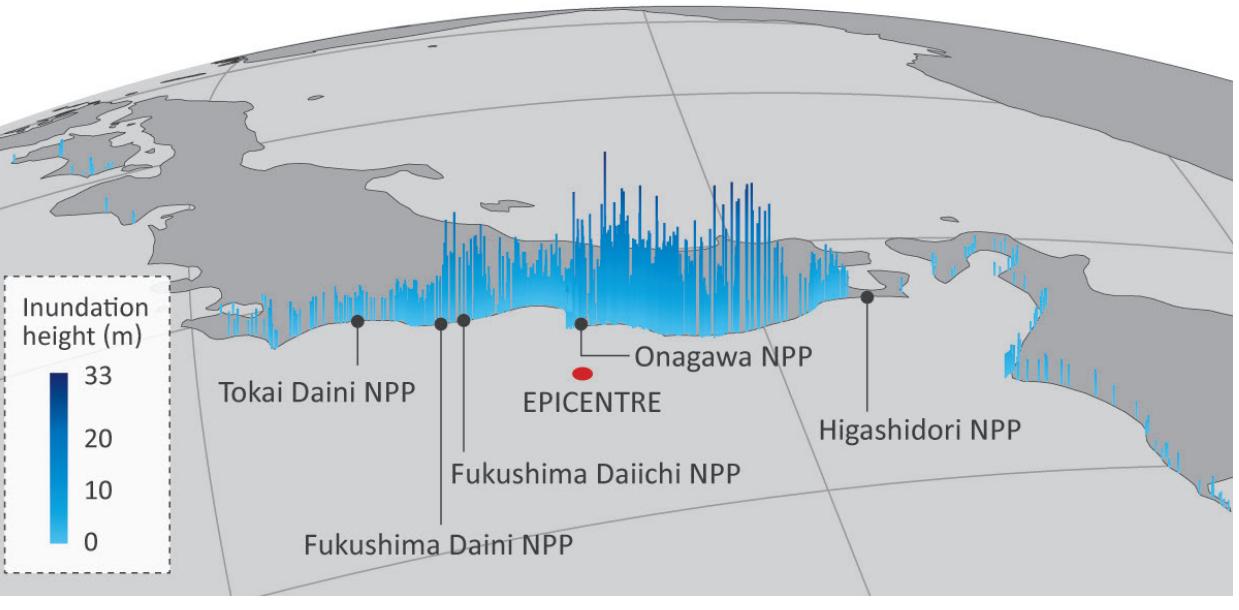
11 March 2011

The Great East Japan Earthquake occurred on 11 March 2011 caused by a sudden release of energy at the interface where the Pacific tectonic plate forces its way under the North American tectonic plate, causing a massive earthquake with a magnitude of 9.0.

The earthquake's epicentre lay off the eastern coastline of Japan generating a tsunami which struck a wide area of coastal Japan, where several waves reached heights of more than ten metres. The earthquake and tsunami caused great loss of life and widespread devastation in Japan.

At the Fukushima Daiichi nuclear power plant (NPP), the earthquake damaged the electric power supply lines and the tsunami caused substantial destruction of the operational and safety infrastructure on the site. The combined effect led to the loss of off-site and on-site electrical power. This resulted in the loss of the cooling function at the three operating reactor units as well as at the spent fuel pools. The four other NPPs along the coast were also affected to different degrees by the earthquake and tsunami.

Despite the efforts of the operators at the Fukushima Daiichi NPP to maintain control, the reactor cores in Units 1–3 overheated, the nuclear fuel melted, and the three containment vessels were breached. Hydrogen was released from the reactor pressure vessels, leading to explosions inside the reactor buildings in Units 1, 3 and 4 that damaged structures and equipment and injured personnel. Radioactive materials were released from the plant to the atmosphere and were deposited on land and on the ocean. There were also direct releases into the sea.



The variation of tsunami wave impact, inundation height, based on the coastal geography and topography.

The Report by the Director General

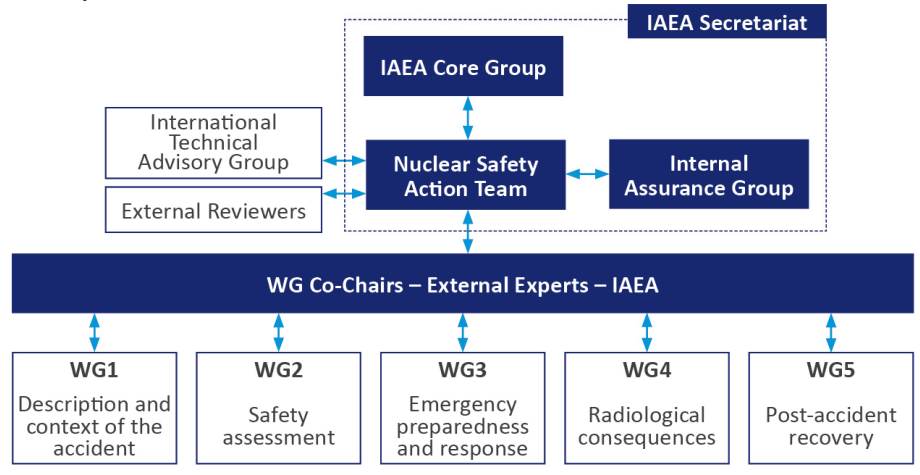
At the IAEA General Conference in September 2012, the Director General announced that the IAEA would prepare a report on the Fukushima Daiichi accident. He stated that this report would be "*an authoritative, factual and balanced assessment, addressing the causes and consequences of the accident as well as lessons learned.*"

The Report by the Director General consists of an Executive Summary and a Summary Report. It draws on five detailed technical volumes prepared by international experts and on the contributions of the many experts and international bodies involved. The report provides a description of the accident and its causes, evolution and consequences, based on the evaluation of data and information from a large number of sources available up to March 2015. It includes the results of the work carried out in implementing the IAEA Action Plan on Nuclear Safety, and it highlights the main observations and lessons. Significant amounts of data were provided by the Government of Japan and other organizations in Japan.

Technical Volumes Prepared by International Experts

This work is the result of an extensive international collaborative effort involving five working groups (WGs) with about 180 experts from 42 Member States, with and without nuclear power programmes, and several international bodies. This ensured a broad representation of experience and knowledge. An International Technical Advisory Group provided advice on technical and scientific issues.

The added value of the Director General's Report and the five Technical Volumes lie in their breadth of coverage and in their detailed description and analyses.



IAEA organizational structure for preparing the report on the Fukushima Daiichi Accident.

What is inside the Report by the Director General?

The report considers human, organizational and technical factors and aims to provide an understanding of what happened, and why, so that the necessary lessons learned can be acted upon by governments, regulators and NPP operators throughout the world. Measures taken in response to the accident, both in Japan and internationally, are also examined.

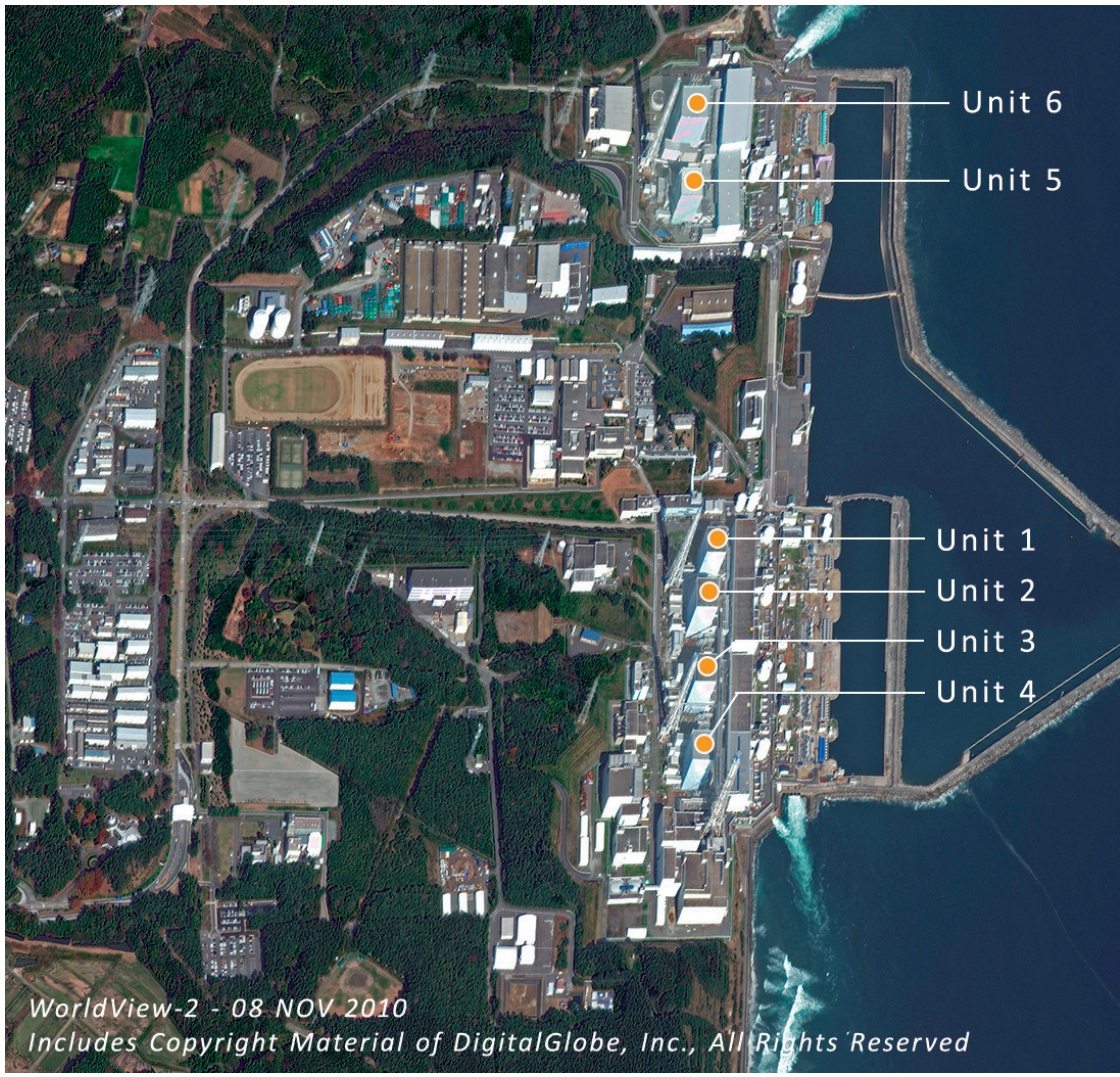
The report builds on the previous international and national data, evaluations and estimates and makes use of new information, in particular information provided by the Japanese authorities to the IAEA. The report contains 45 main observations and lessons.

Section 1: Introduction	The Report on the Fukushima Daiichi Accident					
Section 2: The accident and its assessment	Description of the accident	Nuclear safety considerations	Technical Volumes 1 & 2			
Section 3: Emergency preparedness and response	Initial response in Japan to the accident	Protecting emergency workers	Protecting the public	Transition from the emergency phase to the recovery phase and analyses of the response	Response within the international framework for emergency preparedness and response	Technical Volume 3
Section 4: Radiological consequences	Radioactivity in the environment	Protecting people against radiation exposure	Radiation exposure	Health effects	Radiological consequences for non-human biota	Technical Volume 4
Section 5: Post-accident recovery	Off-site remediation of areas affected by the accident	On-site stabilization and preparations for de-commissioning	Management of contaminated material and radioactive waste	Community revitalization and stakeholder engagement	Technical Volume 5	
Section 6: The IAEA response to the accident	IAEA activities	Meetings of the Contracting Parties to the Convention on Nuclear Safety	Technical Volumes 1 & 3			

Structure of the Summary Report and its relationship to the content of the technical volumes.

Highlights of the Director General's Report

- Detailed event timeline for each reactor unit at Fukushima Daiichi;
- Assessment of nuclear safety issues;
- Japanese and international emergency preparedness and response framework;
- Evaluation of radiological consequences using up to date radiation dose measurements for workers and the public;
- Description and analyses of the post-accident recovery measures at the Fukushima Daiichi NPP and in the affected areas of Japan.



An aerial view of the Fukushima Daiichi NPP site.

Description and Context of the Accident

Technical volume one describes the key events that happened before, during and after the Fukushima Daiichi accident based on objective and factual information.

Also described are the Fukushima Daiichi NPP site, the reactor designs, the structure of the nuclear industry in Japan and the Japanese regulatory framework at the time of the accident.

It depicts in detail the earthquake, the tsunami, the events at the Fukushima Daiichi NPP and the actions taken there and elsewhere for post-accident management up to December 2014.

The epicentre of the Great East Japan Earthquake and the NPPs nearby.

Safety Assessment

Technical volume two evaluates how the design of the reactors were assessed for protection against external events such as earthquakes and tsumani.

The accident management provisions are also considered along with the effectiveness of the regulatory programme, the human and organizational factors and the safety culture.

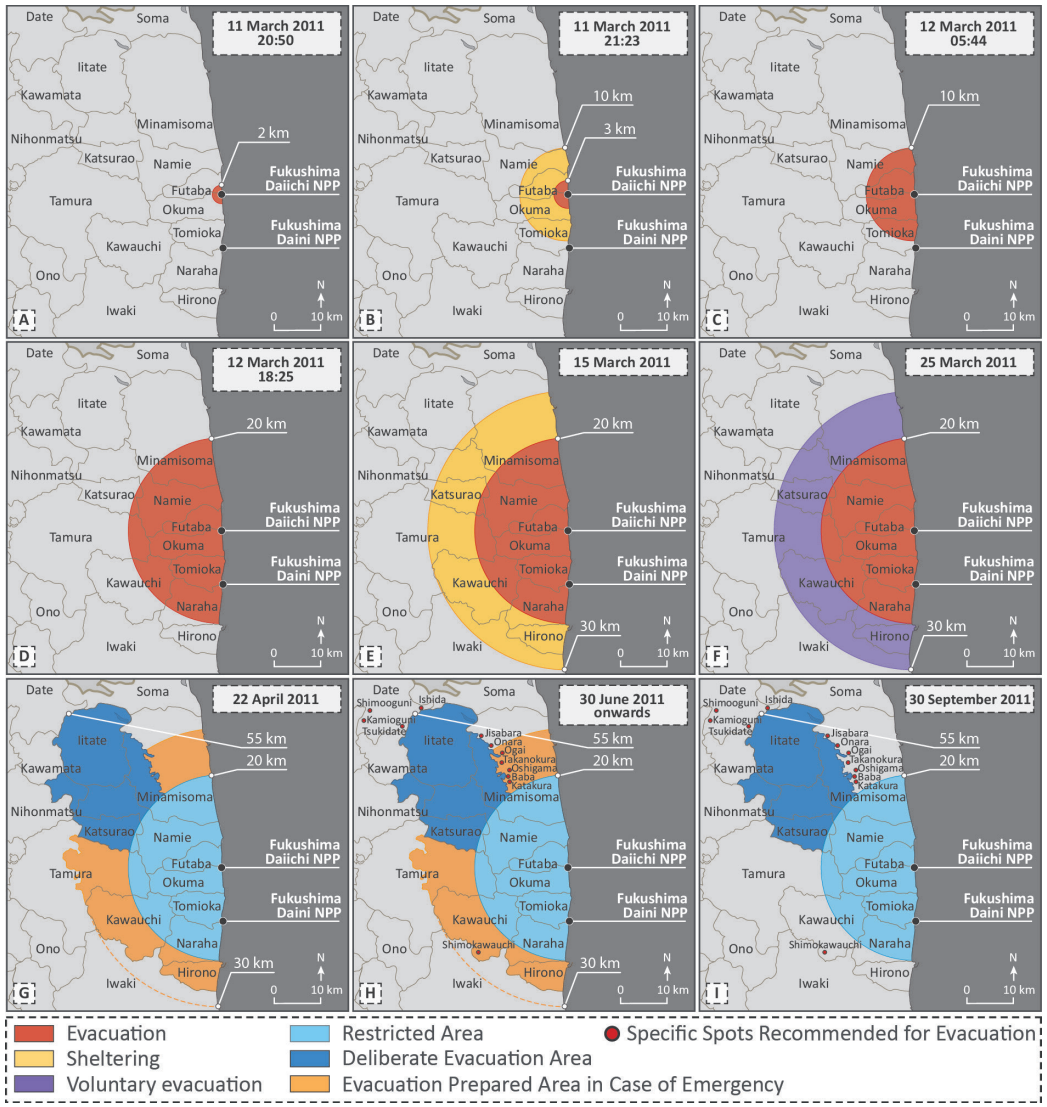
Members of the IAEA fact-finding team in Japan visit the Fukushima Daiichi NPP on 27 May 2011 to examine the devastation wrought by the 11 March earthquake and tsunami.

Emergency Preparedness and Response

Technical volume three describes the key events and response actions from the onset of the accident on 11 March 2011 until 1 April 2012.

It provides insights into the relevant parts of the national emergency preparedness and response system in place at the time of the accident and related response actions to allow a better understanding of what measures were taken in Japan in response to the accident.

The international response to the accident is described, including that of the IAEA and other relevant international organizations. The provision of international assistance to Japan and the response of States with regard to the protective actions recommended to their nationals in Japan are also discussed.



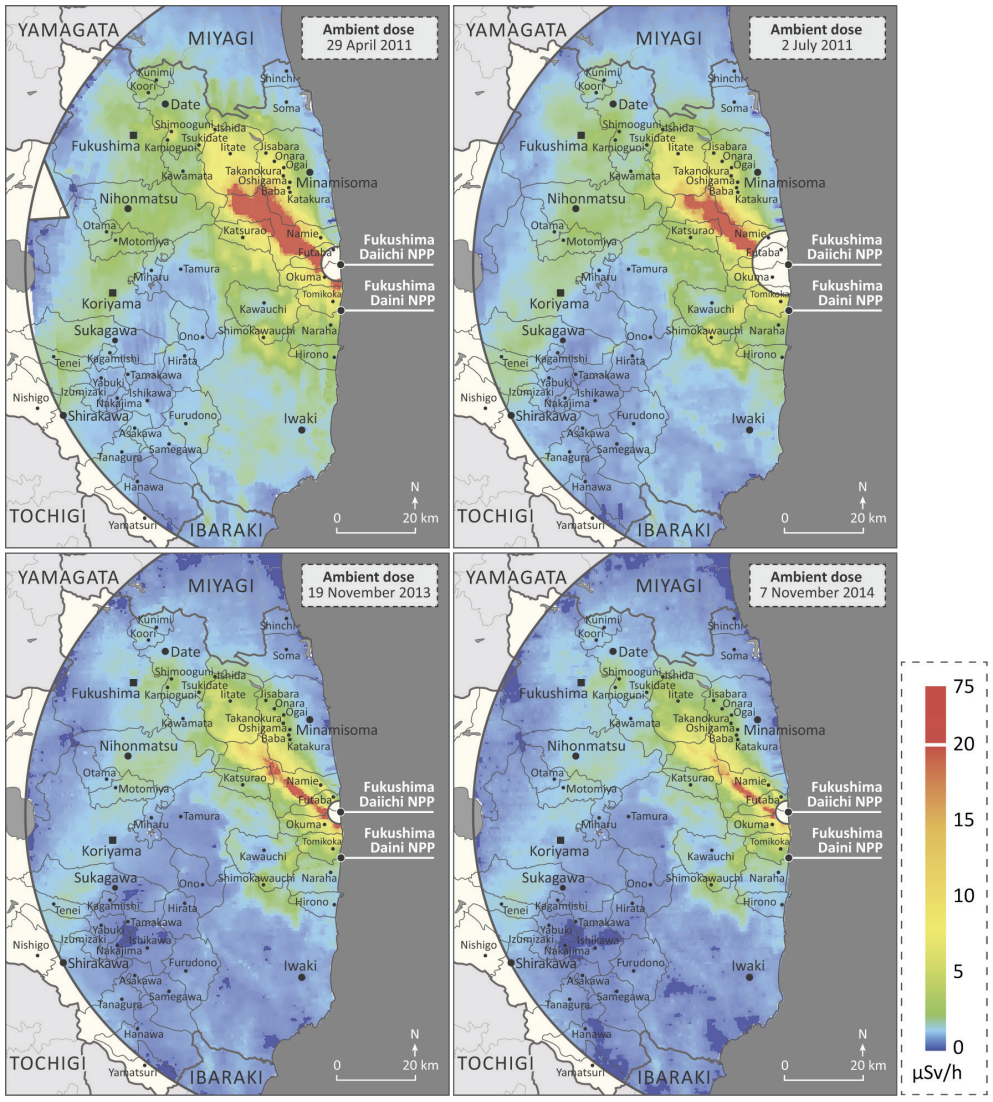
Areas and locations where protective actions were ordered or recommended until 30 September 2011.

Radiological Consequences

Technical volume four describes the consequences associated with the release of radioactive materials during the Fukushima Daiichi accident for people and the environment.

A number of international organizations have already issued authoritative reports on the potential health and environmental consequences of the accident, notably the World Health Organization (WHO) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

The assessments in the report build on their work, using more recent data where it is available. Quantitative information arising from both personal and environmental radiation monitoring has been provided by the Government of Japan.



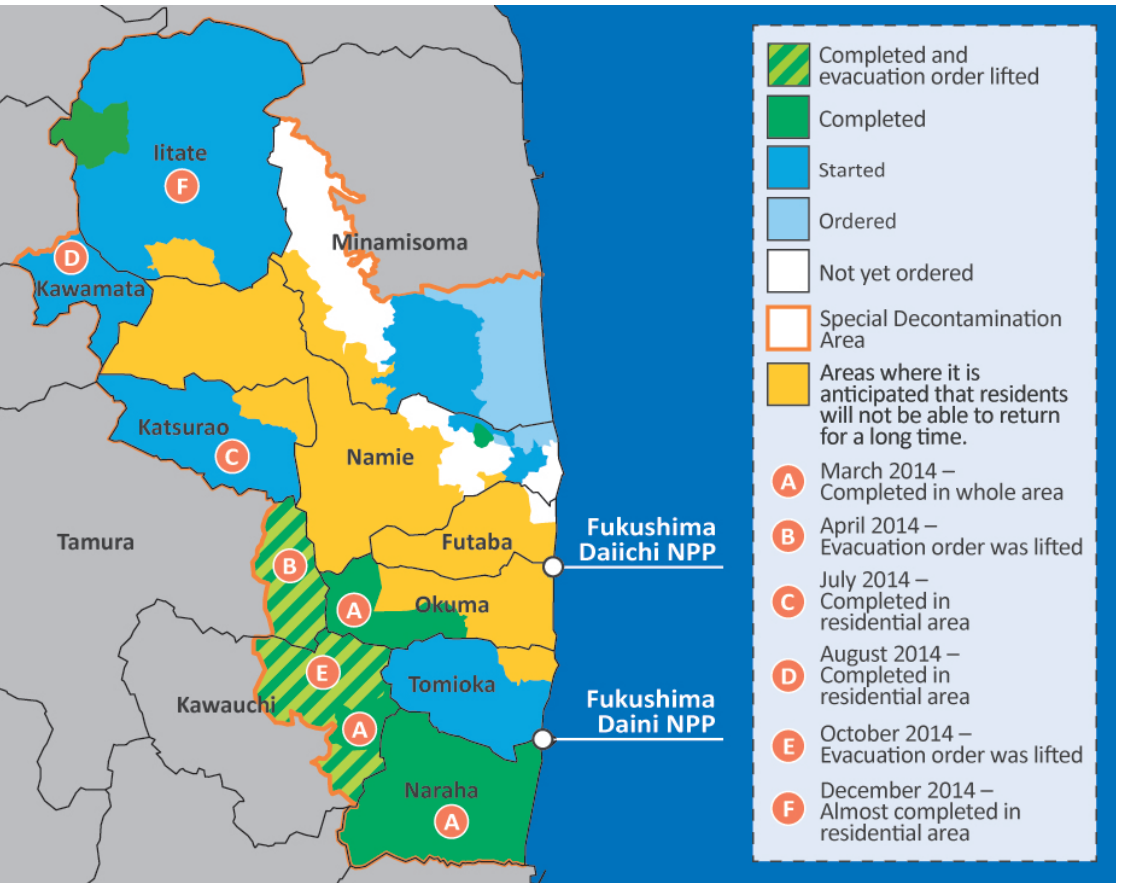
Measured aerial dose rates (in μSv/h) resulting from deposits from the releases that spread in areas to the north-west of the plant.

Post-accident Recovery

Technical volume five covers the recovery stage following the Fukushima Daiichi accident. It provides a description and analysis of the initial recovery actions and looks ahead to further recovery activities.

The on-site and off-site recovery efforts following the emergency phase of the accident are described including:

- The remediation of contaminated areas;
- The stabilization of the damaged reactors, leading towards their eventual decommissioning;
- The effective and safe management of the resulting contaminated material and radioactive waste, leading to their ultimate disposal;
- The re-establishment of infrastructure and the revitalization of communities.



Progress of remediation in the special decontamination areas up to December 2014.

Although nuclear safety remains the responsibility of each individual country, nuclear accidents can transcend national borders.

The Fukushima Daiichi accident underlined the vital importance of effective international cooperation. The IAEA is where most of that cooperation takes place. Our Member States adopted the IAEA Action Plan on Nuclear Safety a few months after the accident and have been implementing its far-reaching provisions to improve global nuclear safety.

IAEA

International Atomic Energy Agency
Vienna International Centre, PO Box 100, B0921
1400 Vienna, Austria
https://www.iaea.org/

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