IAEA
Original English

IAEA
International Atomic Energy Agency

# MISSION REPORT

## THE GREAT EAST JAPAN EARTHQUAKE EXPERT MISSION

# IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

**Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP, Japan**

***24 May – 2 June 2011***

IAEA MISSION REPORT

DIVISION OF NUCLEAR INSTALLATION SAFETY

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

IAEA
Original English

# REPORT

## THE GREAT EAST JAPAN EARTHQUAKE
## EXPERT MISSION

# IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

**REPORT TO**
**THE IAEA MEMBER STATES**

**Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and**
**Tokai Dai-ni NPP, Japan**

**24 May – 2 June 2011**

# REPORT

## THE GREAT EAST JAPAN EARTHQUAKE EXPERT MISSION

# IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

| | |
|---|---|
| **Mission date:** | 24 May – 2 June 2011 |
| **Location:** | Tokyo, Fukushima Dai-ichi, Fukushima Dai-ni and Tokai Dai-ni, Japan |
| **Facility:** | Fukushima and Tokai nuclear power plants |
| **Organized by:** | International Atomic Energy Agency (IAEA) |

**IAEA Review Team:**

| | |
|---|---|
| WEIGHTMAN, Michael | HSE, UK, Team Leader |
| JAMET, Philippe | ASN, France, Deputy Team Leader |
| LYONS, James E. | IAEA, NSNI, Director |
| SAMADDAR, Sujit | IAEA, NSNI, Head, ISCC |
| CHAI, Guohan | People’s Republic of China |
| CHANDE, S. K. | AERB, India |
| GODOY, Antonio | Argentina |
| GORYACHEV, A. | NIIAR, Russian Federation |
| GUERPINAR, Aybars | Turkey |
| LENTIJO, Juan Carlos | CSN, Spain |
| LUX, Ivan | HAEA, Hungary |
| SUMARGO, Dedik E. | BAPETEN, Indonesia |

| | |
|---|---|
| SUNG, Key Yong | KINS, Republic of Korea |
| UHLE, Jennifer | USNRC, USA |
| | |
| BRADLEY, Edward E. | IAEA, NEFW, RRS |
| WEBB, Gregory Paul | IAEA, MTPI |
| PAVLICEK, Petr | IAEA, MTPI |
| NAMMARI, Nadia | IAEA, NSNI |

Issue Date: 16 June 2011

# REPORT

## THE GREAT EAST JAPAN EARTHQUAKE EXPERT MISSION

# IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

## CONTENTS

# ACRONYMS

| | |
|---|---|
| AC | Alternate Current |
| BAF | Bottom of Active Fuel |
| BWR | Boiling Water Reactor |
| DC | Direct Current |
| EDG | Emergency Diesel Generator |
| EPR | Emergency Preparedness and Response |
| EPREV | Emergency Preparedness Review |
| FAO | Food and Agriculture Organization |
| HPCI | High Pressure Coolant Injection |
| IAEA | International Atomic Energy Agency |
| IC | Isolation Condenser |
| ICRP | International Commission on Radiation Protection |
| IEC | Incident and Emergency Centre |
| IRRS | Integrated Regulatory Review Service |
| ISSC | International Seismic Safety Centre |
| LPCI | Low Pressure Coolant Injection |
| MAAP | Modular Accident Analysis Programme |
| MUWC | Makeup Water Condensate |
| NISA | Nuclear Industrial Safety Agency |
| NPP | Nuclear Power Plant |
| NSC | Nuclear Safety Commission |
| OECC | On-site Emergency Control Centre |
| PSA | Probabilistic Safety Assessment |
| RCIC | Reactor Core Isolation Cooling |
| RHR | Residual Heat Removal |
| RPV | Reactor Pressure Vessel |
| SAMG | Severe Accident Management Guidelines |
| SFP | Spent Fuel Pool |
| SRV | Safety Relief Valve |
| SSC | Structures, Systems and Components |
| TAF | Top of Active Fuel |
| TEPCO | Tokyo Electric Power Company |

# SUMMARY

The Great East Japan Earthquake on 11 March 2011, a magnitude 9 earthquake, generated a series of large tsunami waves that struck the east coast of Japan, the highest being 38.9 m at Aneyoshi, Miyako.

The earthquake and tsunami waves caused widespread devastation across a large part of Japan, with 15 391 lives lost. In addition to this, 8 171 people remain missing, with many more being displaced from their homes as towns and villages were destroyed or swept away. Many aspects of Japan’s infrastructure have been impaired by this devastation and loss.

As well as other enterprises, several nuclear power facilities were affected by the severe ground motions and large multiple tsunami waves: Tokai Dai-ni, Higashi Dori, Onagawa, and TEPCO`s Fukushima Dai-ichi and Dai-ni. The operational units at these facilities were successfully shutdown by the automatic systems installed as part of the design of the nuclear power plants to detect earthquakes. However, the large tsunami waves affected all these facilities to varying degrees, with the most serious consequences occurring at Fukushima Dai-ichi.

Although all off-site power was lost when the earthquake occurred, the automatic systems at Fukushima Dai-ichi successfully inserted all the control rods into its three operational reactors upon detection of the earthquake, and all available emergency diesel generator power systems were in operation, as designed. The first of a series of large tsunami waves reached the Fukushima Dai-ichi site about 46 minutes after the earthquake.

These tsunami waves overwhelmed the defences of the Fukushima Dai-ichi facility, which were only designed to withstand tsunami waves of a maximum of 5.7 m high. The larger waves that impacted this facility on that day were estimated to be over 14 m high. The tsunami waves reached areas deep within the units, causing the loss of all power sources except for one emergency diesel generator (6B), with no other significant power source available on or off the site, and little hope of outside assistance.

The station blackout at Fukushima Dai-ichi and the impact of the tsunami caused the loss of all instrumentation and control systems at reactors 1–4, with emergency diesel 6B providing emergency power to be shared between Units 5 and 6.

The tsunami and associated large debris caused widespread destruction of many buildings, doors, roads, tanks and other site infrastructure at Fukushima Dai-ichi, including loss of heat sinks. The operators were faced with a catastrophic, unprecedented emergency scenario with no power, reactor control or instrumentation, and in addition, severely affected communications systems both within and external to the site. They had to work in darkness with almost no instrumentation and control systems to secure the safety of six reactors, six nuclear fuel pools, a common fuel pool and dry cask storage facilities.

With no means to confirm the parameters of the plant or cool the reactor units, the three reactor units at Fukushima Dai-ichi that were operational up to the time of the earthquake quickly heated up due to the usual reactor decay heating. Despite the brave and sometimes novel attempts of the operational staff to restore control and cool the reactors and spent fuel, there was severe damage to the fuel and a series of explosions occurred. These explosions caused further destruction at the site, making the scene faced by the operators even more demanding and dangerous. Moreover, radiological contamination spread into the environment. These events are provisionally determined to be of the highest rating on the International Nuclear Event Scale.

To date no confirmed long term health effects to any person have been reported as a result of radiation exposure from the nuclear accident.

By agreement with the Government of Japan, the International Atomic Energy Agency conducted a preliminary mission to find facts and identify initial lessons to be learned from the accident at Fukushima Dai-ichi and share this information across the world nuclear community. To this end, a team of experts undertook this Fact Finding Mission from 24 May to 2 June 2011. The results of the Mission will be reported to the IAEA Ministerial Conference on Nuclear Safety at IAEA headquarters in Vienna on 20  24 June 2011.

During the IAEA Mission, the team of nuclear experts received excellent cooperation from all parties, receiving information from many relevant Japanese ministries, nuclear regulators and operators. The Mission also visited three affected nuclear power plants (NPP) — Tokai Dai-ni, Fukushima Dai-ni and Dai-ichi — to gain an appreciation of the status of the plants and the scale of the damage. The facility visits allowed the experts to talk to the operator staff as well as to view the on-going restoration and remediation work.

The Mission gathered evidence and undertook a preliminary assessment and has developed preliminary conclusions as well as lessons to be learned. These preliminary conclusions and lessons have been shared and discussed with Japanese experts and officials. They fall broadly under the three specialist areas of external hazards, severe accident management and emergency preparedness. They are of relevance to the Japanese nuclear community, the IAEA and the worldwide nuclear community to learn lessons to improve nuclear safety.

The IAEA Mission urges the international nuclear community to consider the following 15 conclusions and 16 lessons in order to take advantage of the unique opportunity created by the Fukushima accident to seek to learn and improve worldwide nuclear safety.

**Conclusion 1: The IAEA Fundamental Safety Principles provide a robust basis in relation to the circumstances of the Fukushima accident and cover all the areas of lessons learned from the accident.**

**Conclusion 2: Given the extreme circumstances of this accident the local management of the accident has been conducted in the best way possible and following Fundamental Principle 3.**

**Conclusion 3: There were insufficient defence-in-depth provisions for tsunami hazards. In particular:**

- **although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Dai-ichi NPP as described during the meetings and the expected tsunami height was increased to 5.7 m (without changing the licensing documents) after 2002, the tsunami hazard was underestimated;**
- **thus, considering that in reality a 'dry site' was not provided for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the high tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and dynamic impact of large debris with high energy);**
- **moreover, those additional protective measures were not reviewed and approved by the regulatory authority;**
- **because failures of structures, systems and components (SSCs) when subjected to floods are generally not incremental, the plants were not able to withstand the**

**consequences of tsunami heights greater than those estimated leading to cliff edge effects; and**

- **severe accident management provisions were not adequate to cope with multiple plant failures.**

**Conclusion 4: For the Tokai Dai-ni and Fukushima Dai-ni NPPs, in the short term, the safety of the plant should be evaluated and secured for the present state of the plant and site (caused by the earthquake and tsunami) and the changed hazard environment. In particular, if an external event Probabilistic Safety Assessment (PSA) model is already available, this would be an effective tool in performing the assessment.**

**Short term immediate measures at Fukushima Dai-ichi NPP need to be planned and implemented for the present state of the plant before a stable safe state of all the units is reached. Until that time the high priority measures against external hazards need to be identified using simple methods in order to have a timely plan. As preventive measures will be important but limited, both on-site and off-site mitigation measures need to be included in the plan. Once a stable safe state is achieved a long term plan needs to be prepared that may include physical improvements to SSCs as well as on-site and off-site emergency measures.**

**Conclusion 5: An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Earthquake and Tsunami, fulfilling the requirements and using also the criteria and methods recommended by the relevant IAEA Safety Standards for comprehensively coping with earthquakes and tsunamis and external flooding and, in general, all correlated external events. The national regulatory documents need to include database requirements compatible with those required by IAEA Safety Standards. The methods for hazard estimation and the protection of the plant need to be compatible with advances in research and development in related fields.**

**Conclusion 6: Japan has a well organized emergency preparedness and response system as demonstrated by the handling of the Fukushima accident. Nevertheless, complicated structures and organizations can result in delays in urgent decision making.**

**Conclusion 7: Dedicated and devoted officials and workers, and a well organized and flexible system made it possible to reach an effective response even in unexpected**

**situations and prevented a larger impact of the accident on the health of the general public and facility workers.**

**Conclusion 8: A suitable follow up programme on public exposures and health monitoring would be beneficial.**

**Conclusion 9: There appears to have been effective control of radiation exposures on the affected sites despite the severe disruption by the events.**

**Conclusion 10: The IAEA Safety Requirements and Guides should be reviewed to ensure that the particular requirements in design and severe accident management for multi-plant sites are adequately covered.**

**Conclusion 11: There is a need to consider the periodic alignment of national regulations and guidance to internationally established standards and guidance for inclusion in particular of new lessons learned from global experiences of the impact of external hazards.**

**Conclusion 12: The Safety Review Services available with the IAEA's International Seismic Safety Centre (ISSC) would be useful in assisting Japan's development in the following areas:**

- **External event hazard assessment;**
- **Walkdowns for plants that will start up following a shutdown; and**
- **Pre-earthquake preparedness.**

**Conclusion 13: A follow-up mission including Emergency Preparedness Review (EPREV) should look in detail at lessons to be learned from the emergency response on and off the site.**

**Conclusion 14: A follow-up mission should be conducted to seek lessons from the effective approach used to provide large scale radiation protection in response to the Fukushima accident.**

**Conclusion 15: A follow-up mission to the 2007 Integrated Regulatory Review Service (IRRS) should be conducted in light of the lessons to be learned from the Fukushima accident and the above conclusions to assist in any further development of the Japanese nuclear regulatory system.**

**Lesson 1: There is a need to ensure that in considering external natural hazards:**

- **the siting and design of nuclear plants should include sufficient protection against infrequent and complex combinations of external events and these should be considered in the plant safety analysis – specifically those that can cause site flooding and which may have longer term impacts;**
- **plant layout should be based on maintaining a 'dry site concept', where practicable, as a defence-in-depth measure against site flooding as well as physical separation and diversity of critical safety systems;**
- **common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;**
- **any changes in external hazards or understanding of them should be periodically reviewed for their impact on the current plant configuration; and**
- **an active tsunami warning system should be established with the provision for immediate operator action.**

**Lesson 2: For severe situations, such as total loss of off-site power or loss of all heat sinks or the engineering safety systems, simple alternative sources for these functions including any necessary equipment (such as mobile power, compressed air and water supplies) should be provided for severe accident management.**

**Lesson 3: Such provisions as are identified in Lesson 2 should be located at a safe place and the plant operators should be trained to use them. This may involve centralized stores and means to rapidly transfer them to the affected site(s).**

**Lesson 4: Nuclear sites should have adequate on-site seismically robust, suitably shielded, ventilated and well equipped buildings to house the Emergency Response Centres, with similar capabilities to those provided at Fukushima Dai-ni and Dai-ichi, which are also secure against other external hazards such as flooding. They will require sufficient provisions and must be sized to maintain the welfare and radiological protection of workers needed to manage the accident.**

**Lesson 5: Emergency Response Centres should have available as far as practicable essential safety related parameters based on hardened instrumentation and lines such as coolant levels, containment status, pressure, etc., and have sufficient secure communication lines to control rooms and other places on-site and off-site.**

**Lesson 6: Severe Accident Management Guidelines and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state and high radiation fields.**

**Lesson 7: External events have a potential of affecting several plants and several units at the plants at the same time. This requires a sufficiently large resource in terms of trained experienced people, equipment, supplies and external support. An adequate pool of experienced personnel who can deal with each type of unit and can be called upon to support the affected sites should be ensured.**

**Lesson 8: The risk and implications of hydrogen explosions should be revisited and necessary mitigating systems should be implemented.**

**Lesson 9: Particularly in relation to preventing loss of safety functionality, the robustness of defence-in-depth against common cause failure should be based on providing adequate diversity (as well as redundancy and physical separation) for essential safety functions.**

**Lesson 10: Greater consideration should be given to providing hardened systems, communications and sources of monitoring equipment for providing essential information for on-site and off-site responses, especially for severe accidents.**

**Lesson 11: The use of IAEA Safety Requirements (such as GS-R-2) and related guides on threat categorization, event classification and countermeasures, as well as Operational Intervention Levels, could make the off-site emergency preparedness and response even more effective in particular circumstances.**

**Lesson 12: The use of long term sheltering is not an effective approach and has been abandoned and concepts of ‘deliberate evacuation’ and ‘evacuation-prepared area’ were introduced for effective long term countermeasures using guidelines of the ICRP and IAEA.**

**Lessons 13: The international nuclear community should take advantage of the data and information generated from the Fukushima accident to improve and refine the existing methods and models to determine the source term involved in a nuclear accident and refine emergency planning arrangements.**

**Lesson 14: Large scale radiation protection for workers on sites under severe accident conditions can be effective if appropriately organized and with well led and suitable trained staff.**

**Lesson 15: Exercises and drills for on-site workers and external responders in order to establish effective on-site radiological protection in severe accident conditions would benefit from taking account of the experiences at Fukushima.**

**Lesson 16: Nuclear regulatory systems should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.**

# 1. INTRODUCTION

## 1.1. BACKGROUND

The “2011 Off the Pacific Coast of Tohoku Earthquake” occurred at 05:46 UTC (14:46 JST) on 11 March 2011. The magnitude ($M_w$) of the earthquake was 9.0. Extreme vibratory ground motion and tsunami were generated from this large earthquake. These caused massive devastation with 15 391 lives lost and 8 171 people still missing.

Because of the widespread disaster caused by this large earthquake, it is called the Great East Japan Earthquake. The hazard of severe vibratory ground motion and tsunami hit five nuclear power plant (NPP) sites in the North Eastern coast of Japan — Higashi Dori, Onagawa, Fukushima Dai-ichi (1F), Fukushima Dai-ni (2F) and Tokai Dai-ni. A sequence of events initiated by the earthquake led to the severe accident at the Fukushima Dai-ichi NPP site.

The epicentre of the earthquake was located at 38.1N and 142.9E (130 km ESE off Ojika Peninsula), at a focal depth of 24 km on the subduction zone between the North American plate and the Pacific plate. The earthquake is estimated to have originated from the rupture of a subduction zone area having a length of more than 400 km and width of about 200 km. The main shock was preceded by a strong motion foreshock and followed by a number of aftershocks over a long period. Table 1.1 contains information on the foreshock and some of the aftershocks (magnitude greater than or equal to 7.0) that occurred shortly after the main shock. Large tsunamis were created by the earthquake. Tsunamis were observed to be more than 8.5 m at Miyako, 8.0 m at Ofunato and 9.3 m at Soma. The maximum tsunami height was 38.9 m in Aneyoshi, Miyako.

The location of the five power plants site vis-à-vis the epicentre of earthquake is shown in Fig. 1.1. All sites have NPPs of the boiling water reactor (BWR) type. There is one BWR-5 reactor of 110 MW(e) in Higashi Dori. The Onagawa site has one BWR-4 reactor of 524 MW(e) capacity and two BWR-5 of 825 MW(e) capacity. Fukushima Dai-ichi has the largest number of reactors among the five sites. Six reactors are located on this site: Unit 1 (BWR3) 460 MW(e), Units 2, 3, 4 and 5 (4-BWR4) 784 MW(e), and Unit 6 (BWR5) 1100 MW(e). There are four units of BWR5 reactors each having 1100 MW(e) capacity at the Fukushima

Dai-ni site. Tokai Dai-ni has one operating BWR-5 unit of 1100 MW(e) capacity. Pictorial views of Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP are given in Figs 1.2, 1.3 and 1.4 respectively.

At the time of the earthquake, all the reactors were in operation except the one unit of Higashi Dori and Units 4, 5 and 6 of Fukushima Dai-ichi NPP. The earthquake caused automatic shutdown of all the operating units. Large tsunamis caused by this earthquake hit all the five sites within an hour of the main shock and caused damage at several sites. The status of the NPP reactors is summarized in Table 1.2.

The worst affected sites were Fukushima Dai-ichi and Fukushima Dai-ni. Fukushima Dai-ni lost some safety related equipment but off-site and on-site power remained available albeit somewhat degraded. On the other hand, Fukushima Dai-ichi lost much of its safety related equipment from the tsunami and all off-site and on-site power except for one diesel serving Unit 6. This led to a loss of cooling for the reactors of Units 1, 2 and 3 and the spent fuel pools (SFP) of Unit 4. In addition, cooling for other safety related equipment was unavailable or inaccessible. All these resulted in accident conditions at four units of Fukushima Dai-ichi NPP.

The International Seismic Safety Centre (ISSC) of the International Atomic Energy Agency (IAEA) received information about the earthquake on 11 March 2011 through its “External Event Notification System” within about half an hour. The ISSC promptly conveyed the information to the IAEA Incident and Emergency Centre (IEC).

The Japanese authorities subsequently informed the IAEA about the event. The IAEA has been in constant contact with the Government of Japan and disseminating information to Member States on a regular basis since that time. The IAEA Director General, Yukiya Amano, called for a robust follow-up action. The IAEA has been collaborating with the Government of Japan in sharing information about the status of the damage at the nuclear power plants and its effect on the surrounding areas. As immediate assistance, the IAEA sent seven expert teams to Japan, including a joint IAEA/FAO team on food monitoring to coordinate information sharing on radiation and environmental monitoring, on boiling water reactors and on marine environment monitoring.

Since late March 2011, the Government of Japan and the IAEA were engaged in consultations over sending a fact finding expert mission to explore the impact of the earthquake and tsunami on several of Japan’s NPPs, including Fukushima-Dai-ichi. The Government of Japan and the IAEA agreed to send to Japan a mission comprising international experts together with IAEA staff in order to provide a preliminary assessment of the accident at Fukushima Dai-ichi and recommend areas that need further exploration. The Mission was one of the initial activities of the IAEA and would be followed by other missions as well as relevant international cooperative activities including further information exchange. These future activities may include facilities not covered by the scope of the present Mission and would comprise technical studies, discussions with the participation of relevant Member State institutions, and the organization of international, regional and national workshops and training courses. Covering the areas of external hazards and structural response, safety assessment and management of severe accidents, and monitoring, emergency preparedness and response, the IAEA could support the development and incorporation of the lessons learned from different issues identified by this and subsequent relevant missions.

The findings of the Mission are being shared with the international community to assist in identifying the lessons learned and their incorporation into the global nuclear safety structure. In this connection, the Director General informed IAEA Member States that an IAEA Ministerial Conference on Nuclear Safety will be held from 20 to 24 June 2011, in Vienna. The more specific objectives of the Conference are the following:

- To provide a preliminary assessment of the Fukushima Dai-ichi NPP accident;
- To assess national and international emergency preparedness and response levels in light of the Fukushima Dai-ichi NPP accident, with a view to strengthening them;
- To discuss safety implications and identify those areas of safety which may be reviewed with the aim of strengthening them through launching a process to that effect;
- To identify lessons learned and possible future actions.

The findings of the Mission will be reported to the Ministerial Conference.

TABLE 1.1. FORESHOCK, MAIN SHOCK, AFTERSHOCKS AND ASSOCIATED EVENTS OF THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

| Shock | Date | Location | | Magnitude |
|---|---|---|---|---|
| | | Epicentre | depth | |
| Foreshock | 9 Mar. 11:45 (JST) | N38d20m, E143d17m | 8 km | M7.3 |
| Main shock | 11 Mar. 14:46 (JST) | N38d06m, E142d52m | 24 km | M9.0 |
| Aftershocks | 11 Mar. 15:08 (JST) | N39d50m, E142d47m | 32 km | M7.4 |
| | 11 Mar. 15:15 (JST) | N36d06m, E141d16m | 43 km | M7.7 |
| Associated events | 11 Mar. 15:25 (JST) | N37d50m, E144d54m | 34 km | M7.5 |
| | 7 Apr. 23:32 (JST) | N38d12m, E141d55m | 66 km | M7.1 |
| | 11 Apr. 17:16 (JST) | N36d57m, E140d40m | 6 km | M7.0 |

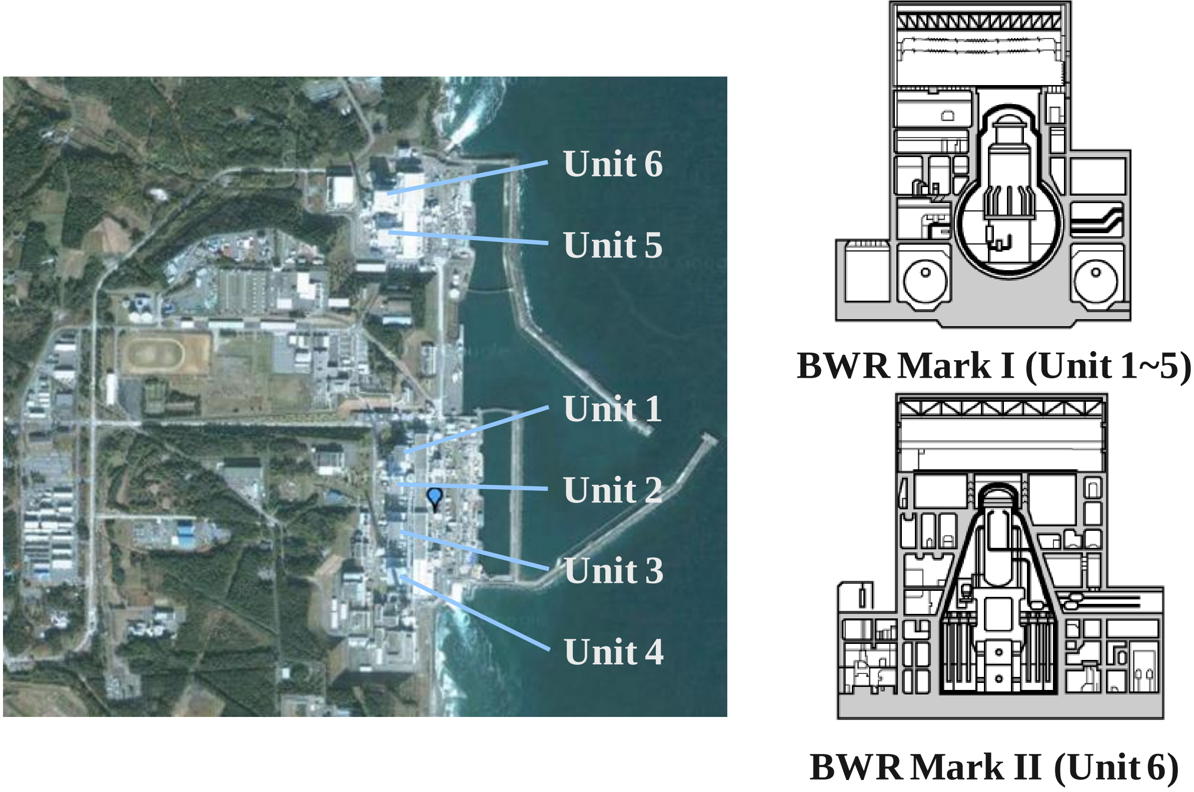
TABLE 1.2. STATUS OF NPPS AFFECTED BY THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

| NPP | Unit | Type | | Capacity (MW(e)) | Status | | |
|---|---|---|---|---|---|---|---|
| | | CV** type | Safety system | | Before earthquake | After earthquake | After tsunami |
| Higashi Dori | 1 | Mark I R | BWR-5 | 1,100 | Outage | Cold Shutdown | Cold Shutdown |
| Onagawa | 1 | Mark I | BWR-4 | 524 | Operating | Automatic Scram | Cold Shutdown |
| | 2 | Mark I | BWR-5 | 825 | Reactor Start | Automatic Scram | Cold Shutdown |
| | 3 | Mark I | BWR-5 | 825 | Operating | Automatic Scram | Cold Shutdown |
| Fukushima Dai-ichi | 1 | Mark I | BWR-3 | 460 | Operating | Automatic Scram | Loss of Cooling |
| | 2 | Mark I | BWR-4 | 784 | Operating | Automatic Scram | Loss of Cooling |
| | 3 | Mark I | BWR-4 | 784 | Operating | Automatic Scram | Loss of Cooling |
| | 4 | Mark I | BWR-4 | 784 | Outage | Cold Shutdown | Loss of SFP* cooling |
| | 5 | Mark I | BWR-4 | 784 | Outage | Cold Shutdown | Cold Shutdown |
| | 6 | Mark II | BWR-5 | 1,100 | Outage | Cold Shutdown | Cold Shutdown |
| Fukushima Dai-ni | 1 | Mark II | BWR-5 | 1,100 | Operating | Automatic Scram | Cold Shutdown |
| | 2 | Mark II R | BWR-5 | 1,100 | Operating | Automatic Scram | Cold Shutdown |
| | 3 | Mark II R | BWR-5 | 1,100 | Operating | Automatic Scram | Cold Shutdown |
| | 4 | Mark II R | BWR-5 | 1,100 | Operating | Automatic Scram | Cold Shutdown |
| Tokai Dai-ni | - | Mark II | BWR-5 | 1,100 | Operating | Automatic Scram | Cold Shutdown |

*: Spent Fuel Pool
**: Containment Vessel

*FIG. 1.1. NPP sites affected by the "2011 Off the Pacific Coast of Tohoku Earthquake".*

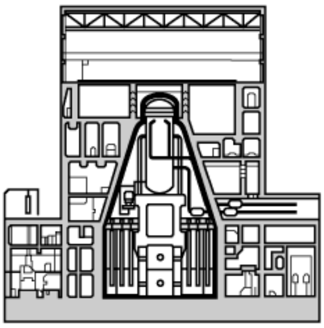
a) Pictorial view



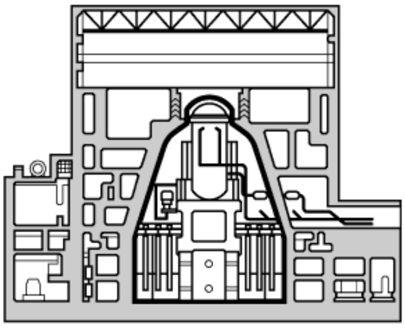
b) Layout

*FIG. 1.2. Fukushima Dai-ichi NPP.*

a) Pictorial view



**BWR Mark II (Unit 1)**

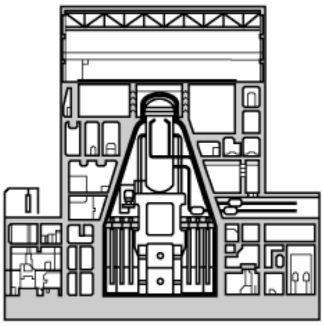


**BWR Mark II R (Unit 2~4)**

b) Layout

*FIG. 1.3. Fukushima Dai-ni NPP.*

a) Pictorial view



**BWR Mark II (Unit 1)**

b) Layout

*FIG. 1.4. Tokai Dai-ni NPP.*

## 1.2. OBJECTIVE OF THE MISSION

The Mission conducted a fact finding activity for a preliminary assessment of the accident (in particular at the Fukushima Dai-ichi NPP (1F)). The Mission also collected information on the Fukushima Dai-ni (2F) and Tokai Dai-ni (T2) NPP sites located in Fukushima Prefecture and in Ibaraki Prefecture respectively to make a preliminary assessment of the generic safety issues associated with the natural events and the identification of issues that need further exploration or assessment based on IAEA Safety Standards.

The Mission received information on the progress reached to date on the Japanese assessment of the accident and discussed specific technical issues to develop an informed assessment of the accident for sharing with the international nuclear community.

## 1.3. SCOPE OF THE MISSION

The scope of the Mission, while focusing on overall nuclear safety issues, covered the following specific areas:

a. External events of natural origin;

b. Plant safety assessment and defence-in-depth;

c. Plant response after an earthquake and tsunami;

d. Severe accident;

e. Spent fuel management under severe facility degradation;

f. Emergency preparedness and response; and

g. Radiological consequences.

The Government of Japan provided the Mission Team with all relevant information it had readily available at the time of the Mission.

## 1.4. CONDUCT OF THE MISSION

The Mission was conducted through discussions with the counterparts and observations made during the visit to the sites.

The official language of the Mission was English and Mission documents were prepared and finalized in English. The documents summarize the studies and inspections performed and the results obtained, and recommend future actions.

The Mission consisted of meetings at offices in Tokyo and a two-day visit to the Fukushima Dai-ichi, Fukushima Dai-ni and Tokai Dai-ni sites.

Courtesy visits were paid to various Ministers.

The meetings over the first two days in Tokyo addressed the general safety issues listed under Section 1.3. Presentations by the Japanese counterparts during these meetings included the requirements, regulations and procedures pertaining to the issues addressed in this report.

The visits to the sites included question and answer sessions in which the Japanese counterparts provided detailed answers to the questions of the Mission Team.

The Mission Team was divided into the three following groups:

1. **External Hazards Group** — comprising experts on the assessment of external hazards of natural origin and plant response. They interacted with the Japanese experts on assessment of hazards of natural origin and their incorporation in design, and on the response of the plants, including structures, systems and components, against the hazards.

2. **Safety Assessment and Management Group** — comprising experts in the area of safety assessment, of severe accident and management, and defence-in-depth analysis. The team held discussions with the Japanese experts on the response of plant systems after the events, severe accident management, defence-in-depth and fuel pool cooling after severe plant degradation.

3. **Monitoring, Emergency Preparedness and Response Group** — comprising experts in the areas of emergency preparedness and response (EPR), and of radiological consequences. They addressed the plant specific protective actions taken and reviewed the details of the governmental infrastructure and communication along with the radiological consequences of the accident.

The experts attended multiple presentations to address cross-cutting issues. The meetings of the groups were held in parallel following the site visits in order to gain as much information as possible from the Japanese experts prior to the finalization of the Mission Report, including the development of conclusions and lessons learned. Press contacts with the Mission leader were arranged, as appropriate. The Mission was conducted by a team of international experts and IAEA staff. The list is given on page iii and iv of this report.

# 2. SEQUENCE LEADING TO THE FUKUSHIMA DAI-ICHI NPP ACCIDENT

## 2.1 FUKUSHIMA DAI-ICHI NUCLEAR POWER STATION

The Fukushima Dai-ichi site NPP has six BWR reactor units. Unit 1 is a BWR-3 reactor with a Mark I containment, Units 2–5 are BWR-4 reactors with Mark I containments, and Unit 6 is a BWR-5 reactor with a Mark II containment. At the time of the earthquake, Units 1–3 were operating and Units 4–6 were in refuelling/maintenance outages. In response to the earthquake, Units 1–3 automatically scrammed (shutdown). All six off-site power lines were lost as a result of the earthquake and all 12 of the available plant’s emergency diesel generators (EDG) started. The site has 13 EDGs but one had been taken out of service for maintenance. About 46 minutes after the earthquake, the first tsunami wave hit the site. It was followed by several additional tsunami waves leading to the inundation of the site. The resulting ground acceleration at Units 1, 4 and 6 did not exceed the standard seismic ground motion, whereas at Units 2, 3 and 5, the resulting ground acceleration did exceed the standard seismic ground motion. The tsunami exceeded the design basis at all units. The standard seismic ground motion was established for each unit for the purpose of a seismic back check based on the Seismic Design Review Guideline revised in 2006.

The extent of flooding was extensive, completely surrounding all of the reactor buildings at the Fukushima Dai-ichi site. The tsunami caused the loss of all nine available EDGs cooled by sea water and the loss of all but one of the three EDGs cooled by air. The air-cooled EDG at Unit 6 was the remaining source of AC power at the six-unit site. Workers were temporarily evacuated from the site as a result of several after-shocks and accompanying tsunami alerts. On the entire site, no means of communication between the On-site Emergency Control Centre (OECC) and on-site personnel executing recovery actions was available. Only one wired telephone was available between the OECC and each control room. The seawater pumps and motors located at the intake were totally destroyed so the ultimate heat sink was lost.

## Core Damage Progression of Units 1–3

With the loss of all AC power, all safety and non-safety systems driven by AC power became unavailable. At Units 1 and 2, the 125 V DC batteries were flooded, so no instrumentation and control was available, thereby hampering the ability of the operators to manage the plant conditions. No lighting was available in the main control rooms in either unit. At Unit 3, DC power and, in turn, main control room lighting and instrumentation and control systems, were available for 30 hours but were lost once the batteries drained, as the battery charger was flooded and AC power was not available. During the initial response, work was conducted in extremely poor conditions, with uncovered manholes and cracks and depressions in the ground. Work at night was conducted in the dark. There were many obstacles blocking access to the road such as debris from the tsunami and rubble that was produced by the explosions that occurred in Units 1, 3 and 4. All work was conducted with respirators and protective clothing and mostly in high radiation fields. All three units experienced severe core damage but during the Mission no further detail was provided. The system response described below is preliminary and lacks a number of details in many areas. It is likely that the description will be changed once TEPCO can obtain more information and analyse it.

Some systems were available to cool the cores in Units 1–3 after the earthquake. In Unit 1, the Isolation Condenser (IC) is designed to operate through gravity driven natural circulation of coolant from the reactor pressure vessel (RPV) through a heat exchanger immersed into a large tank of water in the reactor building at an elevation above the core. The Unit 1 IC was designed to have a decay heat removal capacity of about 8 hours. A valve must be manipulated to bring the IC into service. It was started at 14:52 on 11 March after the earthquake. Although unconfirmed it appears to have operated for about 11 minutes and was then manually shutdown at 15:03 because the RPV temperature was dropping rapidly. This action is consistent with the plant operating procedures which direct the operator to control the IC so that the RPV temperature reduction rate does not exceed 55°C per hour. After the tsunami, at about 18:18, the IC was started by manually opening the DC powered valve as it is located outside of containment. At about 18:25 the valve was closed. It was then reopened at 21:30. Steam generation was confirmed in the IC pool after the valve was opened at 18:18 and 21:30, so it appears that heat was being removed from the core to the IC pool during these periods. The IC was the only system available to cool the core during this period and it eventually failed. TEPCO is further investigating the failure of the IC and operator actions related to its operation during this period.

As designed, the Reactor Core Isolation Cooling (RCIC) systems in Units 2 and 3 utilize a pump which is driven by a turbine that takes steam from the RPV. The turbine exhaust steam is discharged to the suppression pool. The RCIC systems are limited to operation when the steam pressure in the RPV is above a certain pressure rating. In order to start the RCIC systems, valves must be realigned. Some are operated with AC power and some are operated with DC power. After the earthquake at Fukushima Dai-ichi, the RCIC systems in Units 2 and 3 were manually started and then tripped on a high RPV water level automatically before the tsunami. After the tsunami, the RCIC systems were started at 15:39 and 16:03 in Units 2 and 3, respectively. Conditions indicate that the RCIC system of Unit 2 operated as designed for about three days until 14 March at 13:25, although the actual status could not be confirmed in the control room. The RCIC system in Unit 3 stopped after about 19.5 hours, on 12 March at 11:36, and after an approximately 1 hour delay the turbine-driven high pressure coolant injection (HPCI) system started automatically on a low RPV water level signal and remained operable for about 14 hours. Their failures will be investigated by TEPCO once stable conditions are achieved.

Once the IC in Unit 1, the RCIC system in Unit 2, and the RCIC and HPCI systems in Unit 3 were unavailable, an alternative cooling process had to be established. In Unit 1, the alternate process involved injecting feed from a low discharge pressure fire engine pump through the fire protection and makeup water condensate (MUWC) lines connected to the core spray line. On 11 March at approximately 20:00, the reactor pressure was 6.9 MPa. Once the pressure reading could be taken again on 12 March at 2:45 (the lack of DC power for instrumentation required the use of car batteries so only intermittent readings were available), the pressure was 0.8 MPa. The cause of the depressurization will be investigated once conditions are stable. As a result, the fire engine pump could begin to inject freshwater into the core, and it was initiated at 5:46 on 12 March. Over the next nine hours, approximately 80 tonnes of water was supplied to the core until the water supply ran out. As steam was bled from the RPV to the containment through an unconfirmed pathway, the containment pressure increased and it became necessary to align the valves in order to vent the containment and reduce pressure. Venting requires instrument air as well as AC power. High radiation levels in the reactor building impeded the work. Beginning on the morning of 12 March, the operators attempted to open the valves manually. In the afternoon, an engine driven air compressor (typically used for construction work) and an engine-generator to provide AC power to a solenoid valve were used. At approximately 14:30 on 12 March, the operators confirmed a decrease in the dry well pressure, providing some indication that venting had been successful. Approximately an hour later, the first hydrogen explosion occurred at the site in the Unit 1 reactor building at 15:36 on 12 March. About 3.5 hours after the explosion a means to inject sea water (borated intermittently to ensure subcriticality of the core) was established. This was discontinued on 25 March, once a source of fresh water was secured. Injection using fresh water is now provided through a pump taking suction from a filtered water tank and injecting into the feedwater line. Fresh water is obtained via a piping system that connects the site to a dam located approximately 10 km away. Measures have been taken to inert the containment with nitrogen.

The alternative cooling process used in Units 2 and 3 involved feeding water to the RPV using a fire engine pump injecting sea water, which was borated intermittently, and bleeding the steam to the suppression pool through the safety relief valves (SRVs). This “feed and bleed” process essentially moves heat from the core to the containment and therefore the suppression pool temperature increases as does the pressure of the wet well. Since the ultimate heat sink was lost, venting from the containment was used to reduce pressure, as discussed below.

After RCIC failed in Unit 2, approximately six hours elapsed until an alternative injection source could be established using a fire engine pump injecting sea water. The RPV pressure was reduced using the SRVs to allow injection, due to the low discharge pressure of the fire engine pump. Several attempts were made to open the SRVs, which require both DC power and adequate nitrogen pressure in the valves’ accumulators to assist in the manipulation of the valve. The operators tried to open several valves using a car battery as the DC power source but the nitrogen pressure in the valves’ accumulators was insufficient to either open the valves or keep them open. A valve was eventually opened and the RPV pressure was reduced. A nitrogen cylinder was used to maintain a vent path through the SRVs. About 9197 tonnes of sea water was injected between 14 March and 26 March through the fire protection and MUWC lines connected to the low pressure coolant injection (LPCI) lines. LPCI is one mode of the residual heat removal (RHR) system. At one point, the injection was temporarily discontinued when the truck ran out of fuel. After 26 March, a fresh water source was established similar to that of Unit 1.

Alignment of the valves to vent the Unit 2 containment was carried out on 13 March by opening an air operated valve using an air cylinder and another valve with AC power supplied by an engine generator. After the Unit 3 explosion, discussed below, the valve was rendered inoperable. The operators then attempted to open another air operated valve to establish the vent path. An engine driven air compressor and AC power supplied by an engine generator were used and the valve appeared to open slightly. However, the successful venting of the Unit 2 containment could not be verified.

After the HPCI failed in Unit 3 on 13 March, approximately seven hours elapsed until an alternative injection source could be established. The RPV pressure was reduced through steam discharge through one of the SRVs into the suppression pool. The accumulator of the SRV contained adequate nitrogen pressure so the SRV could be opened with car batteries. Once pressure was reduced, injection of water was established using a fire engine pump injecting through the fire protection and MUWC lines connected to the LPCI (one mode of the RHR system) lines. Boron was added intermittently. The suction of the pump was changed to a pit filled with sea water at one point temporarily interrupting injection for a short time, on the order of minutes. A further interruption occurred for two hours. Once restarted, a total of 4495 tonnes of sea water was injected from 13 March until 25 March, at which time a fresh water source was established similar to that of Unit 1.

Alignment of valves to vent the Unit 3 containment was begun on 13 March at approximately 8:41 using air cylinders and an engine generator. Several attempts were made to open the valves and at 9:20 successful venting was confirmed by the decrease in dry well pressure; however, due to the leakage of air, an engine driven air compressor was finally used to provide the required air pressure. At 11:01 on 14 March, a hydrogen explosion occurred in the Unit 3 reactor building resulting in substantial damage. At approximately 6:00 on 15 March, an explosion occurred in the Unit 4 reactor building. Since the spent fuel in the Unit 4 spent fuel pool appears to have been covered with water precluding the generation of hydrogen, the source of flammable gas is unclear. A potential source is hydrogen in the Unit 4 reactor building backflowing from the Unit 3 standby gas system lines through the vent lines of Unit 4. Units 3 and 4 share a common header that vents to the exhaust stack. This is not confirmed. Plans have been made to inert the Unit 3 containment with nitrogen in the future.

## MAAP Calculations of the Unit 1-3 Core Degradation Sequence

TEPCO has performed a simulation of the accident using the Modular Accident Analysis Programme (MAAP) code. The information below is only an estimate of the core behaviour.

Based on the calculation, assuming an estimated injection rate, the top of active fuel (TAF) was reached in Unit 1 about three hours after the plant trip. The core was completely uncovered two hours later. Core damage is calculated to have begun four hours after the trip and a majority of the fuel in the central region of the core was melted at 5.3 hours after the trip. At 14.3 hours after the trip, the core was completely damaged with a central molten pool and at 15 hours after the trip, all fuel had slumped to the bottom of the vessel. Although the calculation shows that the RPV is severely damaged, measured data show much cooler temperatures. Due to the uncertainty in the instrumentation at Dai-ichi, the state of the vessel is unknown.

The calculation of the accident progression of Unit 2 is based on an assumed seawater injection rate such that the reactor water level was maintained at about the midpoint of the active fuel as measured by the instrumentation available during the event. The calculation shows that when the RCIC system was available, the water level was maintained well above the TAF. Once RCIC was lost and the system was depressurized the water level dropped to the bottom of active fuel (BAF) about 76 hours after the trip. Seawater injection was initiated and according to the instrumentation, the water level remained at the midpoint of the active fuel region, leading to a rapid increase in core temperature, reaching the melting point. A molten pool existed in the central region of the core with melted fuel surrounding it at 87 hours after the trip. The molten pool was shown to grow larger by 96 hours and then begin to cool at 120 hours. At one week after the trip, there was a small molten pool surrounded by melted fuel. Due to the uncertainties in instrumentation which gave information about the selection of seawater injection rate, another calculation was performed using a reduced rate. This model shows that the fuel has slumped and in turn the RPV is extremely damaged at 109 hours after the trip. Although the calculation shows that the RPV is severely damaged, measured data show much cooler temperatures. Due to the uncertainty in the instrumentation at Dai-ichi, the state of the vessel is unknown.

The calculation of the accident progression at Unit 3 is based on an assumed seawater injection rate such that the reactor water level was maintained at about 3 m below the TAF, as measured by the instrumentation available during the event. The calculation shows that the core was covered until the RCIC and HPCI systems failed. Once seawater injection was initiated and the water level stayed at around 3 m below the TAF, the temperature of the core increased quickly, reaching the melting point. The extent of fuel melting is less than that of Unit 1. This is presumed to be because the time between failure of the RCIC and start of the HPCI system was smaller than the time of no injection in Unit 1. At 64 hours after the trip, a molten pool smaller than Unit 1 was surrounded by melted fuel, and a week after the scram the molten pool had cooled somewhat. No slumping of the fuel to the bottom of the RPV was predicted. Due to uncertainties in instrumentation which gave information about the selection of the seawater injection rate used in the calculation, another calculation was performed using a reduced injection rate. This case predicts that slumping of the fuel occurs at 62 hours after the scram. Although the calculation of this scenario shows that the RPV is severely damaged, measured data show much cooler temperatures. Due to the uncertainty in the instrumentation at Dai-ichi, the state of the vessel is unknown.

## Response of Units 5 – 6 and Site Spent Fuel Storage

Units 5 and 6 are located a distance from Units 1–4, and are at a higher elevation than Units 1–4. They suffered less damage than Units 1–4, although the damage was still severe. As a result of the earthquake all off-site power was lost. As in Units 1–4, the seawater ultimate heat sink was lost as a result of the tsunami, and in Unit 5, all EDGs were lost due to flooding. One air cooled EDG was available at Unit 6 because the air intake louvers were located above the tsunami inundation height. Units 5 and 6 had been shutdown since January 2011 and August 2010, respectively, and the fuel had been reloaded into the core recently, awaiting startup. Though decay heat was much lower than the operating plants, cooling the fuel in the cores was necessary and action was taken to restore the seawater cooling system.

On 12 March, measures were successful to provide AC power to important components of Unit 5 using the Unit 6 EDG. On 13 March, the MUWC system was used to inject coolant into the core, and steam was discharged through the SRVs to the suppression pool. Due to the low decay heat of the fuel, venting of the containment was not necessary. On 19 March, an alternate cooling path to cool the RHR system was established. The RHR pump was powered from the Unit 6 EDG. A temporary pump provided sea water to the RHR heat exchangers using an engine-generator to provide AC power. On 20 March, the core was cooled to cold shutdown levels. Plans are underway to provide more heat removal capacity.

There are seven spent fuel pools (SFPs) at the Fukushima Dai-ichi site. One at each unit and a common SFP located behind Unit 4, which contains older fuel removed from the Units' SFPs. SFPs have a large inventory of water above the TAF, approximately 7–8 m, although at Fukushima some of the water inventory could have been lost as the result of the sloshing from the earthquake. Although dependent on the heat load of the fuel stored in the pool, the large inventory of water typically allows many days before the pool would boil to a level below the TAF. Therefore, immediate action to cool the SFPs was not necessary. Because of the lack of instrumentation and high radiation levels, the water levels in the SFPs of Units 1–4 could not be determined in the first several days of the accident. However, the explosions at the site destroyed the reactor building roofs of Units 1, 3 and 4, providing access to the SFPs. Several options were considered to provide coolant to the SFPs periodically. Both fresh and sea water were used. Two techniques involved the use of a water cannon and dropping a water supply from a helicopter. These techniques were used on the Unit 3 SFP beginning 17 March, and then on the Unit 4 SFP beginning 20 March. The success of these techniques could not be verified. Another technique which involved utilizing existing fuel pool cooling system lines and temporary pumps was used on the Unit 2 SFP beginning 20 March and on the Unit 3 SFP beginning 23 May. Beginning 22, 27 and 31 March, coolant was provided to the Unit 4, 3 and 1 SFPs, respectively, using a concrete pumping truck with a hose secured to a boom lifted to the appropriate height. To determine the status of the SFPs, images were taken of the Unit 3 and 4 SFPs remotely. The images verified the presence of a water level and showed that the fuel appeared to be intact. An extensive amount of debris generated by the explosion in Unit 3 had fallen into the Unit 3 SFP, so that the structural integrity of the racks could not be confirmed. There was some debris in the Unit 4 SFP, likely due to the explosion at Unit 4, but the status of the racks and the fuel is reported to be near normal on the basis of present information. At this stage, the concrete pumping truck and boom technique is being applied to the Unit 1 and 4 SFPs. Inventory is being provided to the Unit 2 and 3 SFPs via the fuel pool cooling system lines. Both techniques connect to a header that is fed by a pump taking suction from a large water tank. Fresh water is pumped to the tank from the nearby dam.

Forced cooling was used at the site to cool the Unit 5 and 6 SFPs, using the AC power from the Unit 6 EDG. Forced cooling was established in the common SFP once AC power was provided to the site in late March. Because of its low heat load, no action was necessary earlier in the event.

A dry cask storage building is located adjacent to the Unit 5 turbine building. The building was damaged by the tsunami but the casks appear to be intact. Radioactivity monitoring has been used to determine the status of the fuel. Because no radioactivity release has been detected, the dry casks appear to be unaffected.

## 2.2 FUKUSHIMA DAI-NI NUCLEAR POWER STATION

The Fukushima Dai-ni site has four BWR-5 reactors with Mark II containments. At the time of the earthquake, all four units at Fukushima Dai-ni were operating. In response to the earthquake, all four units automatically scrammed (shutdown). One off-site power source remained operable, while the other three off-site power sources were either lost or in scheduled maintenance. About 37 minutes after the earthquake, the first tsunami wave hit the site followed by several additional tsunami waves, leading to the inundation of the site. Workers were temporarily evacuated from the site as a result of several aftershocks and accompanying tsunami alerts, which hindered recovery actions. The maximum acceleration of the earthquake was less than the standard seismic ground motion for each unit. However, the tsunami was much greater (inundation height of approximately 6.5–7 m) than the reference tsunami level of 5.2 m. The reactor buildings and the turbine buildings are at an elevation of 12 m, and although the run-up wave of the tsunami that reached this elevation caused partial flooding of these buildings, the extent of flooding was less than at Fukushima Dai-ichi.

The tsunami waves flooded the heat exchanger building, the seawater pumps and electric power centres, which caused the loss of core cooling functions and pressure suppression functions in three of the four units. The run-up wave that reached the reactor building of Unit 1 flooded its EDGs. Unit 3 was the least affected and was able to reach cold shutdown the day after the earthquake.

Because the extent of damage caused by the tsunami was not as great as at Fukushima Dai-ichi, the plant superintendent had more options for dealing with the effects of the tsunami. The plant operators were able to continue to provide water to the reactor cores with the RCIC and MUWC system, and to manually depressurize the reactors. The plant superintendent called for mobile power trucks and mobilized the workers on site to lay more than 9 km of temporary power cables in 16 hours. In addition, replacement motors were procured for some of the flooded pumps. This allowed the normal RHR systems to be returned to service three days following the tsunami, and the units were brought to cold shutdown either on the same day or the day after RHR had been restored.

## 2.3 TOKAI DAI-NI NUCLEAR POWER STATION

The Tokai Dai-ni site has a single BWR-5 reactor with a Mark II containment. At the time of the earthquake, Tokai Dai-ni was operating. In response to the earthquake, the reactor automatically scrammed (shutdown). All three off-site power sources were lost and all three emergency diesel generators started automatically. About 30 minutes after the earthquake a tsunami flooded the lower level of the site. The maximum acceleration of the earthquake was less than the design basis of the site. However, the tsunami was 5.4 m (above Hitachi Point) whereas the design value (at the construction time) is 6.61 m (above Hitachi Point).

The tsunami flooded one bay containing some of the seawater pumps which caused the loss of one of the emergency diesel generators and one source of core cooling when the seawater cooling function was lost. The other bay containing seawater pumps had previously been upgraded to be watertight and the bay that was flooded was in the process of being upgraded.

# 3. MAIN FINDINGS, CONCLUSIONS AND LESSONS

## 3.1 PREAMBLE

These main findings are presented against the global context of the IAEA Safety Standards (Fundamental Safety Principles, Requirements and Guides) and Safety Services, and the work of the three groups covering: external hazards; safety assessment and management; and monitoring, emergency preparedness and response. The Fact Finding Expert Mission visited three of the sites affected; Tokai Dai-ni, TEPCO Fukushima Dai-ichi, and Dai-ni. Conclusions and potential lessons for improvement of nuclear safety are derived as are areas for future IAEA work, including issues that need further exploration or assessment. The detailed findings and further information upon which these main findings are based are provided in the form of ‘Finding Sheets’ provided in the Appendices. The findings are the result of meetings the Mission had with various Japanese agencies, including questions and answers, site visits and examination of documents.

## 3.2 CONTEXT

On 11 March 2011 Japan suffered its largest ever recorded earthquake, and within an hour a series of associated tsunami waves hit the east coast of Japan. These caused massive devastation. The infrastructure (roads, electrical supply, communications, etc.) was severely impaired. Whole towns were destroyed or swept away.

Against this background the operators of nuclear facilities in this part of Japan and authorities were faced with securing the safety of nuclear facilities and people. There are several nuclear power plants along the East Coast of Japan that were affected.

The worst affected sites are TEPCO Fukushima Dai-ichi and Fukushima Dai-ni. Fukushima Dai-ni lost some safety related equipment but off-site and on-site power remained available albeit somewhat degraded. On the other hand, Fukushima Dai-ichi lost much of its safety related equipment from the tsunami and all off-site and on-site power except for one diesel generator serving Unit 6. This led to a loss of cooling for the reactors of Units 1, 2 and 3 and the spent fuel pool of Unit 4; in addition cooling of other safety related equipment was unavailable or inaccessible. All these resulted in accident conditions at four units of Fukushima Dai-ichi NPP.

The response on the sites to the impact of the earthquake and tsunami, particularly at Fukushima Dai-ichi, was in unprecedented circumstances and has at times required exceptional levels of leadership and dedication by workers on the sites and elsewhere. At Fukushima Dai-ichi they were presented with a more or less complete prolonged loss of electrical power, compressed air and other services, with little hope of immediate outside assistance, and having to work in darkness with almost no instrumentation and control systems to secure the safety of six reactors, six nuclear fuel pools, a common fuel pool and dry cask storage facilities.

To date no confirmed health effects have been detected in any person as a result of radiation exposure from the associated nuclear accident. A realistic assessment of doses to individuals would require the establishment and implementation of appropriate health monitoring programmes, especially for the most exposed groups of population. Japan has created an expert group to deal with dose assessments and health surveys of residents. This group includes staff from the Fukushima Prefecture and Medical Universities, including Hiroshima and Nagasaki Universities.

It is understood that around 30 workers at the Fukushima plant have been exposed to radiation exposures of between 100 and 250 mSv, although very recent information indicates that some higher internal doses may have been incurred by some workers in the early days. Doses between 100 and 250 mSv, although significant, would not be expected to cause any immediate physical harm, although there may be a small percentage increase in their risk of eventually incurring some health effects. Monitoring programmes of workers, especially those in the group of higher doses and for internal exposures, are necessary as soon as possible to assist in eliminating any uncertainties and to reassure workers.

Three workers are reported to have suffered suspected radiation burns (non-stochastic effects) on their feet/legs from inadvertent exposure to heavily contaminated water in a turbine basement. After hospital treatment they were released after four days with reported no long-term likelihood of significant harm. Early on two workers on site were confirmed as dead (from other than radiation exposure) and several injured. A further worker was reported on 14 May 2011 to have died.

To avert potential radiation exposure to the public, the Japanese authorities took the precautionary action of instructing those within the first 3 km, then 10 km and finally 20 km of the plant to evacuate and those between 20 km and 30 km to shelter and get ready to evacuate. This instruction remains in place after several weeks. Information on the likely exposure of the public is not yet available, although evacuation and sheltering would have limited exposure. Any early exposure to the public before evacuation or sheltering is also not yet clear.

While there appear so far to have been few radiological health consequences the societal and environmental impacts of the accident have been extensive and far reaching, with tens of thousands of people being evacuated from around the plant, some foodstuffs and drinking water restrictions, and significant contamination of the sea. In addition there has been great public anxiety, both in Japan and internationally, about the possible health and other impacts of the radioactivity released. Finally, the economic impact of the failure of the plant is very significant.

Ten weeks after the accident there is much that is not yet known about the accident and others will in due course examine the sequence of events in detail. In particular, the Japanese government has set up an independent Investigation Committee, consisting of scientists, lawyers and others who have no significant connection with the Japanese nuclear industry to examine the details and determine responsibilities.

The present IAEA International Fact Finding Expert Mission set out to gather facts and review them to identify lessons that might be learned to improve nuclear safety worldwide. In doing so it recognized that severe accidents can arise from a variety of causes, not necessarily the direct causes associated with the Fukushima accident, and that therefore the lessons could have wide applicability.

The IAEA has a system of Fundamental Safety Principles, international safety requirements and guides and services. The Fundamental Safety Principles are applicable over all areas of the peaceful use of nuclear energy and radioactivity whereas the safety requirements and guides are more targeted and constitute the accumulated knowledge and experience of the world in nuclear safety over the last fifty years, reflecting best practices in Member States. The IAEA safety services range from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations. They are to assist Member States in applying the standards and appraise their effectiveness.

It is in this context that the Mission has come to the following conclusions and lessons to improve nuclear safety.

## 3.3 IAEA FUNDAMENTAL SAFETY PRINCIPLES: GENERAL

The circumstances of the Fukushima accident and the main conclusions and lessons have been considered in the context of the application of the IAEA Fundamental Safety Principles to securing the highest standards of nuclear safety. In general, it is concluded that:

> **Conclusion 1: The IAEA Fundamental Safety Principles provide a robust basis in relation to the circumstances of the Fukushima accident and cover all the areas of lessons learned from the accident.**

While all principles are relevant, the ones which are most relevant to the circumstances of this accident, and under which the conclusions and lessons of this Mission are summarized, are discussed below.

### 3.3.1 Fundamental Safety Principle 3: Leadership and Management for Safety

This states that effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.

The Mission had the opportunity to receive detailed presentations of the scenario of the accident and its technical management. These presentations were mostly given by TEPCO, at the headquarters and plant levels. Complementary presentations were also given by the Nuclear and Industrial Safety Agency (NISA), the nuclear regulator, other Government Ministries and agencies. These presentations were greatly enhanced by site visits which allowed the Mission to hear and see at first hand the extremely difficult work involved, and have a concrete view of the practical conditions under which the operators had to manage the accident and to perform their interventions.

The extreme difficulties that the operators on the site had to face in Fukushima Dai-ichi have to be once again strongly underlined: loss of all the safety systems, loss of practically all the instrumentation, necessity to cope with simultaneous severe accidents on four plants, lack of human resources, lack of equipment, lack of light in the installations, and general conditions of the installation after the tsunami and after damage of the fuel resulted in hydrogen explosions and high levels of radiation. Access to outside resources and off-site communications dependent on the local telecommunication network were also severely disrupted, although the TEPCO in-house communications network between the site and headquarters had been mostly intact.

Understanding in detail the sequences of the accidents in the plants is a very complex and difficult task which has to be undertaken in the future. Many uncertainties remain today and will hopefully be resolved in the future. However, in view of the information that was provided to the Mission, it is considered that, given the circumstances, the local teams have managed the accident in the best possible way they could. Given the resources available on the site and the difficulty of the situation, it is doubtful at this stage that any better solutions than the ones actually chosen could have been realistically implemented. It is therefore concluded that:

**Conclusion 2: Given the extreme circumstances of this accident the local management of the accident has been conducted in the best way possible and following Fundamental Safety Principle 3.**

### 3.3.2 Fundamental Safety Principle 8: Prevention of Accidents

This states that all practicable efforts must be made to prevent and mitigate nuclear or radiation accidents. A prime aspect of this principle is the concept of ‘defence-in-depth’. Successive layers of protection are provided which are as far as possible independent of each other and each of which is sufficient to prevent harm occurring. Defence-in-depth covers all layers of protection: management systems and cultures; site selection; design incorporating safety margins, diversity and redundancy with appropriate attention to quality and reliability requirements; operating systems; accident and emergency arrangements, etc. Detailed safety analysis is the basis for determining and ensuring the adequacy of these barriers.

#### 3.3.2.1 External Hazards

External hazards, especially those of a natural origin, can cause widespread long term disruption both on and off a nuclear installation site, reaching regional and national scales. This was a particular feature of the Fukushima accident, where the ground motions from one the most extreme earthquakes that have been recorded in Japan was followed by the associated large tsunami. It caused a prolonged loss of off-site power with disruption of roads and communication infrastructure (note, however, that TEPCO’s in-house communications network independent from the local telecommunication network was mostly intact after the earthquake and tsunami, and played an instrumental role in securing communication channels between the site and headquarters, etc.). Although the plant withstood the effects of the earthquake, the tsunami caused the loss of most safety systems for cooling of the reactor cores, supply of emergency power and control of containment pressures, etc. It is concluded therefore that:

**Conclusion 3: There were insufficient defence-in-depth provisions for tsunami hazards. In particular:**

- **although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Dai-ichi NPP as described during the meetings and the expected tsunami height was increased to 5.7 m (without changing the licensing documents) after 2002, the tsunami hazard was underestimated;**
- **thus, considering that in reality a ‘dry site’ was not provided for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the high tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and dynamic impact of large debris with high energy);**
- **moreover, those additional protective measures were not reviewed and approved by the regulatory authority;**
- **because failures of structures, systems and components (SSCs) when subjected to floods are generally not incremental, the plants were not able to withstand the consequences of tsunami heights greater than those estimated, leading to cliff edge effects; and**
- **severe accident management provisions were not adequate to cope with multiple plant failures.**

The status of multiple plants affected by the tsunami makes them more vulnerable to any further extreme natural hazards, even though the reactors are in a shutdown state. It is therefore concluded that:

**Conclusion 4: For the Tokai Dai-ni and Fukushima Dai-ni NPPs, in the short term, the safety of the plant should be evaluated and secured for the present state of the plant and site (caused by the earthquake and tsunami) and the changed hazard environment. In particular, if an external event PSA model is already available, this would be an effective tool in performing the assessment.**

**Short term immediate measures at Fukushima Dai-ichi NPP need to be planned and implemented for the present state of the plant before a stable safe state of all the units is reached. Until that time the high priority measures against external hazards need to be identified using simple methods in order to have a timely plan. As preventive measures will be important but limited, both on-site and off-site mitigation measures need to be included in the plan. Once a stable safe state is achieved a long term plan needs to be prepared that may include physical improvements to SSCs as well as on-site and off-site emergency measures.**

To ensure that all plants are robust to such external events in the longer term and brought under greater regulatory control, it is also concluded that:

**Conclusion 5: An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Earthquake and Tsunami, fulfilling the requirements and using also the criteria and methods recommended by the relevant IAEA Safety Standards for comprehensively coping with earthquakes, tsunamis and external flooding and, in general, all correlated external events. The national regulatory documents need to include database requirements compatible with those required by IAEA Safety Standards. The methods for hazard estimation and the protection of the plant need to be compatible with advances in research and development in related fields.**

From a wider perspective, it is considered that worldwide nuclear safety could be improved in the context of enhanced protection against external hazards, in particular:

**Lesson 1: There is a need to ensure that in considering external natural hazards:**

- **the siting and design of nuclear plants should include sufficient protection against infrequent and complex combinations of external events and these should be considered in the plant safety analysis – specifically those that can cause site flooding and which may have longer term impacts;**
- **plant layout should be based on maintaining a 'dry site concept', where practicable, as a defence-in-depth measure against site flooding as well as physical separation and diversity of critical safety systems;**
- **common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;**
- **any changes in external hazards or understanding of them should be periodically reviewed for their impact on the current plant configuration; and**
- **an active tsunami warning system should be established with the provision for immediate operator action.**

#### 3.3.2.2 Severe accidents

Traditionally, nuclear safety design has been based on the concept that the plant will be designed to withstand all normal conditions and reasonably foreseeable abnormal/fault conditions with a margin. The design basis usually excludes very remote events or combination of events – those typically with a lesser probability of occurrence than 1 in 10 000 to 100 000 per year. However, the designer is also expected to consider beyond design basis events to see whether more can reasonably be done to reduce the potential for harm, especially where major consequences may ensue. Severe accidents, with significant consequences, require particular attention in design, management and emergency response arrangements. Normally, special operating procedures, called 'Severe Accident Management Guidelines' are developed for this. This review of the Fukushima accident has highlighted the following matters.

> **Lesson 2: For severe situations, such as total loss of off-site power or loss of all heat sinks or the engineering safety systems, simple alternative sources for these functions including any necessary equipment (such as mobile power, compressed air and water supplies) should be provided for severe accident management.**

> **Lesson 3: Such provisions as are identified in Lesson 2 should be located at a safe place and the plant operators should be trained to use them. This may involve centralized stores and means to rapidly transfer them to the affected site(s).**

This was clearly demonstrated at Dai-ni where the laying of a completely independent power supply route for provision of cooling in the longer term (involving installing 9 km of heavy electrical cabling in 16 hours) was effective in curtailing the development of a severe accident. Similarly, at Dai-ichi fire tenders were used in series to lift sea water into an intermediate pit for further transfer to provide reactor cooling. Additionally, the normal diesel generators at the Tokai Dai-ni and Fukushima Dai-ni sites were augmented by JAPC’s and TEPCO’s fleet of mobile diesel generators held for loss of power to electrical supply customers, which may not always available in other countries. From such experiences, NISA organized a set of immediate measures for existing plants which addresses the matter including those identified in Lesson 2 and Lesson 3. NISA, on 30 March 2011, requested all of the utilities to implement them without delay.

The response to severe accidents being outside normal design and operating provisions presents special resource, management and instrumentation and control arrangements. This is particularly the case where multiple plants are involved as occurred at Fukushima Dai-ichi. It was apparent that more resources were required than what was available on site. In addition, there is a need for dedicated hardened capable facilities to manage and control the event. This was available and very effective at the Fukushima Dai-ichi and Dai-ni sites. This provides lessons for improvement of worldwide nuclear safety, viz:

> **Lesson 4: Nuclear sites should have adequate on-site seismically robust, suitably**

> **shielded, ventilated and well equipped buildings to house the Emergency Response Centres, with similar capabilities to those provided at Fukushima Dai-ni and Dai-ichi, which are also secure against other external hazards such as flooding. They will require sufficient provisions and must be sized to maintain the welfare and radiological protection of workers needed to manage the accident.**

Nevertheless, the response at least at Fukushima Dai-ichi was hampered by a lack of reliable safety related parameters and communications and this may be a general position in other countries. Thus:

> **Lesson 5: Emergency Response Centres should have available as far as practicable essential safety related parameters based on hardened instrumentation and lines such as coolant levels, containment status, pressure, etc., and have sufficient secure communication lines to control rooms and other places on-site and off-site.**

There were particular challenges at TEPCO's Fukushima Dai-ichi because of the high radiation fields, and with the tsunami and explosions there was considerable debris disrupting normal routes. Additionally, control room access was limited and safety related instrumentation was generally not available or unreliable. Severe Accident Management Guidelines (SAMG) and associated procedures generally assume that instruments, lighting and power are available. This may not be the case. In addition, these documents do not consider the possible state of the plant and the local environmental conditions such as the radiation field that may preclude manual actions from being taken. Consequently, it is considered that:

> **Lesson 6: Severe Accident Management Guidelines and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state and high radiation fields.**

The assessment performed by the Mission also highlighted several lessons related to the arrangements for severe accident management to improve nuclear safety, viz:

> **Lesson 7: External events have a potential of affecting several plants and several units at the plants at the same time. This requires a sufficiently large resource in terms of trained experienced people, equipment, supplies and external support. An adequate pool of experienced personnel who can deal with each type of unit and can be called upon to support the affected sites should be ensured.**

Particular difficulties were experienced in responding at the TEPCO’s Fukushima Dai-ichi site because of the hydrogen explosions. This may not be adequately taken into account in the plant safety case, design and protective measures. Thus, it is considered that:

> **Lesson 8: The risk and implications of hydrogen explosions should be revisited and necessary mitigating systems should be implemented.**

One air cooled EDG in Unit 6 at Fukushima Dai-ichi survived partially because it was air cooled and partially because it was effectively protected against flooding, It ensured the protection of Units 5 and 6 (others are seawater cooled or are air cooled but their associated electrical panel and cables were inundated). This demonstrates the benefits of diverse provision of essential safety related services:

> **Lesson 9: Particularly in relation to preventing loss of safety functionality, the robustness of defence-in-depth against common cause failure should be based on providing adequate diversity (as well as redundancy and physical separation) for essential safety functions.**

### 3.3.3 Fundamental Safety Principle 9: Emergency Preparedness and Response

This states that arrangements must be made for emergency preparedness and response for nuclear or radiation incidents.

#### 3.3.3.1 Off-site Emergency Arrangements to Protect the Public and Environment

The Japanese emergency arrangements involve several layers and different organizations with decision making at high level. Normally, less complicated arrangements are used and decisions such as instigating evacuation made at more local level to ensure that countermeasures are timely and conducted in an orderly way. The earthquake and tsunami degraded the ability to implement effective off-site monitoring in the early stages of the accident. Thus, greater reliance would have had to be placed on understanding the accident, its likely progression and off-site impact. From the Mission's review and observations it is concluded that:

> **Conclusion 6: Japan has a well organized emergency preparedness and response system as demonstrated by the handling of the Fukushima accident. Nevertheless, complicated structures and organizations can result in delays in urgent decision making.**

> **Conclusion 7: Dedicated and devoted officials and workers, and a well organized and flexible system made it possible to reach an effective response even in unexpected situations and prevented a larger impact of the accident on the health of the general public and facility workers.**

The fast changing plant circumstances and absence of real time information on the plant conditions led to the need to take several consecutive countermeasures to protect the public rather than the expected reliance on dose measurements. In the first days after the accident, the environmental monitoring programme failed due to damage of equipment by the earthquake and tsunami. This indicates the need for hardened instrumentation, communication, etc. to provide necessary information for on-site and off-site response management and for early off-site monitoring capability.

> **Lesson 10: Greater consideration should be given to providing hardened systems, communications and sources of monitoring equipment for providing essential information for on-site and off-site responses, especially for severe accidents.**

The effectiveness of the Japanese response seemed not to have been impeded by reliance more on high level laws than detailed emergency plans under them. However, normally effective response is sustained for a range of scenarios through having well established intervention levels and associated plans. Other systems may not be as effective in responding to different scenarios and should be assessed against IAEA Safety Standards for ensuring robust responses to severe accidents.

> **Lesson 11: The use of IAEA Safety Requirements (such as GS-R-2) and related guides on threat categorization, event classification and countermeasures, as well as Operational Intervention Levels, could make the off-site emergency preparedness and response even more effective in particular circumstances.**

A concept of long term indoors sheltering was introduced in some areas to booster long term countermeasures but this has been found not to be practicable and has been replaced by other more established measures using guidelines of the International Commission on Radiological Protection (ICRP) and IAEA.

> **Lesson 12: The use of long term sheltering is not an effective approach and has been abandoned and concepts of 'deliberate evacuation' and 'evacuation-prepared area' were introduced for effective long term countermeasures using guidelines of the ICRP and IAEA.**

The knowledge of the source term involved in an accident is considered of paramount importance to reach a clear understanding of the event and to determine the possible extent of its radiological impact on the public and the environment. The Fukushima accident provides a unique opportunity to extend understanding in this area.

> **Lessons 13: The international nuclear community should take advantage of the data and information generated from the Fukushima accident to improve and refine the existing methods and models to determine the source term involved in a nuclear accident and refine emergency planning arrangements.**

A proper assessment of doses could contribute to defining and optimizing the strategy for individual health monitoring. Direct monitoring of exposure, using suitable equipment (such as personal contamination equipment), and the use of the results of the environmental monitoring, could help in achieving a realistic assessment of doses, and so enhance the confidence of the population, and determine health tracking programmes.

> **Conclusion 8: A suitable follow up programme on public exposures and health monitoring would be beneficial.**

#### 3.3.3.2 On-site Emergency Arrangements to Protect Workers

During the Fukushima accident the extensive disruption from the earthquake and tsunami on and off the sites made the implementation of the nuclear emergency arrangements extremely challenging, sometimes making it impossible to fully follow well established procedures and practices on site. However, the ability of the site management to effectively control doses in exceptional circumstances was commendable. This was further reinforced by the team’s experience at the ‘J-Village’ coordination centre, where it appeared that around 2000 workers a day were being provided with full face masks and other radioactivity protection in a well organized and effective way. Similarly, at all the sites visited by the Mission, including Fukushima Dai-ichi with its severe problems, effective health physics protection was evident. The organization, discipline and devotion during the response to this most complex nuclear multiple accident is an example to all.

After the accident, the operator gradually improved on-site radiological monitoring, and comprehensive radiation maps of the site are currently available and updated on a periodic basis. This information is used to classify the radiological areas in terms of exposure risks and to determine the protection equipment and procedures to be employed by workers in their tasks. Extensive use of the radiological maps to optimize protection of workers, including the establishment of clear physical barriers between the radiological areas, are used to separate those in the highest risk category to prevent possible unexpected or unauthorized entries.

**Conclusion 9: There appears to have been effective control of radiation exposures on the affected sites despite the severe disruption by the events.**

**Lesson 14: Large scale radiation protection for workers on sites under severe accident conditions can be effective if appropriately organized and with well led and suitable trained staff.**

**Lesson 15: Exercises and drills for on-site workers and external responders in order to establish effective on-site radiological protection in severe accident conditions would benefit from taking account of the experiences at Fukushima.**

## 3.4 IAEA SAFETY REQUIREMENTS AND GUIDES

A particular feature of the Fukushima accident was the need to deal with serious events at several reactors on the site. This aspect has implications for multi-plant siting, design, layout, operation and emergency response arrangements. Detailed safety analysis of the progression of the accidents at each of the units at Fukushima Dai-ichi would provide a basis for additional lessons for improving IAEA Safety Requirements and Guides, as appropriate. Lessons should be learned from this experience and it is concluded that:

**Conclusion 10: The IAEA Safety Requirements and Guides should be reviewed to ensure that the particular requirements in design and severe accident management for multi-plant sites are adequately covered.**

## 3.5 IAEA SAFETY SERVICES

The IAEA has in place a series of services for Member States to use to check and enhance their safety arrangements. These have grown over the years and become more comprehensive. Developments in these services reflect the periodic review and updating of IAEA Safety Requirements and Guides. Of particular note has been the expansion of capability to provide a review of provisions for extreme external hazards. The circumstances of the Fukushima accident indicate that the use of these services on a periodic basis could be beneficial in ensuring that the best international practice is sustained across Member States.

> **Conclusion 11: There is a need to consider the periodic alignment of national regulations and guidance to internationally established standards and guidance, for inclusion in particular of new lessons learned from global experiences of the impact of external hazards.**

## Future Missions and Work by the IAEA on Fukushima

### 3.4.1 Road Map to Restoration

The roadmap towards restoration from the accident was presented to the Mission by TEPCO and NISA. This roadmap appears to be ambitious but achievable and to include the issues to be addressed in order to insure sustainable safety as well as protection of the environment. Some subjects appear to be of particular importance such as the installation of sustainable cooling systems for the reactor cores and spent fuel pools, the treatment of the highly contaminated water contained in the basements of the buildings as well as the sheltering of the damaged reactor building in order to protect the environment against further releases. The Mission acknowledged the importance and relevance of the roadmap and considered that it could be a subject for extended international collaboration, if so wished by the Japanese Government, led by the IAEA. It noted that given the circumstances on the site, it may require modification as new or unexpected circumstances are revealed.

The roadmap could usefully be seen as a vital component of a wider plan that could result in remediation of the areas off the site affected by the radioactive releases to allow people evacuated to resume their normal lives. This would be a useful demonstration to the world of what can be achieved in responding to such extreme nuclear events.

### 3.4.2 External Hazards

There is much to be learned in the area of earthquake preparedness and hazard assessment for NPPs in Japan. It is therefore concluded that

**Conclusion 12: The Safety Review Services available with IAEA-ISSC would be useful in assisting Japan's development in the following areas:**

- **External event hazard assessment**
- **Walkdowns for plants that will start up following a shutdown; and**
- **Pre-earthquake preparedness.**

### 3.4.3 Off-site Emergency Response

There is potentially much to learn from the Japanese experience of operating effective emergency responses on and off nuclear sites in extreme circumstances. It is worthy of a more detailed study than was possible in this short Mission. It is therefore concluded that:

**Conclusion 13: A follow-up mission including EPREV should look in detail at lessons to be learned from the emergency response on and off the site.**

### 3.4.4 Organization of Large Scale Radiation Protection for Severe Accident Conditions

As noted above, despite the severity of the accident, to date the organization for large scale radiation protection on and off the site appears to have been very effective. There may be several lessons for other nations in developing their arrangements in this area and therefore it is concluded that:

**Conclusion 14: A follow-up mission should be conducted to seek lessons from the effective approach used to provide large scale radiation protection in response to the Fukushima accident.**

### 3.4.5 Follow-up IRRS Mission

The main objective of the Mission was to collect facts and to perform a preliminary assessment of the Fukushima accident for worldwide learning. Most of the investigations were therefore directed towards technical issues related to nuclear safety and radiation protection of the population and the environment. However, the investigations performed by the Mission allowed it to perceive more general issues related to the framework for safety in Japan, to the clarity of the allocation of responsibilities and to the independence of the regulator. The different contacts of the team with the key players in the management of the accident gave the impression of some lack of consideration for the system and mutual recognition of its participants. Some presentations suggested, for example, that the government has the direct responsibility for safety, while the IAEA Fundamental Safety Principle 1 specifies that this responsibility rests with the utility. Nevertheless, from discussions it is apparent that the site directors at Dai-ichi and Dai-ni recognized their prime responsibilities and acted accordingly.

On the other hand, the local managers of the plants needed to concentrate on effective on-site response rather than serving the needs of wider stakeholders. More generally, it also seems that interactions between NISA and TEPCO could benefit from the development of technical depth rather than formal regulatory relations. This may need an enhancement of NISA's technical capability.

The respective roles of the Nuclear Safety Commission (NSC) and NISA are formally defined; however, some clarification seems necessary in their actual fields of intervention and respective contributions. Finally, the independence of NISA does not appear clearly in the organization put in place to manage the Fukushima accident. The two last points were already highlighted as a result of the IRRS Mission performed in Japan in 2007. Additionally, care has to be exercised in the response to nuclear accidents that the operating organization's prime responsibilities for nuclear safety on sites are not transferred to the regulator or government.

> **Lesson 16: Nuclear regulatory systems should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.**

IAEA Fundamental Safety Principles 1 and 2 form the basis for effective general nuclear arrangements in a country. Their application provides for the establishment of three distinct roles for the utility, the regulator and government. In summary, the utility has prime responsibility for safety and as such has to ensure that it takes appropriate decisions and actions. The regulator oversees the activities of the utility and ensures that it meets its legal obligations through assessment, inspection and enforcement (which can include advice) but in doing so it should not take decisions that make it effectively responsible for safety. Similarly, the government's role is to ensure that there are appropriate laws and regulations in place, that the regulator has the means (resources, technical capabilities, powers, etc.) to provide effective oversight of the utility, and that the regulator is effectively independent of the licensee and of any other body, so that it is free from any undue pressure from interested parties. These roles and responsibilities should not be confused, even in emergency situations. However, in such circumstances close cooperation is required to ensure that optimum protection of the public is ensured and that relevant information is available. This is especially important in severe accidents when off-site countermeasures may be required over extensive areas and need to be enacted through various agencies or departments.

The implementation of a follow-up IRRS Mission would be a good occasion to assess the current situation and its evolution since 2007. Such a mission could provide a useful and independent input to the Japanese Government as a complement to the conclusion of the independent Investigation Committee, set up by the Japanese Government to assess the management of the Fukushima accident.

> **Conclusion 15: A follow-up mission to the 2007 IRRS should be conducted in light of the lessons to be learned from the Fukushima accident and the above conclusions to assist in any further development of the Japanese nuclear regulatory system.**

# 4. ACKNOWLEDGEMENTS

In conducting this Mission we have been greatly humbled by the fortitude, stoicism and nature of the Japanese people in responding to their terrible loss from the effects of the earthquake and associated tsunami. Our sympathy goes out to them in their suffering.

Throughout the Mission, the IAEA team received excellent cooperation from all the Japanese counterparts and organizations involved. Questions asked by the IAEA team were fully answered with expert explanations. Where required, additional documentation was provided. The Mission benefited greatly from the visits to the three sites which were greatly facilitated by staff on-site and off-site who put aside time and effort despite the extreme pressures they had had and were under in responding to the accident.

# APPENDICES

# Appendix 1

## *IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East Japan Earthquake and Tsunami*

## *Japan*

# *FINDING SHEETS*

# *External Hazards*

***IAEA 2011***

# FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A1-01** |
|---|---|
| Assessment Area: | **A1 - EXTERNAL EVENT OF NATURAL ORIGIN** |
| Facility: | **FUKUSHIMA DAI-ICHI NPP** |
| Unit: | **UNITS 1 TO 6** |
| Finding Title: | **EARTHQUAKE HAZARDS** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

The site of a nuclear installation shall be adequately investigated with regard to all characteristics that could be significant to safety and possible external natural and human induced hazardous phenomena.

In this context, earthquakes pose a significant hazard to nuclear installation and they are one of the most important natural events to be adequately investigated and evaluated. In that regard, "…the seismological and geological conditions in the region and the engineering geological aspects and geotechnical aspects of the proposed site area shall be evaluated." Site Evaluation for Nuclear Installations, NS-R-3, 2003, paragraph 3.1. states the following key requirements:

– "*Information on prehistorical, historical and instrumentally recorded earthquakes in the region shall be collected and documented*";

– "*The hazards associated with earthquakes shall be determined by means of seismotectonic evaluation of the region with the use to the greatest possible extent of the information collected.*" (Ref. [1], para. 3.3.);

– "*Hazards due to earthquake induced ground motion shall be assessed for the site with account taken of the seismotectonic characteristics of the region and specific site conditions. A thorough uncertainty analysis shall be performed as part of the evaluation of seismic hazards.*"(Ref. [1], para. 3.4.);

– "*The potential for surface faulting (i.e. the fault capability) shall be assessed for the site. . . .*"(Ref. [1], para. 3.5.)

The above mentioned IAEA Safety Requirements are supported by the detailed recommendations provided in the newly revised Safety Guide SSG—9 in which methodologies and criteria for assessing the seismic hazards and, particularly, the seismic ground motions and the potential for fault capability are provided.

*The general approach to seismic hazard evaluation should be directed towards reducing the uncertainties at various stages of the evaluation process in order to obtain reliable results driven by data. Experience shows that the most effective way of achieving this is to collect a sufficient amount of reliable and relevant data. There is generally a trade-off between the time and effort necessary to compile a detailed, reliable and relevant database and the degree of uncertainty that the analyst should take into consideration at each step of the* *process. All ‘pre-instrumental’ data on historical earthquakes (that is, events for which no instrumental recording was possible) should be collected, extending as far back in time as possible. Palaeoseismic and archaeological information on historical and prehistorical earthquakes should also be taken into account.*

Consequently, after detailed hazard characterization is done, the plant shall be designed to withstand the seismic events according to specific design bases determined as result of this hazard assessment, as indicated in IAEA Safety Requirements-Safety of Nuclear Power Plants: Design, NS-R-1, 2000 Paragraphs 5.16 and 5.17. Moreover, paragraph 5.22 states that “*… The seismic design of the plant shall provide for a sufficient safety margin to protect against seismic events*”.

To comply with such design requirements the IAEA Safety Guide on “Seismic Design and Qualification for Nuclear Power Plants”, NS-G-1.6, 2003, provide detailed recommendations for design of systems, structures and components according to their safety significance and following the recognized international engineering practice and consensus at the time.

Finally, the evaluation of the seismic safety of existing power plants should be conducted as required by:

(a) Evidence of a seismic hazard at the site that is greater than the design basis earthquake arising from new or additional data (e.g. newly discovered seismogenic structures, newly installed seismological networks or new palaeoseismological evidence), new methods of seismic hazard assessment, and/or **the occurrence of actual earthquakes that affect the installation**;

(b) Regulatory requirements, such as the requirement for periodic safety reviews, that take into account the ‘state of knowledge’ and the actual condition of the installation;

(c) Inadequate seismic design, generally due to the vintage of the facility;

(d) New technical findings, such as vulnerability of selected structures, systems or components;

(e) New experience from the occurrence of actual earthquakes;

(f) The need to address the issue of performance of the installation for beyond design basis earthquake ground motions in order to provide confidence that there is no ‘**cliff edge effect**’; i.e. if an earthquake were to occur that were slightly greater than the design basis earthquake, to demonstrate that no significant failures would occur in the installation;

## 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

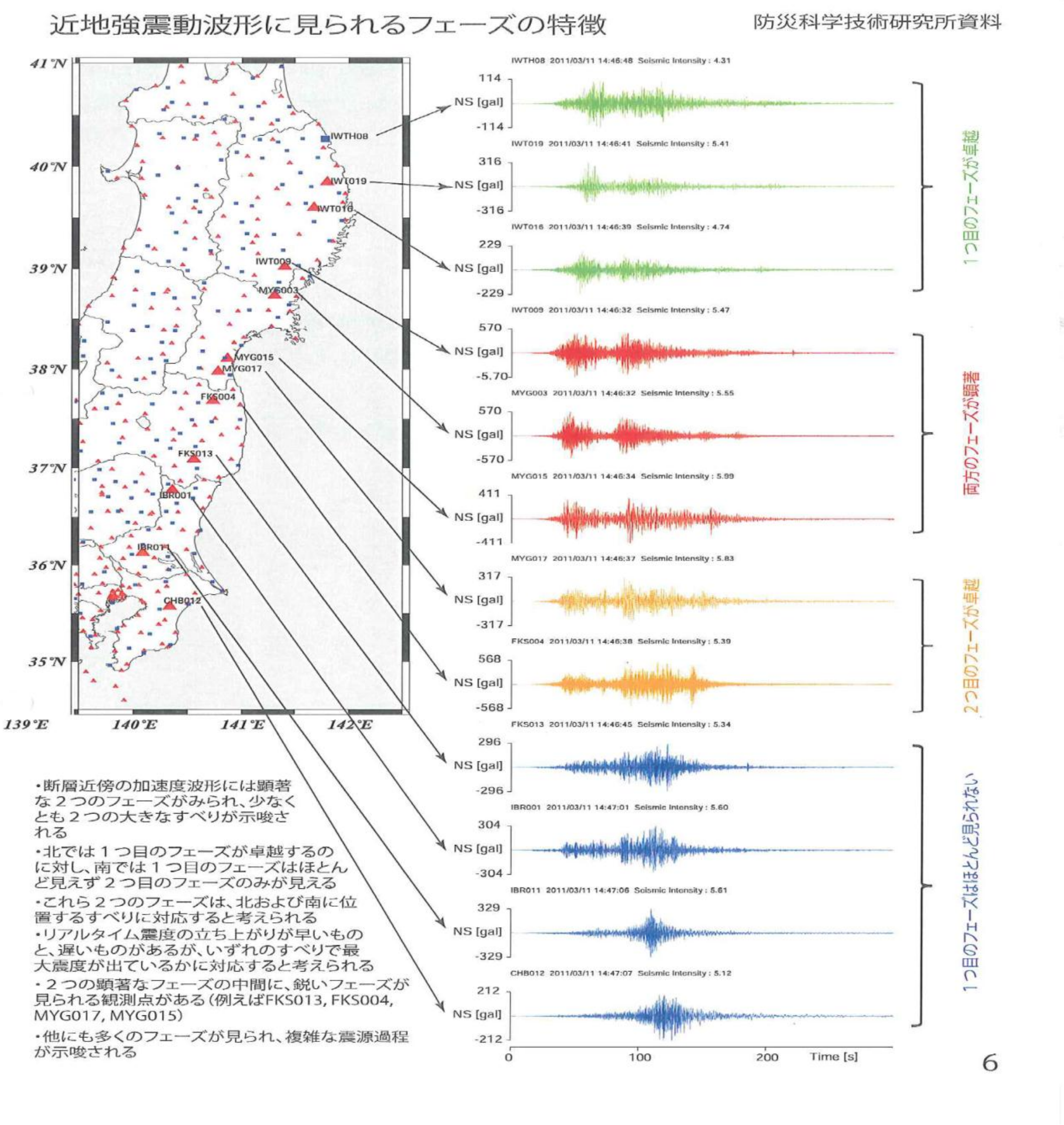
***General framework on applicable regulatory requirements and guidelines in Japan***

- At the time of the construction permit (from 1966 to 1972 for units 1 to 6) of Fukushima Dai-ichi NPP, the applicable and related regulatory requirements were those indicated in the Regulatory Guide for Review Nuclear Reactor Site Evaluation and Application Criteria, issued by the Nuclear safety Commission (NSC) in 1964 and revised in 1990, and in the Regulatory Guide for Reviewing Nuclear Reactor Safety Design, issued by NSC in 1970 and revised in 1977, 1981, 1990 and 2001 which provide general requirements on the need that safety related structures, systems and components (SSCs) shall be classified/categorized for seismic design on the basis of importance of their safety functions and the effects of earthquake caused losses of functions should not be affected by this natural hazards.

- Professional associations in Japan issued detailed guidelines for seismic design as the Japan Electric Association, Technical Guidelines for Seismic Design of Nuclear Power Plants, JEAG 4601-1970, JEA, (1970) and JEAG 4601-1987, JEA, (1987).
- In 2006 NSC issued the new Regulatory Guidelines titled ‘Regulatory Guide for Reviewing Seismic Design of NPP Facilities’ which provides guidance for adequacy of the seismic design for nuclear power plants.
- Accordingly, NISA requested that all NPPs should undergo a back check on the basis of the new 2006 NSC guidelines which include the need to re-evaluate the seismic hazards at the NPP sites to obtain the new so called “Design Basis Earthquake Ground Motion”, DBGM Ss and to execute the required upgrades. The experience gained from the Kashiwazaki-Kariwa case was also part of this process. It should also pointed out here that the NSC guidelines require to perform a residual risk evaluation to take account of the possibility of occurrence of an earthquake ground motion that may exceed the DBGM Ss.
- As indicated in Finding Sheet on Tsunami Safety, in the meeting with NSC authorities, it was indicated that the NSC guidelines are not legally binding and they are not “regulations” although in the practice they are considered as such. It was also expressed that these guidelines will be revised in view of recent experiences and lessons learned.
-

***The Great East Japan Earthquake of 11 March 2011***

- The Magnitude Mw 9.0 earthquake occurred at 14:46 on 11 March 2011, off the Pacific coast of the Tohoku region in the subduction zone. The hypocentre was located at 24 km depth and the epicentre at a distance of about 180 km from Fukushima Dai-ichi NPP site and 130 km from Onagawa NPP site. Its duration was very long, about 140-160 sec, and 2-3 significant pulses are present in the observed records. The following graph shows the observed records in a number of locations in the coastal zone of east Japan.



近地強震動波形に見られるフェーズの特徴

防災科学技術研究所資料

- 断層近傍の加速度波形には顕著な２つのフェーズがみられ、少なくとも２つの大きなすべりが示唆される
- 北では１つ目のフェーズが卓越するのに対し、南では１つ目のフェーズはほとんど見えず２つ目のフェーズのみが見える
- これら２つのフェーズは、北および南に位置するすべりに対応すると考えられる
- リアルタイム震度の立ち上がりが早いものと、遅いものがあるが、いずれのすべりで最大震度が出ているかに対応すると考えられる
- ２つの顕著なフェーズの中間に、鋭いフェーズが見られる観測点がある（例えばFKS013, FKS004, MYG017, MYG015）
- 他にも多くのフェーズが見られ、複雑な震源過程が示唆される

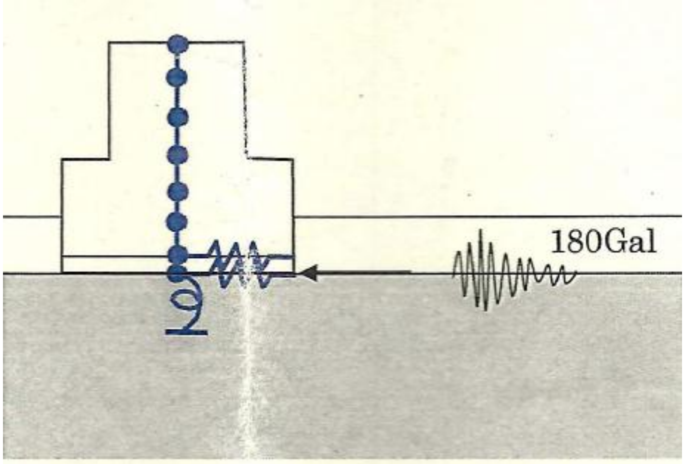
- The JMA Japan seismic intensity, showing the damage produced by the earthquake, at towns near the Fukushima Dai-ichi and Dai-ni sites was 6+ (maximum value of the JMA scale is 7).
- In Appendix XX of this report see detailed maps and graphs describing the seismic event.
- Regarding the observations of the ground motions at the NPP sites the following information on the maximum response accelerations at the level of the foundation base mats of the six (6) units at Dai-ichi and the four (4) units at Dai-ni was received during the meetings including comparisons with the original earthquake design basis (i.e. S1 and S2 level) and the back check DBGM Ss values. Basically, the following 3 sets of values were provided:
-

*At Fukushima Dai-ichi NPP:*

1. Maximum acceleration values (gal) at base mat level **observed during the 11 March 2011 Earthquake**, first 3 columns for NS and EW horizontal and UD vertical components, in red.

2. Maximum response acceleration values (Gals) corresponding to the **original design basis:**

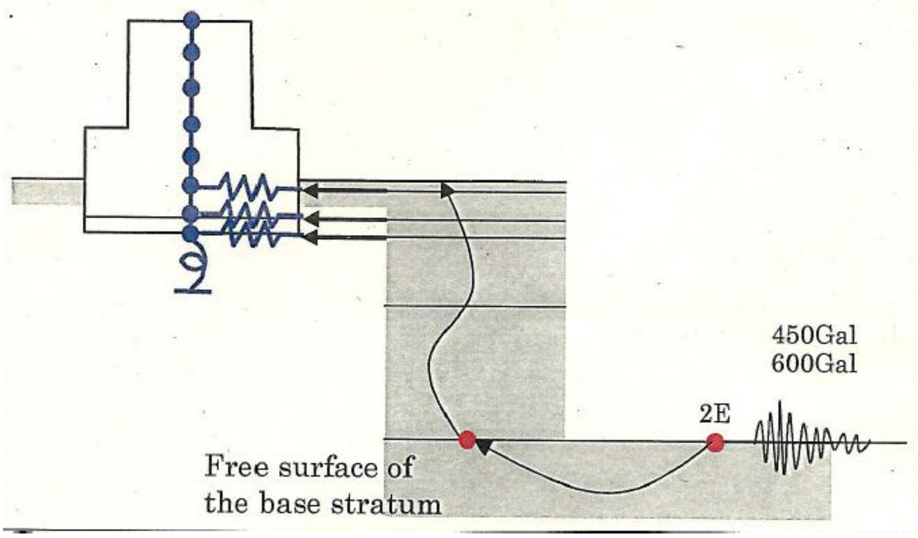
- **The original design basis,** defined according to the criteria valid before the establishment of the NSC Regulatory Guidelines:
  **180 Gals** as direct input to the basemat of the Reactor Building.
  **270 Gals** for confirming function maintenance.



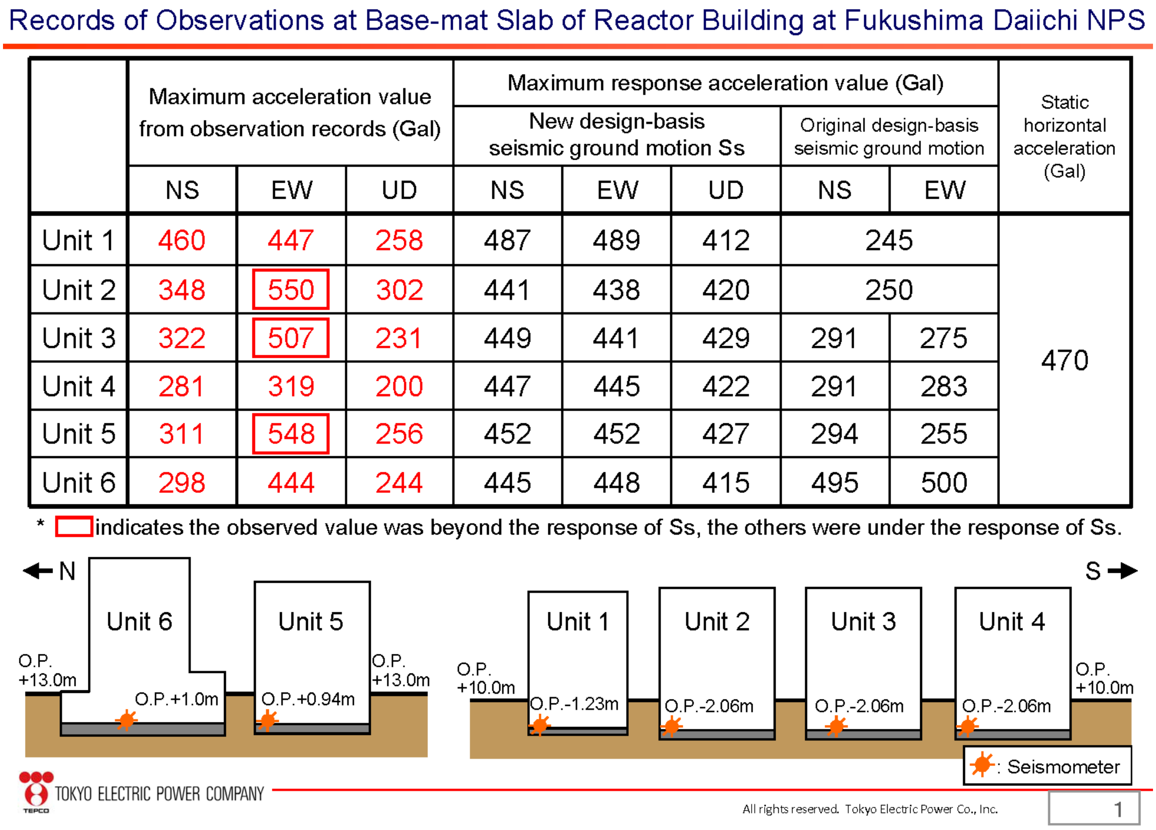
- The **Standard Seismic Ground Motion S1 and S2,** as defined after the establishment of the NSC Regulatory Guidelines:
  **S1= 180 Gals**
  **S2= 270 Gals and 370 Gals**
  , which were defined at the free surface of the base stratum, located at O.P.-196m
- **Static Seismic Acceleration**
  According to the Japanese Building Standard, the static shear force on the base mat is calculated as follows:
  Building Standards: 0.2G * Coefficient * weight =195.8Gal * Coefficient * weight
  With the "Coefficient" corresponding to the "Structural Characteristic Coefficient". In the case of F1, the structural characteristic coefficient is 0.8. Therefore, for the Reactor Building:

195.8Gal * Coefficient * 3 * weight = 195.8Gal * 0.8 * 3= **470 Gals**

3. Maximum response acceleration values (Gals) corresponding to the newly estimated **Design Basis Ground Motion (DBGM)** according to the September 2006 NSC "Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities", or back check requirements, noted as Ss at the free surface of the base stratum, which should be the envelope of three different types of seismic sources:
   Ss1= 450 gals for inland crustal and interplate earthquakes
   **Ss2= 600 gals** for oceanic deep intraplate earthquakes
   Ss3= 450 gals for diffuse seismicity



The estimated values at base mat levels for the six units are indicated in columns 4-6 following table.



Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daiichi NPS

| | Maximum acceleration value from observation records (Gal) | | | Maximum response acceleration value (Gal) | | | | | Static horizontal acceleration (Gal) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | New design-basis seismic ground motion Ss | | | Original design-basis seismic ground motion | | |
| | NS | EW | UD | NS | EW | UD | NS | EW | |
| Unit 1 | 460 | 447 | 258 | 487 | 489 | 412 | 245 | | 470 |
| Unit 2 | 348 | $\boxed{550}$ | 302 | 441 | 438 | 420 | 250 | | |
| Unit 3 | 322 | $\boxed{507}$ | 231 | 449 | 441 | 429 | 291 | 275 | |
| Unit 4 | 281 | 319 | 200 | 447 | 445 | 422 | 291 | 283 | |
| Unit 5 | 311 | $\boxed{548}$ | 256 | 452 | 452 | 427 | 294 | 255 | |
| Unit 6 | 298 | 444 | 244 | 445 | 448 | 415 | 495 | 500 | |

* ☐ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.

TOKYO ELECTRIC POWER COMPANY

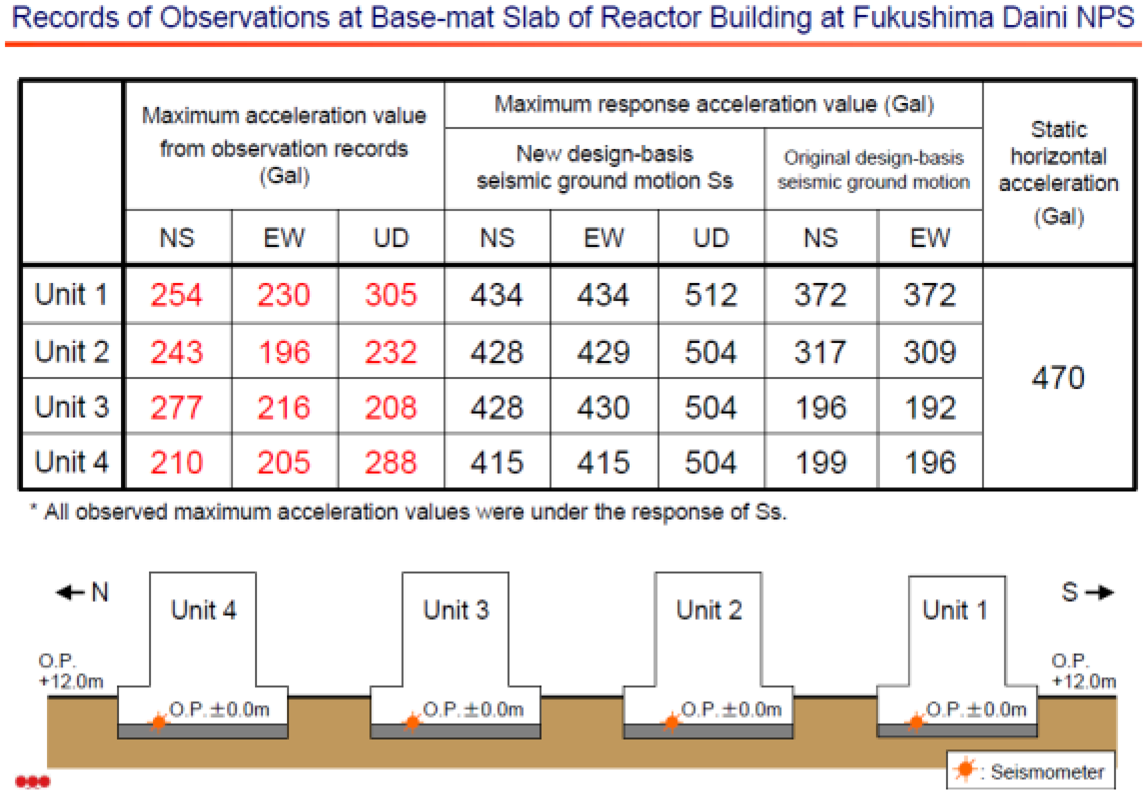
All rights reserved. Tokyo Electric Power Co., Inc.

1

During the Mission, no comparison was made between the observed spectra with the design ones since they were not made available to the Review Team. Regarding the peak accelerations at the foundation base mat level, the recorded maximum response accelerations exceeded the originally design value for S2 earthquake from 1.13 to 2.2 times, with exception of Unit 6 that shows no exceedance.

Regarding the values adopted for the back check evaluation, it was not clear to the Review Team whether this comparison with observed values is valid since no detailed information was provided regarding the physical upgrades effectively executed. The information provided indicated that only some upgrading on piping supports was performed.

*At Fukushima Dai-ni NPP:*



Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daini NPS

| | Maximum acceleration value from observation records (Gal) | | | Maximum response acceleration value (Gal) | | | | | Static horizontal acceleration (Gal) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | New design-basis seismic ground motion Ss | | | Original design-basis seismic ground motion | | |
| | NS | EW | UD | NS | EW | UD | NS | EW | |
| Unit 1 | 254 | 230 | 305 | 434 | 434 | 512 | 372 | 372 | 470 |
| Unit 2 | 243 | 196 | 232 | 428 | 429 | 504 | 317 | 309 | |
| Unit 3 | 277 | 216 | 208 | 428 | 430 | 504 | 196 | 192 | |
| Unit 4 | 210 | 205 | 288 | 415 | 415 | 504 | 199 | 196 | |

* All observed maximum acceleration values were under the response of Ss.

*At Tokai Dai-ni NPP:*
During the meetings at Tokai Dai-ni NPP it was asked that although the back check has been completed regarding the seismic hazard assessment of the DBGM and some upgrades were performed, which is the seismic margin against the original design basis. It was answered that the 'plant is strong enough' and no detailed information was provided. Also, it was indicated that no crack monitoring programme is in place to determine whether or not the earthquake produce a new cracking in concrete structures.

| **3 – CONCLUSIONS** | | **01/06/2011** |
|---|---|---|

1. Although it appears that the Great East Japan earthquake exceeded the licensing based design basis ground motion of the 1F plant at the level of the foundation base mat in all units, according to the information provided by TEPCO and NISA, the operating plants were automatically shutdown and all plants behaved in a safe manner, during and immediately after the earthquake. It was also confirmed that in some cases the observed values even exceeded the recently determined maximum response acceleration values showing apparently an underestimation of the new DBGM Ss.
2. It was also reported that the three fundamental safety functions of (a) reactivity control, (b) removal of heat from the core and (c) confinement of radioactive materials were available until the tsunami reached the sites.
3. Based on the reports from Japanese experts and plant personnel, safety related structures, systems and components of the plant seemed to have behaved well for such a strong extreme earthquake, possibly due to conservatisms introduced at different stages of the design process.
4. The underestimation of the hazard in the original hazard study as well as in more recent re-evaluations mainly result from the use of recent historical seismological data in the

estimation of the maximum magnitudes especially associated with the neighbouring subduction zone east of the sites.

| 4–LESSONS LEARNED | | 01/06/2011 |
|---|---|---|

- Although not applicable to the 1F case considering the present and future status, for the cases of 2F and Tokai Dai-ni the re-evaluation of the seismic hazard at the site should be again conducted to take due account of new data and lessons learned from the Great East Japan earthquake for characterizing the seismogenic sources and perform the necessary safety upgrading in expedited manner. This will also contribute to assess the risk during the short and intermediate period at units with prolonged shutdown when safety measures should be taken for the potential occurrence of future events. Detailed inspection and walkdown programmes should be conducted.
- It should be recognized worldwide the need to consider potential maximum seismic events greater than those observed or recorded in historical time. Although the need to consider prehistorical and historical data is well established in the international safety requirements for assessing the natural hazards at nuclear installations, this has not been followed especially in older nuclear power plants. The current IAEA safety standards establish a clear time scale (going back to historical and prehistorical eras) as well as tectonic capacity considerations in the estimation of maximum magnitudes associated with seismogenic structures. There is a need for Member States regulations to reflect these considerations both for the new build as well as for re-evaluation of existing NPPs.
- Japan has undergone a seismic hazard re-evaluation (back check) recently on the basis of recent investigations and data. However, it was confirmed that these assessments were exceeded by the March 2011 event. This experience shows the importance of a permanent oversight of the potential hazards and of performing all required actions for taking necessary measures for maintaining and increasing the safety level.
- An appropriately conservative approach to seismic hazard analysis, such as recommended in the IAEA Safety Guide SSG-9, would significantly decrease the need for a constant review and revision of seismic design bases at NPP sites.
- The Fukushima experience has also shown that there is a need to have in place a consistent and comprehensive pre-earthquake planning and post-earthquake response actions programme for all NPPs worldwide.

## FINDINGS SHEET

| 1. EXTERNAL EVENT OF NATURAL ORIGIN | Finding Number: **A1-02** |
|---|---|
| Facility: | **FUKUSHIMA DAI-ICHI NPP** |
| Unit: | **UNIT 1 - 6** |
| Assessment Area: | **EXTERNAL EVENTS OF NATURAL ORIGIN** |
| Finding Title: | **TSUNAMI HAZARDS** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

Tsunami waves and associated phenomena may produce severe damage to installations located in coastal areas. Current IAEA safety standards require that, the potential for tsunamis that can affect nuclear power plant safety and the determination of its characteristics shall be assessed, taking into consideration pre-historical and historical data and all types of associated hazards, with account taken of any amplification due to the coastal configuration at the site. (IAEA Safety Requirements-Site Evaluation for Nuclear Installations, NS-R-3, 2003, paragraphs 3.24 to 3.28.)

Consequently, if such potential exists and detailed hazard characterization is done, the plant shall be designed to withstand the event according to specific design bases determined as result of this tsunami hazard assessment, as indicated in IAEA Safety Requirements-Safety of Nuclear Power Plants: Design, NS-R-1, 2000 Paragraphs 5.16 and 5.17.

To comply with such requirements the IAEA Safety Guides on “Flood Hazard for Nuclear Power Plants on Coastal and River Sites, NS-G-3.5, 2003, and on “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, NS-G-1.5, 2003, provide detailed recommendations according to the recognized Member State practice and consensus at the time. In NS-G-3.5 the need to characterize. run-up, drawn-down and associated phenomena (i.e. hydrodynamic forces, debris, sedimentation, etc.) is clearly recommended (Paragraphs 11.21 and 11.22),

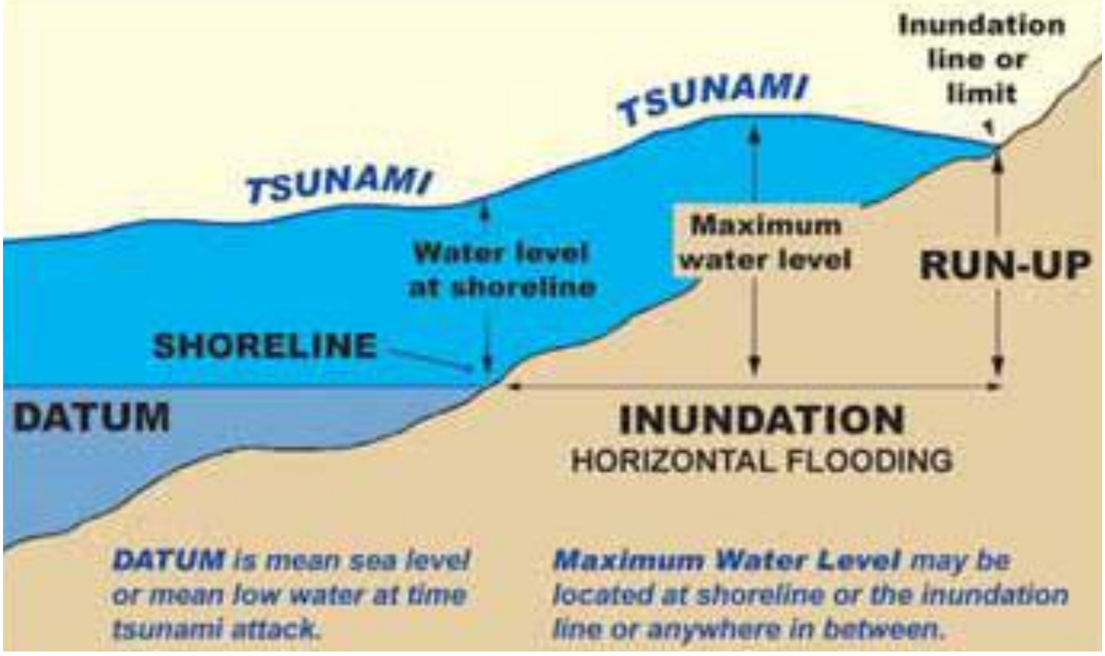
Particularly, in relation to flood events, it is recommended that all items important to safety should be constructed above the level of the design basis flood with account taken of wind wave effects and effects of the potential accumulation of debris. This is the so-called “dry site” concept which is preferred in many Member States to the alternative solution of permanent external barriers such as levees, sea walls and bulkheads, which require periodic inspections, maintenance, monitoring as features important to safety. In both cases, redundant and conservative measures should be taken owing to the intrinsic “cliff edge” characteristics in the overtopping of the protection, such as ensuring the waterproofing and a proper design of items necessary to provide the capability to shut down the reactor and maintain it in safe shutdown conditions (paragraphs 13.5 and 13.6 of NS-G-3.5).

Recently, a revision of the Safety Guide NS-G-3.5 was developed to consider new data, information and lessons learned mainly from the 2004 Indian Ocean tsunami and the draft of this guide, numbered DS417 has been approved by the IAEA Safety Committees (including the Commission of Safety Standards) and it is ready for publication. This new version maintains the concepts and recommendations mentioned above and provides more detailed recommendations related to the protection of NPPs against the effects of tsunamis. As an Annex to this safety guide draft –which is not considered as part of the standard- a reference to current practice in Member States is included and Japan and USA are the countries providing such examples.

In addition to the effects produced by variation of water levels (maximum and minimum) the hazardous effects of tsunami waves are also strong currents in harbours and bays, bores in rivers, estuaries and lagoons, and huge hydrodynamic forces. Sedimentation phenomena, including deposition and erosion, may also be generated owing to large forces at the sea floor.

The following parameters should be defined, as illustrated in the diagram. They are included here for a common understanding of the terminology used in this report:

- ***Run up***: elevation reached by the tsunami wave at the inundation limit or inundation line
- ***Water level at shoreline***
- ***Maximum water level***
- ***Inundation area (or horizontal flooding area)***



## 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

***Before 11 March 2011***

- The tsunami hazard at Fukushima Dai-ichi NPP site was initially estimated at the time of the construction permit (from 1966 to 1972 for units 1 to 6) based on the data and observations from the tsunami generated by the Magnitude 9.4 Chile Earthquake in 1960. The design maximum height was defined at **+3.122 m** over mean sea level (msl) as the observed tide levels at Onahama port, in Fukushima prefecture, located 50 km South of the site. As reported in the working group meeting (by NISA) **this value still represents the official licensing design basis for flooding generated by tsunamis**. The site level for locating the SSCs (structures, systems and components) at the water intake area was selected as +4.00 m while the plant grade level (i.e. elevation of the reactor building) for Units 1-4 was established at +10.00 m and for Units 5-6 at +13.00 m.
- At that time, the applicable and related regulatory requirements were those indicated in the

Regulatory Guide for Review of Nuclear Reactor Site Evaluation and Application Criteria, issued by NSC in 1964 and revised in 1990, and in the Regulatory Guide for Reviewing Nuclear Reactor Safety Design, issued by NSC in 1970 and revised in 1977 and 1990 which provide very general requirements on the need that safety functions should not be affected by this natural hazard.

It was indicated by TEPCO that the numerical simulation of tsunamis based on a tectonic mechanism was carried out only after the mid-1970s. This simulation involved "earthquakes which occurred at the bottom of the ocean to cause uplift and subsidence of the sea bed, subsequently leading to generation of tsunamis. Previously, in the 1960s, i.e. at the time of the application for the construction permit Fukushima Dai-ichi NPP, it was common practice to adopt historical tsunami records as design basis tsunami height and in according to such practice the value of +3.122 was adopted for licensing purposes.

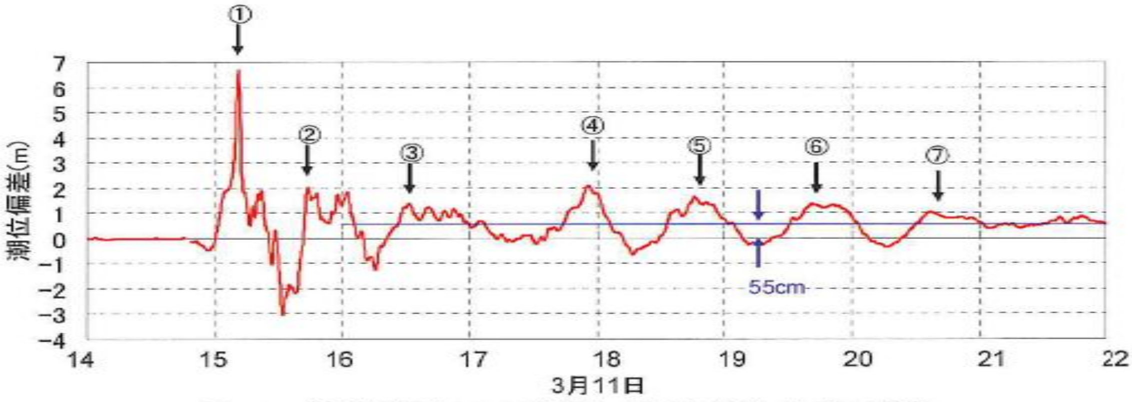
- Later, using the new methodology proposed in 2002 by a professional institution, the Japan Society of Civil Engineers (JSCE), "Tsunami Assessment Method for Nuclear Power Plants in Japan", the tsunami hazard water levels (maximum and minimum) were re-evaluated based on the data and observations from the Magnitude 7.9 Offshore Shioyazaki Earthquake in 1938, which resulted in a maximum high water level of +5.7 m. Minimum water level of -3.60 m was calculated on the basis of the 1960 Chile M=9.4 earthquake. It was estimated that the run up at the water intake area would not be high enough to reach the plant grade at +10.00/+13.00 m. The JSCE methodology is based on a deterministic approach and the uncertainties in the tsunamigenic data is counted through a process of parameter variation studies. In this computation TEPCO used a magnitude of 8.0 for the Shioyakazi source.
- These values, as presented by TEPCO, were not reviewed or validated by NISA as indicated in the meetings. The fact that the tsunami estimate increased by a factor of almost two and the main tsunamigenic source shifted from distant (Chile) to near (Shioyazaki) source would have required the attention of NISA. As these assessment and countermeasures were undertaken by TEPCO voluntarily without any instruction from NISA, they were not pertinent to changes in the licensing documents and thus the officially recognized design bases.
- Other important consideration is the run up values. The estimate corresponds to the tsunami height at what can be called the "intake point", i.e. in the graph above can be assumed as at the "shoreline" point in the entrance to intake structures level. The run up i.e. the water height reached at the maximum inundation point was not indicated in any presentation from TEPCO. When asked, it was said that it was calculated but did not increase significantly the +5.7 m and it did not reach the main grade level of +10 m. It seems also that the calculation of the run up have not considered the specific and detailed arrangements of plant layout.
- The IAEA safety guide, the current one NS-G-3.5 as well as the new draft, indicate the need to consider all associated phenomena as hydrodynamic forces, debris and sand deposition, etc. According to the calculation following the JSCE methodology only the maximum and minimum water levels near the intake structures were calculated. The hydrodynamic forces due to the tsunami were not considered because the methods for these were still evolving.
- The combination of the maximum/minimum water tsunami level with the tide of +1.0 m which led to the +5.7 m seems insufficient also for considering credible scenarios with other oceanographic and meteorological phenomena (such as storm surge, wind waves) plus consideration of aleatory and epistemic uncertainties as well as the consideration of a safety margin. To add +1.0 m to the calculated tsunami value seems too low.
- In 2006 NSC issued the new Regulatory guidelines titled 'Regulatory Guide for Reviewing Seismic Design of NPP Facilities' which addresses tsunami safety in Chapter 8 as an accompanying event of the earthquake stating that "... *safety functions shall not be significantly affected by the tsunami which could be postulated appropriately to attack but*

*very scarcely in the operational period of facilities*'. No detailed or specific requirements or guidance is available, as reported. Regarding combination with other flooding hazards, it was indicated that in practice only the high tide is added to the calculated tsunami water levels.

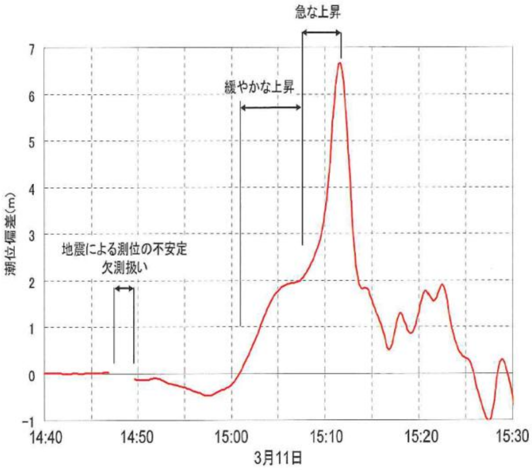
- NISA requested that all NPPs should undergo a back check on basis of the new 2006 guidelines which include the need to re-evaluate the tsunami hazards. TEPCO reported that although studies have started results are not currently available.
- In the meeting with NSC authorities, it was clarified that the NSC guidelines are not legally binding and they are not "regulations" although in practice they are considered as such. It was also expressed that these guidelines will be revised in view of recent experience and lessons learned.
- Regarding the 2002 JSCE Guidelines it should be highlighted that this standard provides methods for calculating tsunami height but does not include associated effects such as hydrodynamic loads, or missiles from transported debris. The values calculated by TEPCO were based on only recent historical data.
- Considering the fact that safety related items for removing the reactor decay heat (link to the ultimate heat sink) and for cooling the diesel generators for emergency power supply are located at +4.00 m, i.e. +1.70 m below the recently estimated inundation level, it was indicated by TEPCO that the motors of the safety related pumps (RHR system) were accordingly elevated to avoid function disruption. However, no additional details were provided about the sufficiency of these measures to cope with such an event for the protection of all related mechanical, electrical and I&C components of the RHR System.

***After 11 March 2011 Tsunami***

- The Magnitude Mw 9.0 earthquake that occurred at 14:46 on 11 March 2011 triggered a tsunami that reached the site at about 15:30, i.e. ~44 minutes later with run-up heights of about 14-15 m, well above the plant main grade. This produced flooding, destruction and disruption of safety functions in the form of inundation, hydrodynamic forces, impact of dragged debris, deposition of sand and silt, debris, etc. The observed record at IWATE Nanbu Oki Tidal Gauge in open sea can be seen in the following graphs.



図－２　岩手南部沖ＧＰＳ波浪計で捉えた津波の初期の波形



In Appendix XX of this report see pictures and maps showing the areas devastated by the earthquake.

- Because of damage to SSCs (mainly mechanical and electrical items) located at the water intake area, the safety functions of removal of decay heat and emergency power supply were severely affected as described in other sections of this report. It should be noted that due to the earthquake, off-site power at the plant was not available at the time of the tsunami.
- The methodology of the JSCE applied by TEPCO does not provide with guidance for estimating the hydrodynamic forces and impact of large debris. This resulted in the underestimation of tsunami effects from a system point of view with a thorough and comprehensive assessment of all effects of water impacting and leaking to buildings, structures and components, affecting safety related items. It should also be noted that there is no reference to influence of simultaneous tectonic subsidence which can influence the wave heights.

### – CONCLUSIONS

**01/06/2011**

1. After the issuance of the Construction Permit about forty years ago, the Regulatory Authority did not provide any requirements or guidance regarding tsunami safety. The guidance provided in 2006 as part of the Seismic Safety Guidelines, does not contain any concrete criteria or methodology that could be used in re-evaluation. The only re-evaluation was performed in 2002 by TEPCO on a voluntary basis. Even this work was not reviewed by NISA. Therefore an effective regulatory framework was not available to provide for the tsunami safety of the NPPs through their operating life.
2. Although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Dai-ichi NPP as described during the meetings and the expected tsunami height was later increased (without changing the licensing documents) after 2002, the tsunami hazard was underestimated.
3. Furthermore, considering that it was not possible to provide for a ‘dry site’ condition for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the unexpectedly higher tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and debris impact). Moreover, the re-evaluation of the hazard after 2002 and the adequacy of the protective actions taken were not reviewed by the Regulatory Authority. Because failures of SSCs when subjected to floods are generally not incremental, the plants were not able to withstand the consequences of tsunami heights greater than those expected (cliff edge effect).
4. Apparently, the tsunami warning and notification system, was not available to provide appropriate and timely response for plant reaction to the event. Japan, and JNES in particular, has developed the TIPEEZ System which was given to IAEA through EBP Tsunami for distributing to member states. This system was not used at 1F plant and the operators were not aware of the approaching tsunami waves.
5. It is recognized worldwide that Japan has a high level of expertise and also experience regarding tsunami hazard and provides leadership in this topic worldwide. This is reflected in the major influence that Japanese academic, scientific and technical institutions have on the international research and development of this topic. In this regard, the IAEA recognizes the valuable support received from JNES on tsunami safety for nuclear power plants which is transferred to Member States through the ISSC. It seems that organizational issues have prevented this expertise to be applied to practical cases at the three NPPs visited during this Mission.

### 4–LESSONS LEARNED

**01/06/2011**

- There is need to incorporate large safety factors to estimate tsunami run up for NPP sites for the following reasons: (i) large aleatory and epistemic uncertainties in parameters involved in tsunami hazard particularly the characterization of the tsunamigenic sources, (ii) significant variations in inundation levels at different parts of the site considering the specific and detailed plant layout and plant sector elevations, (iii) difficulties in incorporating effective tsunami protection measures for operating plants after an increase in tsunami height estimation, (iv) intolerance of NPP SSCs to increased flood levels, i.e. to flood related cliff edge effects.
- There is also need to use a systemic approach for dealing with the design and layout of the

plant SSCs for an effective protection against tsunami hazards. Leak tightness and water resistance should be assured through a comprehensive evaluation of all potential water ways. However, this measure can only be used as a redundancy (i.e. in conjunction with a dry site or an effective site protection measure).

- For well-defined tsunamigenic (fault controlled) sources, a large earthquake will always precede the tsunami. If the source is near the site, the vibratory ground motion will provide a warning. For all tsunamis that may occur at the site, notification from the national tsunami warning system should be transmitted to the control room for immediate operator actions. A clear procedure should be followed by plant management in preparing for a possible tsunami until the warning is lifted.
- An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Tsunami, using also the criteria and methods established in the IAEA related safety standards for comprehensively coping with tsunamis and in general all correlated external events. The national regulatory documents need to include data base requirements compatible with those required by IAEA Safety Standards. The methods for hazard estimation and the protection of the plant need to be compatible with the advances in research and development in this field. Regulatory Authorities need to recognize the importance of these advances and need to keep their regulations in line with IAEA Safety Standards which are updated regularly taking into account of scientific advances and recent occurred events.
- Finally, the potential for scenarios involving flooding hazards and multiple units (and possible multiple sites) needs to be fully and comprehensively investigated for new and existing nuclear power plants worldwide and if they cannot be screened out provisions for plant layout, site protection measures, design, accident management and emergency preparedness and response should be taken in order to adequately protect the installation against these disasters.

## FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A1-03** |

| | |
|---|---|
| Assessment Area: | **A1 - EXTERNAL EVENTS OF NATURAL ORIGIN** |
| Facility: | **FUKUSHIMA DAI-ICHI** |
| Unit: | **UNITS 1 TO 6** |
| Finding Title: | **CROSS CUTTING – PROTECTION OF NPPs AGAINST EXTERNAL HAZARDS DURING EMERGENCY CONDITIONS AND EXTENDED SHUTDOWN** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

The present situation at the 1F as well as the neighbouring NPP sites is unique in terms of plant state, physical plant condition and the hazard environment. The IAEA Safety Standard NS-R-1 provides the following requirement:

> *I.18. For the post-event recovery period (of days or longer), additional events may need to be taken into account, depending upon the length of the recovery period and the expected probabilities of the events. For the recovery period, it may be realistic to assume that the severity of an event that has to be taken in a combination is not as great as would need to be assumed for the same kind of event considered over a time period corresponding to the lifetime of the plant. For example, in the recovery period for a loss of coolant accident, if a random combination with an earthquake needs to be considered, the severity could be taken as less than the severity of the design basis earthquake for the plant.*

This paragraph considers the duration of the recovery period but does not explicitly address the degraded plant state which may actually require considerations of external hazards with lower frequencies of exceedance compared with those applicable for undamaged plants. For example, a nuclear power plant may be well designed against extreme meteorological conditions such as hurricanes or typhoons but in a degraded state there may be weaknesses and vulnerabilities to identify and remedy for events even lower than the original design basis.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- For all three NPPs under consideration plant conditions have radically changed with respect to a normally operating installation. This is because, (i) the plant states are different from an operating plant, (ii) physical conditions of the SSCs are radically different, (iii) there is significant uncertainty regarding plant parameters and physical conditions of the SSCs. Therefore the three plants are in a much more vulnerable situation than undamaged plants regarding external hazards.
- With the occurrence of a very large earthquake such as the Great East Japan Earthquake of 11 March 2011, the exposure of the three plants to some external hazards will have changed. First, all the sites will be experiencing aftershocks of varying magnitudes for some more months (up to a year) to come. Some of these aftershocks may be quite strong and one or two may be large enough to produce tsunamis. While not a proven fact, there may be increased volcanic activity in

the region. Finally, the deteriorated state of the plants would make them more vulnerable to more frequently occurring external hazards in general affecting the recovery actions. Therefore, external events such as typhoons and extreme weather may be of concern to the three plants.

- Tokai Dai-ni is the least affected plant of the three and possibly with the best prospects for a restart. It is outside of the exclusion zone. The plant is in cold shutdown state.
- In Fukushima Dai-ni there are four reactor units with start of operation from 1981 to 1986. The condition of these units after the earthquake and the tsunami show some variations although in general they have similar physical conditions. The plant (i.e. all the reactor units) is in cold shutdown state.
- In Fukushima Dai-ichi, there are six reactor units with start of operation from 1970 to 1979. The state of the plant is further complicated with the more extensive flood damage as well as the damage incurred by three explosions in reactor units 1, 3 and 4. The residual heat removal process in three units is still on-going. The spent fuel pools are also being cooled by water injection from outside. Therefore the vulnerability of Fukushima Dai-ichi to short term external hazards is much more critical than the other two plants.

## 3 –CONCLUSIONS

**01/06/2011**

1. For the Tokai Dai-ni and Fukushima Dai-ni NPPs, in the short term, it is important to evaluate the safety of the plant for the changed plant conditions and the changed hazard environment. In particular, if an external event PSA model is already available for the cold shutdown state, this would be an effective tool in performing the assessment.
2. The short term (immediate) measures at Fukushima Dai-ichi need to be planned during the period before a stable cold shutdown of all the units are attained. Until that time the high priority measures to protect the plant against external hazards need to be identified using simple methods in order to have a timely action plan. As preventive measures will be important but limited, both on-site and off-site mitigation measures need to be included in this plan.
3. Once a stable cold shutdown state is achieved a long term plan needs to be prepared that should include the identification of SSCs needed for this state (a shutdown PSA would be helpful in this regard) and upgrades to these SSCs to ensure their safety function, as well as on-site and off-site emergency measures.
4. Any plans for the future outside of decommissioning or removal of all fuel from the site (for the reactor units that experienced severe core damage), need to take extreme external hazards into consideration for the long term.

## 4 – LESSONS LEARNED

**01/06/2011**

- After a major disaster which may cause severe disruption to the plant the changed plant state and physical conditions of the SSCs need to be taken into consideration. The changed plant state (degraded systems and degraded physical conditions of the SSCs) may have lost design robustness and may have degraded defence-in-depth.
- The safety profile of the plant needs to be well understood (e.g. the required SSCs) for different plant states (e.g. shutdown) in order to provide for a consistent protection and a plan for upgrades.
- A major natural disaster may temporarily alter the hazard environment. In order to provide for an uninterrupted recovery process, there is a need for understanding the plant

vulnerabilities and the new hazard environment and providing protection for the plant and the recovery action accordingly in a timely manner.

# FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A1-04** |
|---|---|
| Assessment Area: | **A1 - EXTERNAL EVENTS OF NATURAL ORIGIN** |
| Facility: | **FUKUSHIMA DAI-ICHI** |
| Unit: | **UNITS 1 TO 6** |
| Finding Title: | **CROSS CUTTING – LESSONS LEARNED FROM KASHIWAZAKI-KARIWA NPP EXPERIENCE** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The use of feedback from experience is a common element to all subjects in nuclear safety. All IAEA safety standards related to the protection of nuclear installations against external hazards consider lessons learned from recent events in their periodic review process. This has been the case for the two major events in the last decade, i.e. the 2004 Indian Ocean tsunami and the Niigataken-Chuetsu Oki earthquake which exceeded the design basis of the Kashiwazaki-Kariwa NPP. The two IAEA Safety Guides related to these issues are SSG-9 (2010) and DS417 (in print), related to seismic and flooding (including tsunami) hazards respectively. These two safety guides were developed taking full account of recent events in order to incorporate the lessons learned from these.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- All plants visited benefited from the lessons learned from the experience of K-K NPP. In particular:
- The on-site fire brigade was extremely useful in providing water injection function to various locations, using the fire engines available at the site.
- The newly built on-site seismically isolated building served a vital function as a technical support service and in general plant emergency response. This building is shielded with charcoal filtered ventilation and also located at a high elevation to be protected against tsunamis.
- In Kashiwazaki-Kariwa case, the fire extinguishing piping which was located outdoors and underground suffered severe damage due to soil failures inducing flooding of the reactor building. As a remedial action, all fire extinguishing piping was re-located above ground with appropriate foundation. This layout solution proved not to be suitable for the tsunami flooding since the above ground piping was severely damaged by the tsunami induced waves and debris and they would not have been operable in case of fire. This was observed, particularly, in case of 2F plant.

## 3 –CONCLUSIONS

**01/06/2011**

1. Lessons learned from the Kashiwazaki-Kariwa experience provided extremely valuable improvements to the emergency response at all the plants.
2. The so called ‘seismically isolated’ building (which is also has charcoal filtered ventilation, shielded and located at a high elevation) provided a safe haven to all plant personnel during this disaster and expedited emergency and recovery actions.
3. The on-site fire brigade was also extremely valuable even though there was no fire at the sites. The fire engines were used for injecting water to various structures to provide cooling.
4. The re-location of the piping for the firefighting system, on the other hand, turned out to be a mistake for the particular hazard scenario (tsunami). The fact that there was no fire at the 2F plant meant that there was no need for this system. Otherwise the on-site fire brigade which had little hands on experience could have been stretched to cope with multi-tasking (i.e. dealing with fires and providing water injection to various structures).

## 4 – LESSONS LEARNED

**01/06/2011**

1. Lessons learned from the Kashiwazaki-Kariwa experience proved to be extremely useful in dealing with the on-site emergency situation at the plants. On-site TEPCO personnel have clearly expressed the view that if it had not been for the on-site fire brigade and the on-site emergency control centre, the situation would have deteriorated much more rapidly.
2. By extension, the lessons learned from the Fukushima Dai-ichi experience may prove to be very important for the international nuclear community in the future. There is need to understand the implications of all aspects of this event in order to benefit from these lessons learned.
3. Due to the nature of this accident lessons learned will cover a very wide area which involves all findings of this Mission.

# FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A1-05** |
|---|---|
| Assessment Area: | **A1 - EXTERNAL HAZARDS** |
| Facility: | **FUKUSHIMA DAI-ICHI** |
| Unit: | **ALL** |
| Finding Title: | **CROSS CUTTING- COMPLEX SCENARIO OF EXTREME EXTERNAL EVENTS AFFECTING ALL UNITS AT MULTIPLE SITES** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The complexity of the events of the Great East Japan Earthquake and Tsunami stems from the fact that the hazards were (and still are) multiple and the NPP sites exposed to these hazards are also multiple (Tokai Dai-ni, Fukushima Dai-ichi, Fukushima Dai-ni, Onagawa and Tohoku Higashidori). This means that fifteen reactor units at five sites were simultaneously exposed to extremely high hazards. Although many Member States have multi unit sites and in some cases neighbouring sites may be exposed a large hazard simultaneously, guidance regarding multi unit sites with respect to external hazards is lacking.
- The common cause nature of these hazards plays an important role in off-site emergency preparedness and response because these natural disasters produce local, regional and national impact. In this regard NS-R-3 Paragraph 2.29 provides the following requirement: *'The external zone for a proposed site shall be established with account of the potential for radiological consequences for people and the feasibility of implementing emergency plans, and of any external events or phenomena that may hinder their implementation.'*
- For on-site severe accident management, large and complex external hazards also have serious implications for securing the reactor cooling and containment functions by stretching the available human and material resources. The situation off-site due to the destruction by the disasters will limit the movement of resources from off-site to the plant.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- Although, the lessons learned from the Kashiwazaki-Kariwa experience were very useful particularly for on-site emergency, there was major regional disruption which hampered immediate recovery actions. The regional nature of the destruction and the damage incurred at multiple units at multiple sites (eventually leading to severe accidents at the 1F NPP) caused significant delays and disruptions in recovery actions.
- Following the tsunami, 1F1 to 1F5 had fallen into the Station Black Out (SBO) and the seawater systems were totally destroyed and the Ultimate Heat Sink was lost.
- Following the Abnormal Operating Procedure (AOP), operation after SBO should be interchangeable from the neighbour plant. However, the interchangeability was unable to be conducted since the other plants also lost the power.

- After the tsunami, approximately 400 people (about 130 for operation, about 270 for maintenance) were available for the recovery processes. The number of the operation people was totally insufficient for the recovery operation of six units.
- Only very limited devices and tools were available. Some of which were in the warehouses of the affiliated companies and difficult to find.

*Fukushima Dai-ni:*

- In Fukushima Dai-ni (2F) the simultaneous loss of ultimate heat sink in Unit-1, 2 and 4 is a typical common mode failure caused by extreme natural phenomena in multi-unit plant.

## 3 –CONCLUSIONS

**01/06/2011**

1. Japan is a country known for high level of awareness of natural disasters and has an excellent system of warning, preparedness and response to cope with these. In reviewing the situation at the NPPs after the Great East Japan Earthquake, it was concluded by the IAEA Mission Team, that the magnitude of the disaster was not anticipated in the original and revised hazard assessments.
2. Consequently a contingency plan for the failure of multiple units at multiple sites within a regional disaster context was not available.
3. For effective mitigation of the common mode failures affecting simultaneously to multi unit plants at the same time, sufficient large resource in terms of trained experienced people, equipment, supplies and external support. In addition, an adequate pool of experienced personnel is recommended.
4. The procedures should be prepared for the logistics, human resources, supplies, external support to rapidly countermeasure severe accident and to reduce the radiation spreading. Operators and supporting persons like fire fighters should be effectively trained to understand their duties and be capable of implementing the procedures for mitigating the severe conditions.

## 4 – LESSONS LEARNED

**01/06/2011**

The interference of the complex scenarios resulting from the natural disasters at 1F and 2F plants that affected recovery actions and mitigation measures need to be well documented in order to develop lessons learned for the international nuclear community.

The potential for complex scenarios involving multiple hazards and multiple units (and possibly sites) need to be fully investigated for new and existing NPPs worldwide and if they cannot be screened out, provisions for plant layout, site protection measures, design, accident management and off-site emergency preparedness and response should be taken in order to adequately protect the plants from these disasters.

# FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A1-06** |
| Assessment Area: | **A1 - EXTERNAL EVENTS OF NATURAL ORIGIN** | |
| Facility: | **FUKUSHIMA DAI-ICHI** | |
| Unit: | **UNITS 1 TO 6** | |
| Finding Title: | **CROSS CUTTING – EXTERNAL EVENTS PSA** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- It is important for plants to identify and address all means initiating accident, including those that stem from natural phenomena.
- Internal events include equipment failures and human errors occurring within the plants such as pipe breaks, stuck valves, damaged pumps, instrument failures and operator errors. External events include those of natural and human induced origin generated outside of the plant, such as earthquakes, severe meteorological and hydrological phenomena, volcanic hazards, aircraft crashes and explosions.
- Generally, more attention has been focused on internal events than external events in PSA.
- The frequencies of internal events are generally better known due to the wealth of operating experience that has been accumulated throughout the world. In particular, about 15,000 full power years of plant operation has been accumulated using similar equipment. Additional information regarding operability of components has been generated through the periodic in-service testing of these components required by all regulatory bodies.
- Human factors including human reliability analysis has been an important focus of study since the 1979 accident at Three Mile Island in the United States in which operator error played a key role. These research programmes and associated techniques allow the prediction and quantification of human error under specific circumstances.
- Although uncertainty in internal initiating event frequencies remains, most PSAs developed throughout the nuclear community include a far more thorough analysis of internal event risk than external event risk. However, depending on the particular site of a plant, external events can dominate overall risk.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- In May 2002, Japanese licensees reported the accident management measures developed for each unit together with PSAs of internal events for representative reactor types for the purpose of quantifying safety. The PSA of internal events for all commercial reactor facilities under operation were reported to NISA by the licensees in March 2004. No PSAs for external events were required by NISA.

| **3 –CONCLUSIONS** | | **01/06/2011** |
|---|---|---|

- For the 1F plant an internal events PSA was conducted and the results of the study reported to NSC and NISA. NSC evaluated the results of the PSA and found them to be reasonable.
- For plants in cold shutdown state a ‘shutdown PSA’ would be very useful to identify the SSCs needed to keep the plants in a stable safe state. This would also help in the identification of all items that need to be protected from external hazards in the short term.

| **4 – LESSONS LEARNED** | | **01/06/2011** |
|---|---|---|

- There is a need for the nuclear community to increase effort in developing PSA for external events.
- Even in Member States where conduct of external event PSAs is a regulatory requirement, many external events are screened out using approximate criteria and not included in rigorous PSA treatment. There is a need to review the screening approaches in order to take full benefit of PSA.

# Appendix 2

## *IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East Japan Earthquake and Tsunami*
## *Japan*

# *FINDING SHEETS*

# *Safety Assessment and Management*

***IAEA 2011***

# FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-01** |
| Assessment Area: | **A2 - SAFETY ASSESSMENT AND MANAGEMENT** | |
| Facility: | **GENERAL** | |
| Unit: | | |
| Finding Title: | **EQUIPMENT LAYOUT, PHYSICAL SEPARATION AND INTERNAL BARRIERS NEED TO BE REVIEWED** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The Operation of most of the safety systems of traditional design NPPs depends on the power supply from off-site power and Emergency Diesel Generators (EDGs) in case of loss of off-site power. There are 13 emergency DGs at the Fukushima Dai-ichi NPP, most of them are located in the lower part of the turbine building (B1F). As a result, the DGs themselves as well as the associated electric panel and cable were submerged and failed due to the tsunami on 11 March 2011.
- The heat transfer path from the core and the spent fuel pool to the ultimate heat sink is very important to achieve a stable safe state. There are two trains of residual heat removal system for each unit, but all of them were submerged and failed due to the tsunami on 11 March 2011.
- The DC power supply (batteries) must be available to power the control system, some safety related motor-operated valves, and the post-accident monitoring system. However, the DC power supply failed at Fukushima Dai-ichi after the tsunami of 11 March 2011.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- Most of safety related system and component such as EDGs, DC power supply system, RHR are failed due to submerged after Tsunami.
- The equipment layout and physical separation of safety important equipment need to be reviewed.
- Internal barriers need to be reviewed because they are typically design for internal flooding and fires and they may not be enough to prevent common cause failures caused by severe external flooding.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Equipment layout, physical separation and internal barriers need to be reviewed and improved.

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |
| Equipment layout, physical separation and internal barriers need to be reviewed and improved. | | |

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A2-02** |
|---|---|
| Assessment Area: | **A2 - SAFETY ASSESSMENT AND DEFENCE-IN-DEPTH** |
| NPP: | **FUKUSHIMA-DAI-ICHI NPP** |
| Unit: | **UNITS 1 TO 6** |
| Finding Title: | **DIVERSITY DESIGN OF ULTIMATE HEAT SINK NEED TO BE IMPROVED** |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Generally speaking, the design of Emergency Core Cooling System of Fukushima Dai-ichi NPPs is good, there are Isolation Condenser (IC, only for Unit 1), Reactor Core Isolation Cooling system (RCIC, for unit 2-6), Core Spray system (CS, for Unit 1-5), High-Pressure Coolant Injection system (HPCI, for Unit 1-5), Automatic Depressurization System (ADS), Low-Pressure Core Spray system (LPCS, for Unit 6), Low-Pressure Coolant Injection system (LPCI, for unit 2-6), and Residual Heat Removal system (RHR). The IC (only for Unit 1), the RCIC (for Unit 2 and 3) and the HPCI (for Unit 1-3), the latter two are driven by natural circulation have provided the emergency core cooling for the cores of Unit 1-3 at the first phase of Fukushima Accident which was mainly caused by Station Blackout for long time than expected.
- The heat transfer path from the core and the spent fuel pool to the ultimate heat sink is very important. The ultimate heat sink of Fukushima Dai-ichi NPP units 1-6 is sea water of Pacific Ocean, there are two trains of heat removal system for each unit, they are located in the separated room, but the elevation of the motor of the RHR-S are same, 4-5.7 m above the sea level. Due to 14-m-height Tsunami on 11 March, all of them are submerged and damaged, so the path to removal the decay heat in the core and spent fuel pool to the ultimate heat sink (Pacific Ocean) is broken. For recovery of Dai-ichi Units 1-4, TEPCO is installing air-cooled equipment for each unit to serve as the ultimate heat sink for the cores and spent fuel pools.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

- At Fukushima Dai-ichi, the heat transfer paths to the ultimate heat sink for units 1-6 were lost. For recovery of Dai-ichi units 1-4, TEPCO is constructing an air cooler tower for each unit to serve as the ultimate heat sink for the cores and spent fuel pools. The original design of ultimate heat sink lack of consideration for diversity.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

- According to the National and International standards for the design of NPPs, safety systems should be designed with high levels of diversity to improve their reliability. However, the recommended levels of diversity have not been clearly quantified or defined in the same way as the consideration of single failure has been established.

- It is common in the traditional designs of NPPs (including PWR and BWR) for the heat transfer path to the ultimate heat sink to have minimal diversity requiring feed and bleed to be used in many cases which potentially affects the ability to ensure the containment of radioactivity.
- **With the consideration to prevent and mitigate Beyond Design Basis Accident especially caused by extreme natural hazards, diversity of the ultimate heat sink are important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.**
- **The additional diversity train of RHR could provide defence-in-depth method to remove the decay heat in the core and in the spent fuel pool. It should be seismic classified to avoid common cause failure such as due to earthquake, but it may not be designed as safety classified system in order to cope with beyond design basis accident especially caused by external natural hazard.**

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

**With the consideration to prevent and mitigate Beyond Design Basis Accident especially caused by extreme natural hazards, diversity of the ultimate heat sink are important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.**

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A2-03** |
|---|---|
| Assessment Area: | **A2 SAFETY ASSESSMENT AND DEFENCE-IN-DEPTH** |
| NPP: | **FUKUSHIMA-DAI-ICHI NPP** |
| Unit: | **UNIT 1 TO 6** |
| Finding Title: | **DIVERSITY DESIGN OF EMERGENCY AC POWER NEED TO BE IMPROVED** |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The operation of most of the safety system of traditional design NPP depends on power supply from off-site power and emergency power supply from emergency Diesel Generator in case of loss of off-site power.
- There are 13 EDGs in Fukushima Dai-ichi NPP, each unit of Unit 1-5 has 2 EDGs, and unit 6 has 3 EDGs, named as DG1A, DG1B, DG2A, DG2B, DG3A, DG3B, DG4A, DG4B, DG5A, DG5B, DG6A, DG6B, DG6H (HPCS DG), most of them are located in their relevant Reactor Building (underground room, B1F) and cooled by sea water except DG2B, DG4B and DG6B which are located above the ground and cooled by air. All of the EDGs that were available at the time started up automatically when loss of off-site power due to earthquake during Fukushima Accident, but they all failed after Tsunami, except DG6B. The investigation results show that DG1A, DB1B, DG2A, DG3A, DG3B, DG4A, DG5A, DG5B, DG6A and DG6H are submerged and their Emergency high voltage switchboard (M/C) are submerged or water damaged too, DG2B and DG4B are damaged due to their associated electric panel and cable are submerged. DG6B is survived due to its M/C is located in a higher location.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

- Fukushima Dai-ichi NPP have a relatively good diversity design of the Emergency Diesel Generator, compared to other traditional design NPP, but the elevation of some EDGs are too low, and the physical separation and water-tight sealing of the of EDG room need to be improved.
- The elevation of Emergency high voltage switchboard (M/C) for most EDGs is too low, and the physical separation and water-tight sealing of the room need to be improved.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Diversity of the emergency AC power is an important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.

The equipment layout and physical separation of The Emergency high voltage switchboard should be improved.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

Diversity of the emergency AC power is an important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.

The equipment layout and physical separation of The Emergency high voltage switchboard should be improved.

# FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A2-04** |
| Assessment Area: | **A2 - SAFETY ASSESSMENT AND DEFENCE-IN-DEPTH** | | |
| NPP: | **FUKUSHIMA-DAI-NI NPP** | | |
| Unit: | **UNITS 1 TO 4** | | |
| Finding Title: | **DIVERSITY DESIGN OF ULTIMATE HEAT SINK NEED TO BE IMPROVED** | | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Generally speaking, the design of Emergency Core Cooling System of Fukushima Dai-ni NPPs (BWR-5) is good, there are Reactor Core Isolation Cooling system (RCIC), High-Pressure Core Spray system (HPCS), Low-Pressure Core Spray system (LPCS), Automatic Depressurization System (ADS), Low-Pressure Coolant Injection system (LPCI), and Residual Heat Removal system (RHR). Some of them provided the emergency core cooling for the core during Accident.
- The heat transfer path from the core and the spent fuel pool to the ultimate heat sink is very important. The ultimate heat sink of Fukushima Dai-ni NPP units 1-4 is sea water of Pacific Ocean, there are two trains of heat removal system for each unit, their seawater cooling system (RHR-S) are located in the relevant Heat Exchange Building (Hx/B), the motor of the RHR-S is located in 1F pump room (4 m above the sea level), and their power centres are located in the B1F control panel of Hx/B. Due to the tsunami (maximum run-up height of approximately 14 m) on 11 March, all of them except RHR-S-3B are submerged and damaged, so the path to removal the decay heat in the core and spent fuel pool to the ultimate heat sink (Pacific ocean) is broken. The survival of RHR-S-3B is just due to luck that is why unit 3 can reach cold shutdown state more early than Unit 1, 2, 4. The site superintendent reported the central and local governments nuclear emergency situation because the temperature of the suppression pools of Unit 1,2,4 became more than 100 ℃ during accident, but afterward with temporary power cable laid and urgent procurement of motors, one train of RHRS, RHRC, EECW for each unit of Unit 1,2,4 has recovered and restarted. Up to now, all units of Fukushima Dai-ni have reached cold shut states.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-NI NPP

The Ultimate heat sink of Fukushima Dai-ni NPP units 1-4 is sea water of Pacific Ocean, it is broken due to Tsunami on 11 March 2011.

| | | |
|---|---|---|
| **3 –CONCLUSIONS** | | **__/__/2011** |

With the consideration to prevent and mitigate Beyond Design Basis Accident especially caused by extreme natural hazards, Diversity of the ultimate heat sink are important means to ensure the robustness of a design, and additional attention should be paid to diversity in

|  |  |  |
|---|---|---|
| new NPP designs. | | |
| **4 – LESSONS LEARNED** | | **__/__/2011** |
| With the consideration to prevent and mitigate Beyond Design Basis Accident especially caused by extreme natural hazards, Diversity of the ultimate heat sink are important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs. | | |

## FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-05** |
| Assessment Area: | **A2 - SAFETY ASSESSMENT AND DEFENCE-IN-DEPTH** | |
| NPP: | **FUKUSHIMA-DAI-NI NPP** | |
| Unit: | **UNITS 1 TO 4** | |
| Finding Title: | **DIVERSITY DESIGN OF EMERGENCY AC POWER NEED TO BE IMPROVED** | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The operation of most of the safety system of traditional design NPP is depend on power supply from off-site power and emergency power supply of emergency Diesel Generator in case of loss of off-site power.
- There are 12 Emergency Diesel Generators (EDGs) in Fukushima Dai-ni NPP (4 units), each unit has 3 EDGs, named as DG1A, DG1B, DG1H, DG2A, DG2B, DG2H, DG3A, DG3B, DG3H, DG4A, DG4B, DG4H, all of them are located in the outer area of their relevant Reactor Building (underground room B2F) and cooled by sea water (located in Hx/B building). All of these EDGs startup automatically due to low bus voltage when the earthquake hit the site on 11 March, but they all failed after Tsunami, except DG3B, DG3H and DG4H due to luck, because all of their associated sea water cooling pumps and inter-cooling pumps were submerged due to the tsunami. The main difference between Fukushima Dai-ni and Fukushima Dai-ichi is that one 500 kV line was available for Fukushima Dai-ni (due to higher height and robust electric tower structure), it means that Fukushima Dai-ni had off-site power supply (Fukushima Dai-ichi was in SBO with blind condition), so the reactor were kept in a stable safe state for a long time, first by RCIC followed by MUWC, so that the operator have enough time to repair the heat transfer path to the heat sink.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-NI NPP

- Most of the EDGs failed due to failure of their associated seawater cooling system and inter-cooling system, even though three EDGs survived due to luck. It seems that the design of emergency AC power lack of diversity.

| | | |
|---|---|---|
| **3 –CONCLUSIONS** | | **__/__/2011** |

The Operation of most of the safety system of traditional design NPP is depend on power supply from off-site power and emergency Diesel Generator in case of loss of off-site power, Diversity of the emergency AC power is an important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |

Diversity of the emergency AC power is an important means to ensure the robustness of a design, and additional attention should be paid to diversity in new NPP designs.

# FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A2-06** |
| Assessment Area: | **A2 - SEVERE ACCIDENT** | | |
| NPP: | **FUKUSHIMA-DAI-ICHI NPP** | | |
| Unit: | **UNITS 1 TO 4** | | |
| Finding Title: | **THE CREATION OF A COMMON POOL OF TRAINED PERSONS TO RESPOND TO ABNORMAL SITUATIONS** | | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

Japan has several sites operating BWRs. Each site has a number of BWRs. In order to optimize the resources in the interest of economy, the number of trained persons for operation maintenance and other functions are minimized to the extent possible. While this works well during normal circumstances, under abnormal circumstances when multiple units are affected the number of trained persons available are inadequate.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-CHI NPP

As a consequence of the earthquake followed by a Tsunami all the three operating units went into a crisis situation as almost all the safety systems became inoperative due to loss of all sources of electric power. Under the circumstances remedial measures were required to be implemented in all the units. Obviously the available manpower was inadequate.

Since there are several sites having similar Nuclear Power Plants, BWRs in this case, it can be suggested that such sites can maintain a pool of trained persons that can be deployed at the NPP site that is going through an event.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Sites having the same type of plants can develop and maintain a pool of trained people to provide immediate support to each other when necessary.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-07** |
|---|---|---|

| | |
|---|---|
| Assessment Area: | **A2 - SEVERE ACCIDENT** |
| NPP: | **FUKUSHIMA-DAI-CHI NPP** |
| Unit: | **UNITS 1 TO 4** |
| Finding Title: | **THE AVAILABILITY OF A SEISMICALLY ROBUST BUILDING FOR THE FUNCTIONING OF THE EMERGENCY RESPONSE CENTRE (ERC)** |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

The Kashiwazaki-Kariwa Earthquake in 2007 affected all the units at the site. Though all the operating units were safely shut down, the possibility of a significant damage to all the buildings and structures was highlighted. Based on this experience the creation of a seismically robust building at all the NPP sites was recommended.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-CHI NPP

Following the earthquake and tsunami on 11 March 2011 three operating units suffered severe core degradation. Several structures, including the administration building and staff offices, were damaged. Increased radiation levels around the plant also made those areas uninhabitable.

Based on the recommendations of the 2007 earthquake affecting Kashiwazaki-Kariwa NPP, a seismically robust building was built in Fukushima Dai-ichi as well as in Fukushima Dai-ni. These buildings are not only built to withstand earthquakes but are also shielded and have filtered ventilation systems to ensure the habitability during accident conditions involving the spread of radiation. The buildings are provided with communication facilities with plant control rooms, as well as external agencies, such as TEPCO Headquarters in Tokyo.

During the accident and its mitigation phase this building provided a safe location to operate the Emergency Response Centre. The building continues to provide the only safe place in the vicinity of the NPP to house a large number of persons (over 2000) who are engaged in the recovery operations.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

It was extremely useful to have on-site a seismically robust, shielded, ventilated and well equipped building at Fukushima Dai-ichi and Dai-ni NPPs. Such facilities can be considered by all NPPs as a means to deal with severe accidents.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

# FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-08** |
|---|---|---|
| Assessment Area: | **A2 - SEVERE ACCIDENT** | |
| NPP: | **FUKUSHIMA-DAI-NI NPP** | |
| Unit: | **UNITS 1 TO 4** | |
| Finding Title: | **The comparison and assessment of the event progression and operator actions at different units of Fukushima Dai-ichi and Dai-ni NPPs** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Following the earthquake and tsunami, the event progression at different units of Dai-ni and Dai-ichi were considerably different. The plant conditions and operator actions were also correspondingly different. Given the fact that the units at Dai-ni survived whereas the units at Dai-ichi suffered severe core degradation it would be quite useful to compare the event progression and impact of operator actions at different units.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-ICHI AND DAI-NI NPP

- At the time of the earthquake and tsunami three units at Dai-ichi and all the four units at Dai-ni were in operation. Though the tsunami levels at the two NPPs were different and the off-site power was available at Dai-ni major safety systems were affected in both NPPs. Though all the four units at Dai-ni were brought to safe configuration they were perilously close to a serious situation. The workers of Dai-ni laid several kilometers of cable to get power back to safety systems.
- At Dai-ichi the events progressed much too fast for operators to respond in an organized manner. Normally the mission times of IC/RCIC should have given the operators some time before the core was exposed and radiation levels increased making several reactor areas inaccessible. It is not clear if and why these systems did not function the way they should have.
- A detailed comparison of the event progression and operator actions at different units of the same NPP, as well as between the units of Dai-ni and Dai-ichi could bring out significant inputs for the prevention and management of severe accidents.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

The comparison and assessment of the event progression and operator actions at different units of Fukushima Dai-ni and Dai-ichi could provide significant inputs for the prevention and management of severe accidents.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

# FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-09** |
|---|---|---|
| Assessment Area: | **A2 - SEVERE ACCIDENT** | |
| NPP: | **FUKUSHIMA-DAI-ICHI NPP** | |
| Unit: | **UNITS 1F1 TO 1F6** | |
| Finding Title: | **EXTERNAL EVENTS HAVING A POTENTIAL OF AFFECTING MULTIUNITS PLANTS AT THE SAME TIME** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The FUKUSHIMA-DAI-ICHI site has a total of 6 NPPs (1 BWR-3, 5 BWR-4, and 1 BWR-5) Units 1, 2, 3 and 4 are located on the site level of O.P.+10 m, while Unit 5 and 6 are located on the site level of O.P.+ 13 m. Most EDGs are located under the ground (B1FL) in turbine buildings except for five EDGs, that are, 2B and 4B DGs on the first floor of the shared pool building. 6A and HPCS DG on the B1FL in CS, and 6B on the first floor in a dedicated building.
- According to higher tsunami than expected value, most EDGs were submerged or water damaged except EDG 6B. Most batteries (125 V DC) except 1F3 were also unavailable since they were located under the ground level.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

- According to the tsunami, 1F1 to 1F5 had fallen into the Station Black Out(SBO) and the seawater systems were totally destroyed ( No Ultimate Heat Sink )
- Following the Abnormal Operating Procedure (AOP), operation after SBO should be interchangeable from the neighbor plant. However, the interchangeability was able to be conducted since the other plants also lost the power.
- After the tsunami, approximately 400 people (about 130 for operation, about 270 for maintenance) were available for the recovery processes. The number of the operation people was totally insufficient for the recovery operation of six units.
- Only very limited devices and tools were available. Some of which were in the warehouses of the affiliated companies and difficult to find.

## 3 –CONCLUSIONS

**__/__/2011**

For effective mitigation of the common mode failures affecting simultaneously to multi unit plants at the same time, sufficient large resource in terms of trained experienced people, equipment, supplies and external support. In addition, an adequate pool of experienced personnel is recommended.

The procedures should be prepared for the logistics, human resources, supplies, external support to rapidly countermeasure severe accident and to reduce the radiation spreading. Operators and supporting persons like fire fighters should be effectively trained to understand their duties and be capable of implementing the procedures for mitigating the

| | | |
|---|---|---|
| severe conditions. | | |
| **4 – LESSONS LEARNED** | | **__/__/2011** |
| External events have a potential of affecting several plants and several units at the plants at the same time. This requires a sufficiently large resource in terms of trained experienced people, equipment, supplies and external support. An adequate pool of experienced personnel who can deal with each type of unit and can be called upon to support the affected sites should be ensured. | | |

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A2-10** |
|---|---|
| Assessment Area: | **A2 - SEVERE ACCIDENT** |
| NPP: | **FUKUSHIMA-DAI-ICHI NPP** |
| Unit: | **UNITS 1F1 TO 1F6** |
| Finding Title: | **POTENTIAL UNAVAILABILTY OF INSTRUMENTS AND LIGHTING** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- There were particular challenges at Fukushima Dai-ichi with high radiation fields, and with the tsunami and explosions there was considerable debris disrupting normal routes. Additionally, control room access was very limited and safety related instrumentation was generally not available or unreliable.

### 2.2 FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

- It was found that reactor water level gauges in 1F1 had drifted sometime during the accident progression when the instrumentation was calibrated in May. It is assumed that water in a reference tube for measurement evaporated due to high temperature in the circumstance, which brought higher reactor water level than actual value. Similar phenomena might have occurred in 1F2 and 1F3 as well. Limited number of parameters and less reliable measured values of core, reactor vessel and containment vessel have been used for severe accident management in 1F1 to 1F3.
- Severe Accident Management Guidelines (SAMG) and associated procedures generally assume that instruments, lighting and power are available. This may not be the case. In addition, these documents do not consider the possible state of the plant and the local environmental conditions such as radiation fields that may preclude manual actions from being taken. Some instruments installed in core, reactor vessel and containment in 1F1 to 1F3 are supposed to be unreliable. Level gauges at reactor vessel might be indicating overly-estimated values as was confirmed in the case for 1F1.

### 3 –CONCLUSIONS

**__/__/2011**

Robustness of the instruments, lighting and power to countermeasure the accident elevation was not sufficiently considered in Severe Accident Management Guidelines (SAMG) or plant specific procedures.

### 4 – LESSONS LEARNED

**__/__/2011**

Severe Accident Management Guidelines and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state and high radiation fields.

## FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A2-11** |
| Assessment Area: | **A2 - SEVERE ACCIDENT** | | |
| NPP: | **FUKUSHIMA-DAI-NI NPP** | | |
| Unit: | **UNITS 2F1 - 2F4** | | |
| Finding Title: | **EXTERNAL EVENTS HAVING A POTENTIAL OF AFFECTING MULTIUNITS PLANTS AT THE SAME TIME** | | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The height of tsunami to FUKUSHIMA DAI-NI site ranged from approximately O.P 7 m to O.P 15 m at south of Unit 1-4. All plants are located at the height of O.P 12 m, which is 2m higher than FUKUSHIMA DAI-ICHI. Even in case of great earthquake accompanying unexpected tsunami, Station Black Out was not happened. Instead, due to the flooding into heat exchanger building most residual heat removal seawater systems (RHRS) except Unit-3 were not available, which led to the loss of ultimate heat sink. By using the mobile power trucks, temporary power cable, and installing of procured motors the function of ultimate heat sink was recovered.

### 2.3 FINDINGS AT FUKUSHIMA-DAI-ICHI NPP

- The simultaneous loss of ultimate heat sink in unit-1, 2 and 4 is a typical common mode failure caused by extreme natural phenomena in multi-unit plant.

### 3 –CONCLUSIONS

**__/__/2011**

For effective mitigation of the common mode failures affecting simultaneously to multi unit plants at the same time, sufficient large resource in terms of trained experienced people, equipment, supplies and external support. In addition, an adequate pool of experienced personnel is recommended.

The procedures should be prepared for the logistics, human resources, supplies, external support to rapidly countermeasure severe accident and to reduce the radiation spreading. Operators and supporting persons like fire fighters should be effectively trained to understand their duties and be capable of implementing the procedures for mitigating the severe conditions.

### 4 – LESSONS LEARNED

**__/__/2011**

External events have a potential of affecting several plants and several units at the plants at the same time. This requires a sufficiently large resource in terms of trained experienced people, equipment, supplies and external support. An adequate pool of experienced personnel who can deal with each type of unit and can be called upon to support the affected sites should be ensured.

## FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-12** |
| Assessment Area: | **A2 - SEVERE ACCIDENT** | |
| NPP: | **FUKUSHIMA-DAI-NI NPP** | |
| Unit: | **UNITS 2F1 - 2F4** | |
| Finding Title: | **POTENTIAL UNAVAILABILTY OF INSTRUMENTS AND LIGHTING** | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The survivability of instrumentations during severe accidents in FUKUSHIMA DAI-NI site could not be identified since all reactors safely arrived to cold shutdown states within three days without entering severe accident conditions.

### 2.4 FINDINGS AT FUKUSHIMA-DAI-NI NPP

- The Severe Accident Management Guidelines (SAMG) of FUKUSHIMA DAI-NI plant are supposed to have similar contents and strategies with DAI-ICHI plant. It is very likely that the instrumentations installed around reactor and containment vessel would indicate fault values during severe accident conditions. It could provide operators and decision-makers with incorrect information to lead them to improperly countermeasure in response of the transients.
- SAMGs and associated procedures generally assume that instruments, lighting and power are available. This may not be the case. In addition, these documents do not considered the possible state of the plant and the local environmental conditions such as radiation fields that may preclude manual actions from being taken.

### 3 –CONCLUSIONS

**__/__/2011**

Robustness of the instruments, lighting and power to countermeasure the accident elevation was not sufficiently considered in Severe Accident Management Guidelines (SAMG) or plant specific procedures

### 4 – LESSONS LEARNED

**__/__/2011**

Severe Accident Management Guidelines and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state and high radiation fields.

## FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A2-13** |
| Assessment Area: | **A2 - SEVERE ACCIDENT** | | |
| Facility: | **GENERAL** | | |
| Unit: | | | |
| Finding Title: | **SEVERE ACCIDENT MANAGEMENT** | | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- An external initiating event of sufficient magnitude may have the potential to directly cause multiple component failures potentially leading to core damage. The 11 March 2011 tsunami did just that to three operating units at Fukushima Dai-ichi and led to complications at four spent fuel pools. Having a clear understanding of external initiating event risk can assist a utility in having pre-staged portable equipment to successfully carry out the essential safety functions of the plant, including criticality control, core and spent fuel pool heat removal and maintenance of containment integrity. Generally, in most boiling water reactors, a large contributor to core damage frequency is station blackout (SBO) which results in the unavailability of both ac and dc power. SBO precludes the operation of pumps and valves both necessary to perform the essential safety functions. This situation can be mitigated through the use of portable equipment provided it can be obtained and implemented in a timely manner, typically within a few hours. In order to do so, the equipment should be pre-staged, procedures developed and the operators trained to execute the plans. The equipment should be stored in a location that limits the probability of damage by the external event. It is also vital that adequate equipment be available for all the units on a site, including the spent fuel pool because of the potential for an external event affecting all units on a site. In addition, adequately trained staff must be available to respond to the event at all units on a site.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI AND FUKUSHIMA DAI-NI NPP:

- Subsequent to the events on 11 March 2011, Fukushima Dai-ichi received such equipment and it appears that they have been able to halt the severe accident progression, preventing containment liner melt through and energetic failure of primary containment. The plant is now attempting to develop more reliable and redundant means to provide the essential safety functions to the core and spent fuel pool, to ultimately achieve cold shutdown.
- The Fukushima Dai-ni plant was less damaged and the plant operators were able to continue to provide water to the reactor cores and depressurize the reactors. To aid in achieving a cold shutdown state, the plant superintendent called for mobile power trucks and mobilized the workers on-site to lay over 9 km of temporary power cables. In addition, replacement motors were procured for some of the flooded pumps. This allowed the normal residual heat removal systems to be returned to service 3 days following the tsunami and the units were brought to cold shutdown either on the same day or the day after RHR had been restored.

| | |
|---|---|
| - | Japanese utilities have implemented voluntary measures for preventing severe accidents and mitigating the impacts based on the NSC guidance document, “Accident Management Measures Against Severe Accidents in Light Water Nuclear Power Facilities,” dated 28 May 1992 and revised on 20 October 1997. Typical modifications to plants include installation of alternative pumps or procedures for core flooding using containment spray systems, water injection using fire pumps, and additional provisions for ac power using a tie-line from a neighbouring installation. These measures provide diversity for essential safety functions but are vulnerable to a large external event since they are located on the site. Subsequent to the events of 11 March 2011, NISA has taken action to confirm that licensees have followed this guidance and has additionally required that some equipment, such as power vehicles and pump trucks are located off-site. |

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|
| The lack of adequate supply of pre-staged portable equipment to carry out the essential safety functions of the plant hindered the ability to respond to the event. | | |

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: | **A2-14** |
|---|---|---|
| Assessment Area: | **A2 - SEVERE ACCIDENT** | |
| Facility: | **GENERAL** | |
| Unit: | | |
| Finding Title: | **MANAGEMENT AND PROCEDURE – CONSIDERATIONS FOR SEVERE ACCIDENT MANAGEMENT FOR NEW AND EXISTING JAPANESE NPPS** | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Severe Accident Management Guidelines (SAMGs) and associated procedures have been developed and implemented at most power reactors worldwide since the 1990's. Additional operating experience and research has led to the continuous enhancement of knowledge regarding severe accidents and subsequent improvements in SAMGs.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- The Japanese utilities voluntarily implemented SAMGs in the early 1990's. Their programmes include the documentation of procedures and a training programme, including the conduct of drills at plants on an annual basis. Because no core damage occurred at Dai-ni or Tokai Dai-ni, the operators were able to execute these plans although damage to the sites complicated their execution. At Dai-ichi, core damage resulted in high radiation levels at the site. There was some loss of inventory from the SFP due to boil off and there is a possibility of water loss from sloshing. These levels prevented the access to many areas of the plant, precluding implementation of the procedures.

### 3 –CONCLUSIONS

**__/__/2011**

The nuclear community worldwide should consider potential radiation levels in their procedures. The result may require action being taken earlier in the event than previously thought and may also necessitate the use of remote-controlled equipment that must be pre-staged. Due to the need for radiation protection measures including respirators and protective clothing, drills should be conducted with this equipment to verify that the actions can be taken in a timely manner. Additionally, operators must be appropriately trained in the use of remote-controlled equipment and equipment functionality should be ensured under severe conditions, including high radiation fields.

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |

The presence of high radiation fields in the plant needs to be considered to ensure manual actions can be executed under accident conditions.

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |

For most severe situations, such as total loss of power or loss of all the engineering safety systems, the equipment (such as mobile power and water supplies) that is necessary to manage the accident should be identified. This should be located at a safe place and the plant operators should be trained to use them

External events have a potential of affecting several plants at the same time. This requires the independence of the safety system. In addition, this requires multiple resources in terms of trained people, equipment, supplies and external support

# Appendix 3

## *IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East Japan Earthquake and Tsunami*
## *Japan*

# *FINDING SHEETS*

# *Monitoring, Emergency Preparedness and Response*

***IAEA 2011***

## FINDINGS SHEET

| | |
|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: **A3-01** |
| Assessment Area: | **A3 - MONITORING, EMERGENCY PREPAREDNESS AND RESPONSE** |
| Facility: | **GENERAL** |
| Unit: | |
| Finding Title: | **THE NUCLEAR EMERGENCY RESPONSE SYSTEM IN JAPAN** |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The emergency response system in Japan is organized in a three-tier form. The National Government establishes a Nuclear Emergency Response Headquarters (headed by the Prime Minister), and Nuclear Emergency Response Local Headquarters (headed by the Senior Vice Minister of METI), prepares national plans and procedures and takes decisions on important moves and countermeasures. The Local Government operates a Local Emergency Response Headquarters and is responsible for the implementation of emergency activities including monitoring, urgent protective actions (sheltering, evacuation, iodine prophylaxis) and long term countermeasures, municipalities also operate Emergency Response Headquarters. The operator of a nuclear facility (licensee) is responsible for the on-site emergency response including notification on events to the competent minister, to the governor of the prefecture and to the municipalities.
- The legal basis of the nuclear emergency preparedness in Japan is the Basic Act on Disaster Control Measures (related to every type of disasters) and the Act on Special Measures Concerning Nuclear Emergency Preparedness. The countermeasures are in line with the Basic Plan of Disaster, which concerns also emergencies different from nuclear
- Responsibilities on the governmental level are distributed among several ministries. Thus METI is responsible for nuclear power plants, fuel cycle facilities and fuel transportation, whereas MEXT is responsible for research reactors and radiation sources.
- During the 11 March earthquake and tsunami the functioning of the emergency preparedness and response system could not be performed according to the emergency plans and regulations for the damages caused by the earthquake in the local infrastructure. Therefore the central headquarter took over certain functions of the local off-site emergency centre.
- There is no formal and legally binding coordination between the responses to various types of emergencies, although the consequences of the 2007 Kashiwazaki-Kariwa earthquake event indicated the necessity of such coordination.

| **2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:** |
|---|
| - |

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|
| Japan has established a concise and well organized nuclear emergency preparedness and response system. The legal background of the nuclear emergency preparedness and response system is sound, the responsibilities are clearly defined. The handling of the Fukushima accident has demonstrated the capabilities and strength of the Japanese nuclear emergency preparedness. Nevertheless the system of nuclear emergency preparedness appears to be complicated in its structure and organization. This may result in unnecessary delays in taking urgent decisions. | | |

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|
| Coordination of responses to various types of emergencies may make the protective actions more effective. Similarly, simplification of the organizational scheme might result in shorter reaction times and smother functioning.<br>Flexibility and well trained feature of the emergency response system in Japan has made it possible to reach an effective response even in unexpected situations needing innovative solutions. | | |

## FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-02** |
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** | |
| Facility: | **GENERAL** | |
| Unit: | | |
| Finding Title: | **AUTHORITY, ACTIVITY AND COORDINATION** | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Authority and activity of the various players in the nuclear emergency preparedness in Japan is stipulated in the Act on Special Measures Concerning Nuclear Emergency Preparedness. The Act defines the roles and obligations of the licensees, and of the local and national governments
- Article 10 of the Act defines the conditions under which the licensee is bound to notify the government and the local authorities on the occurrence of abnormal operational events. Notification is required if the dose rate exceeds given values in given circumstances or the plant status warrants it. The limiting conditions are given in separate regulations.
- Article 15 of the Act defines the conditions under which the licensee is bound to declare an emergency situation. This is communicated to the national government and the Prime Minister takes the necessary steps to initiate preventive and response actions. Declaration of an emergency situation is conditioned by the existence of given radiological circumstances or facility states. The limiting conditions are determined in separate regulations.
- In contrast to the practice of some other countries no alert state is defined in the Japanese nuclear emergency preparedness system and no specific classification of emergencies is defined. Note also that the notions, definitions and methods of emergency preparedness and response as recommended by IAEA have found only limited scope application in the Japanese practice.
- Coordination of the various players in the nuclear emergency preparedness is defined by the relevant acts (c.f. A1-06-01). Nuclear facilities bear the sole responsibility for the emergency response to events in the facility. Nevertheless, actions having impact on the general public (like e.g. venting or water injection in case of the Fukushima accident) necessitate the approval of higher level response organizations or of the national government/Prime Minister.
- During the Fukushima accident the extreme natural conditions and events have made for the nuclear emergency preparedness system extremely difficult, sometimes impossible to follow the well established procedures and practices. In such cases the decision makers have selected novel solutions in the best interest of the general public, facility workers and environment.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

| 3 –CONCLUSIONS | | __/__/2011 |
|---|---|---|

The authority, functioning and coordination of the various components of nuclear emergency preparedness and response organizations in Japan have been and are being demonstrated by the activities in response to the Fukushima accident. Dedicated and devoted officials and workers, and a well organized and flexible system prevented a still larger catastrophe and saved lives among both the general public and the facility workers. Certain well established techniques, also recommended by IAEA, however, are not in use in the Japanese nuclear emergency practice.

| 4 – LESSONS LEARNED | | __/__/2011 |
|---|---|---|

Dedication and devotion of the Japanese emergency response players and their innovative activity deserve the interest of the international emergency preparedness community.

Use of IAEA guidance on threat categorization, event classification and countermeasures could make the off-site emergency preparedness and response in Japan still more effective.

## FINDINGS SHEET

| 1. FINDING IDENTIFICATION | | Finding Number: | A3-03 |
|---|---|---|---|
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** | | |
| Facility: | **GENERAL** | | |
| Unit: | | | |
| Finding Title: | **PLANS, PROCEDURES AND GUIDELINES** | | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The activities, duties and actions are described in acts, regulations and manuals of various levels. No specific national emergency response plan is in use.
- The most important requirements related to nuclear emergency preparedness and response are given in the Act on Special Measures Concerning Nuclear Emergency. It also contains the essential information, which is included in the national emergency response plans in some other countries.
- There exist manuals, commonly compiled by the operators that summarize practical information on the cooperation of various organizations, on preparatory and advisory steps to assist decision makers. Ministries with various roles in the emergency preparedness system have specific manuals; the cooperation of the ministries is realized on a working level. Local level (prefectures, municipalities) plans define the respective duties and activities.
- Licensees have their emergency preparedness plans for every nuclear facility.
- No emergency classification system is in use in the sense of the respective IAEA guidance. A single emergency planning zone has been defined for every nuclear facility; this is about 8-10 km for a nuclear power plant. Introduction of the notion of Urgent Protective action planning Zone and the extension of the planning zone to the size as recommended by IAEA is under consideration.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

| 3 –CONCLUSIONS | | __/__/2011 |
|---|---|---|

Japan relies more on regulations than on nuclear emergency plans in organizing its nuclear emergency response, this fact, however, seemed not to impede the effectiveness of the response.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|
| Use of a nuclear emergency planning system as suggested by the respective IAEA requirements, guides and technical documents may further enhance the capabilities of the emergency preparedness and response organizations in Japan. In this context definition and introduction of various emergency planning zones and the preparation of emergency response plans accordingly might reduce the burden on the response organizations in the early phase of an emergency. | | |

# FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-04** |
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** | |
| Facility: | **GENERAL** | |
| Unit: | | |
| Finding Title: | **PROTECTIVE ACTIONS** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Rules for protective actions are presented; refer to the administrative documents/guidelines compiled by NSC. These guidelines give numerical limiting values of radiation for sheltering and evacuation, as well as guidance on how to use other information and data
- Specifically for evacuation considerations in the Basic Disaster Prevention Plan as well as the Regulatory Guide: Emergency Preparedness for Nuclear Facilities by NSC are also to be taken into account
- Iodine prophylaxis is to be exercised in case the perceived committed dose exceeds a given value. This value is unique for all population groups; however the quantity of stable iodine to be administered depends on the age of the patient. Adults over 40 are not supposed to be involved.
- Long term protective actions including food restrictions are regulated in details and take into account the specific consumption habits in Japan. The action levels are somewhat different from those generally proposed by IAEA.
- Application of Operational Intervention Levels does not appear in the NSC guidelines and is not under consideration either.
- The terms of relocation and resettlement are not in use in the Japanese emergency preparedness practice.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

## 3 –CONCLUSIONS

**__/__/2011**

Application of protective action is properly defined and regulated in Japan. Some of the IAEA suggested methods are not in use; however, fully equivalent methods are in place.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|
| Consideration on applying Operational Intervention Levels (OILs) for urgent protective actions is suggested. Application of OILs may ease and make more effective the application of urgent protective actions. Revision in line with the IAEA recommendations of the terms and conditions used for evacuating people from an area might ease the long term management of the issue. | | |

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: **A3-05** |
|---|---|
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** |
| Facility: | **GENERAL** |
| Unit: | |
| Finding Title: | **PROTECTIVE ACTIONS – IN CASE OF THE FUKUSHIMA ACCIDENT** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- All appropriate measures have been taken to save lives. The National Government, the local government and the operator of the facility promptly took the actions necessary to minimize the consequences of a nuclear or radiological emergency. Emergency services have been made available to support the response at the facilities and the responders have implemented all practicable and appropriate actions to minimize the consequences and to protect emergency workers in accordance with international standards
- Urgent protective actions were implemented to prevent to the extent practicable the occurrence of severe deterministic health effects and to avert doses. As soon as the Government declared the state of nuclear emergency on 11 March 2011, radiation monitoring and environmental sampling and assessment have been initiated in order to identify new hazards promptly and to refine the strategy for response.
- On 16 March the local Headquarters instructed the local government that iodine prophylaxis should be performed when the evacuation is ongoing, however by that time the majority of the population has already left the 20 km area.
- Evacuation has been ordered on a gradually increasing area around the Fukushima Dai-ichi power plant as the situation in the plant aggravated. (For further details on urgent protective actions, see A1-06-06.)
- Agricultural countermeasures and longer term protective measures were taken to avert doses. In this action the Nuclear Emergency Response Headquarter gave instruction on restriction of distribution and/or consumption of food on 23 March 2011, in accordance with the Food Sanitation Act and the Act on Special Measures Concerning Nuclear Emergency Preparedness. For this decision the standards to be applied have been determined as late as 17 March, the measurements took two days whereas the decision was taken in another two days.
- Return criteria have so far not been determined, they are expected to be between 1 and 20 mSv/y.
- Compensation scheme for the damages has not yet been elaborated, the actual regulation is not relevant. A provisional guideline to this is expected to be elaborated by July 2011.
- Protection of workers and monitoring of contamination are treated in chapter “Radiological Consequences”

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Protective actions related to the Fukushima accident proved to be effective and well posed. Certain delays are to be attributed to the extreme conditions and unusual situations. Informing the affected population was an important part of the official activity. Exercises on handling the consequences of multiple disasters have been held in a very limited scope, yet the actual activities were efficient and saved lives.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

1. Organization, discipline and devotion during the response to the largest ever multiple catastrophes is to be posed as an example to the emergency preparedness and response organizations all over the world.
2. Timely decision making with less players and faster decisions on countermeasures can contribute to an even more efficient protection of the general public
3. Exercises and drills assuming multiple catastrophe situations should be included into the emergency exercise programme at sites potentially affected by such events.

## FINDINGS SHEET

| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-06** |
|---|---|---|
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** | |
| Facility: | **GENERAL** | |
| Unit: | | |
| Finding Title: | **PROTECTIVE ACTIONS - URGENT PROTECTIVE ACTIONS IN FUKUSHIMA** | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Notification according to Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness was sent from the Fukushima NPP to the government and the local authorities on 15:42, 11 March 2011. The minister of METI had to establish the local headquarters in 60 minutes.
- Emergency has been communicated to the government on 16:36, by 19:03 the national headquarters reached its active state and declared a nuclear emergency situation
- Evacuation of the population in the 2 km radius around Unit 1 of Fukushima Dai-ichi was decided on 11 March. Normally evacuation decision is based on dose measurements, however, in this case no reliable measurement was available and the decision was based on the Unit 1 status (loss of cooling). The same day the radius of the evacuation zone was extended to 3 km, whereas the next day pressure elevation triggered further extension to 10 km. This is the area of evacuation zone in the emergency plan.
- Hydrogen explosion on 12 March lead to the evacuation of residents from the 20 km zone.
- On 15 March another explosion struck Unit No. 2 and the residents in the area between 20 and 30 km radii were instructed to stay in-house (sheltering), whereas the same residents were suggested to take voluntary evacuation.
- On 16 March the local headquarters instructed the local government to administer iodine tablets whenever evacuation is performed. However, by this time the great majority of the evacuation has been completed.
- Long term sheltering (“indoors evacuation”) was in effect for more than a month.
- On 23 and 25 March NSC advised the Nuclear Emergency Response Local Headquarters to implement the survey on thyroid exposure for 1080 juveniles between 0 and 15 years have measured; in no cases has the 0.2 mSv/h screening level been exceeded. 190 000 inhabitants underwent external contamination measurements, the 100 000 cpm level was exceeded in 102 times
- On 21 April access to the 20 km radius area was prohibited.
- Sheltering in the area between the radii of 20 and 30 km has been lifted on 22 April and at the same time a Deliberate Evacuation Area has been established where there is the threat that the dose may reach 20 mSv in a year. In such cases the residents are requested to evacuate within one month. The threat was determined from measured and interpolated

dose values. No measured individual data are yet available from these territories. Three out of the five villages involved have already been evacuated.

- Parallel to that an Evacuation-Prepared Area is defined the residents of which need to be prepared for immediate evacuation should another emergency occur.
- The facility was little involved in emergency response activities in the classical sense of the word; its main activity was accident management.

**2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:**

-

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Unavailability of measurements has resulted in initiating urgent protection action based on the plant status. The fast changing plant circumstances made it imperative to take several consecutive measures (mostly evacuations) to protect the residents. Long term sheltering was not in line with international practice and has been abandoned and the notions of “deliberate evacuation” and “evacuation-prepared area” were introduced instead.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

1. Use of long term sheltering (“in-house evacuation”) was an unusual and not fully justified action that will need further analysis in the future.
2. For the sake of a still better organization and efficient functioning of the national emergency preparedness and response system the facility Emergency Response Teams should put emphasize on the activities as required by the respective IAEA documents

## FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-07** |

| | |
|---|---|
| Assessment Area: | **A3 – EMERGENCY PREPAREDNESS AND RESPONSE** |
| Facility: | **GENERAL** |
| Unit: | |
| Finding Title: | **ADDRESSING PUBLIC CONCERNS** |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Public communication is the responsibility of the local authorities. Residents affected by evacuation have been informed via local loudspeakers, car-messengers and the media. The central government asked the national and local media to assist in informing the population. The Prime Minister has called upon the residents via a televised speech. However, those who were affected the most could not use their television set for lack of electricity. Radio proved to be the most efficient means of communication.
- Population affected by countermeasures can obtain information and advice from the web pages of the Japanese Government and the Ministry of Health, Labor and Welfare (MHLW). National medical centres (neurology, psychiatry) are also prepared to advice the residents affected.
- Daily ground monitoring and aerial monitoring results are given to the media and the general public. Translation to English, Korean and Chinese is done as much as possible. MEXT with JAEA has established a telephone service for the general public on health concerns and radiation data. National Institute on Radiation Sciences has established a hotline to respond radiological exposure and health concerns.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

| | | |
|---|---|---|
| **3 –CONCLUSIONS** | | **__/__/2011** |

Informing the general public is of primary importance for the Japanese government and local authorities. Various means of communication and information are used with success.

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |

Open attitude, dedication, factual rightness and sufficient resources are absolutely necessary to cope with the information needs of the public.

## FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A3-08** |
| Assessment Area: | **A3 - EMERGENCY PREPAREDNESS AND RESPONSE** | | |
| Facility: | **GENERAL** | | |
| Unit: | | | |
| Finding Title: | **ADDRESSING INTERNATIONAL CONCERNS** | | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- In the early phases of the accident the Japanese Government was not able to supply sufficient information to the interested international community. It did not want to conceal anything but had no sufficient information either. E.g. on 4 April TEPCO released low level radioactive water into the sea, NISA had notified the IAEA before the event, however, for the fast changes and communication deficiencies the Japanese Government was unable to provide sufficient information to the neighboring countries. The government strives for improvements. It has changed its communication, in case of important actions not only IAEA but also the neighbouring countries are notified.
- The government is aware of import restrictions in some countries. It has been providing explanations on the accident to the diplomatic corps and governments through official channels. The government understands that the international community has concerns and also believes that it is important to react using scientific arguments. The government is aware of the fact that Japan's inability to provide sufficient information has led to the elevation of restrictions in some countries.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

-

| | | |
|---|---|---|
| **3 –CONCLUSIONS** | | **__/__/2011** |

The Japanese Government strives for open, sincere and complete information of the international community. Initial failures had objective reasons and no intention of concealing facts has ever occurred to the Japanese officials

| | | |
|---|---|---|
| **4 – LESSONS LEARNED** | | **__/__/2011** |

Information of the general public and especially the international community is a crucial and very delicate issue in case of a large scale emergency. Information techniques should be elaborated and practiced to cope with this issue.

# FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A3-09** |
| Assessment Area: | **A3 – RADIOLOGICAL CONSEQUENCES** | | |
| Facility: | **GENERAL/ FUKUSHIMA DAI-ICHI NPP** | | |
| Unit: | | | |
| Finding Title: | **SOURCE TERM** | | |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- The knowledge of the radioactive releases to the environment is necessary for the correct understanding of the event and for the decision making on countermeasures to protect the population. The estimation of source term constitutes one the main features in the process to have a clear estimate of the radioactive releases and to know the behaviour of some important structures and systems of the plant.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- The current available estimation of the source term was done by NISA (with the support of JNES) and NSC with the support of JAEA. On 12 April NISA calculated the estimated values for the purpose of rating the event on the INES scale that resulted in a level 7. The results are presented in the following table:

| | Assumed amount of the discharge from Fukushima Dai-ichi NPS | | Amount of discharge from Chernobyl |
|---|---|---|---|
| | NISA Bq | NSC Bq | |
| I-131 …(a) | $1.3 \times 10^{17}$ | $1.5 \times 10^{17}$ | $1.8 \times 10^{18}$ |
| Cs-137 | $6.1 \times 10^{15}$ | $1.2 \times 10^{16}$ | $8.5 \times 10^{16}$ |
| Converted value to I-131 …(b) | $2.4 \times 10^{17}$ | $4.8 \times 10^{17}$ | $3.4 \times 10^{18}$ |
| (a) + (b) | $3.7 \times 10^{17}$ | $6.3 \times 10^{17}$ | $5.2 \times 10^{18}$ |

Additionally, TEPCO has estimated that a total amount of $4.7 \times 10^{15}$ Bq was directly discharged into the sea as liquid effluents.

All those estimations are found provisional and limited, because they do not consider all the involved isotopes and the fact that releases have not yet stopped.

The reconstruction of a most realistic source term could include the analysis of the chronological event sequence and real data from environmental monitoring and from meteorological conditions, in an iterative feedback process. This process should consider the dispersion models at different time and distance ranges. All possible groups of isotopes should be considered in the analysis (Noble Gases, I, Cs, Te, Sr, Pu…), as well as some very indicative isotope ratios (v.gr. Sr-89/Sr-

90). Differences in isotopic components found inside the Containment Buildings versus those found outside could give information on the integrity of the Containment Pressure Vessels during the discharges.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

The knowledge of the source term involved in the accident is considered of paramount importance to reach a clear understanding of the event and to determine the possible extend of its radiological impact on the public and the environment.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

International nuclear community should take advantage of the Fukushima accident to improve and to refine the existing methods and models to determine the source term involved in a nuclear accident and to help decision making in emergency situations.

# FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-10** |

| | |
|---|---|
| Assessment Area: | **A3 – RADIOLOGICAL CONSEQUENCES** |
| Facility: | **GENERAL. FUKUSHIMA DAI-ICHI NPP** |
| Unit: | |
| Finding Title: | **OFF-SITE RADIOLOGICAL CONSEQUENCES. ASSSESMENT OF PUBLIC DOSES** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Assessment of doses to the population is a key factor to conduct a proper management of a nuclear emergency. This is usually done using Decision Support Systems to predict doses in different time and distance ranges, while they take feedback from the real data from the environmental monitoring. Direct monitoring of exposure to individuals is found crucial for public confidence.
- Regarding the chronological sequence of the Fukushima accident and how radioactive releases were produced, it was no possible to predict in advance the off-site impact. For this reason, data from monitoring the individuals and the environment pay a unique role for the assessment of radiological consequences of the accident.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- Japanese authorities have conducted direct monitoring of persons as well as the results of the environmental monitoring to support the assessment of doses. No significant doses have been concluded as results of the personal contamination measurements.

- As a result of the accident, significant amounts of radioactive materials were discharged into the atmosphere, contaminating some areas around the facility. Nevertheless the early application of the Emergency Plans, such as evacuation (20 Km) and sheltering (20-30 km), seems to have prevented significant exposure to the population.

- Additionally, the authorities have decided to evacuate some towns in the NW area (Planned Evacuation Zone), beyond the 20 km initial evacuation zone, based on the application of the 20 mSv-year projected dose criteria (ICRP for relocation) and the real radiological conditions (interpolation values were used where no measurements were available).

- The evacuation of this NW area started several weeks after the accident and has not finalized yet. Up to now there is not an estimation of real doses received in the Planned Evacuation Zone, especially taken into account the exposure to I-131 (cloud and deposition) and not only the deposited long or intermedium lived isotopes (Cs134 and

Cs137)

- For the mentioned purpose, the Japanese authorities have created an especial group in charged to define and to conduct health surveys and dose assessment of residents, including those living in the NW area (Planned Evacuation Zone). This group composed by Fukushima Prefecture and Medical Universities, including Hiroshima and Nagasaki Universities.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

The proper assessment of doses to population is considered a key issue in the management of a nuclear emergency, both to give feedback to the decision making process, in order to optimize protection strategies, and to gain confidence from the public. Additionally, a proper assessment of doses could contribute to define and optimize the strategy for individual health monitoring. Japanese authorities have conducted direct monitoring of persons as well as the results of the environmental monitoring to support the assessment of doses, and have created an expert group in charged to define and to conduct health surveys and dose assessment of residents, including those living in the NW area (Planned Evacuation Zone).

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

Direct monitoring of individual exposure, when possible, and the use of the results of the environmental monitoring, could help in achieving a realistic assessment of doses, to enhance the confidence of the population and to determine the individual health tracking programmes.

## FINDINGS SHEET

| | | | |
|---|---|---|---|
| **1. FINDING IDENTIFICATION** | | Finding Number: | **A3-11** |
| Assessment Area: | **A3 – RADIOLOGICAL CONSEQUENCES** | | |
| Facility: | **GENERAL/ FUKUSHIMA DAI-ICHI NPP** | | |
| Unit: | | | |
| Finding Title: | **ENVIRONMENTAL MONITORING** | | |

### 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Environmental radiological monitoring is a key element for the management of a nuclear emergency, especially in cases with significant radiological releases.
- In the Fukushima Dai-ichi accident, the start of the environmental monitoring was delayed due to the many difficulties found by the Fukushima Prefecture in charge of this monitoring. Most of the mentioned difficulties were caused by the same original events that were in the origin of the nuclear accident; i.e. the earthquake, the tsunami and the SBO. For that reason, at the beginning of the post accidental situation no many environmental data were collected. Only after MEXT became in charge of the monitoring programme, on 15 March, they started to collect valuable environmental data.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- In Japan, the Governments of Prefectures are in charge of emergency environmental radiological monitoring. After the accident in Fukushima Dai-ichi NPP, the Prefecture of Fukushima found a lot of difficulties to start the pre-established monitoring programmes, most of them due to the damages on the equipments caused by the earthquake, the tsunami and the SBO. As for example, 23 out of 24 monitoring posts were broken down in Fukushima prefecture and the off-site centre became not operable.

- Some actions were adopted to deal with that situation, using monitoring vehicles, but not many data were collected in the period between the 11 and 15 March.

- There were not available useful data on environmental monitoring for the evacuation decision, which was adopted regarding NPP status.

- On 15 March MEXT became the central agency for environmental monitoring. From 18 March the monitoring has been enhanced and reinforced (aerial, oceanic, land). Some important support from IAEA and US-DOE contributed to the improvement. Sophisticated monitoring equipments are in use (mobile units, aircraft, ships…). The most significant exposure ways are currently monitored, including land, marine and sky. Monitoring items include:

  - Dose rate. Fixed post and mobile units, aircrafts and ships
  - Integrated dose at fixed monitoring posts
  - Radionuclide analyses (mainly I-131 and Cs-137)
    - Dust, soil, pond water, weed
    - Drinking water, fallout (47 Prefectures)
    - Sea water and sea bottom soil

- Airborne measurements using aircrafts are conducted in the 80 km environment around the plant. From the obtained data they will decide on extension of the range.

- Monitoring data were used for the decision on the Planned Evacuation Zone.

- No summarized maps are yet available for ground monitoring, so far they have concentrated on the population. Currently they are in progress to define a mesh and make mapping.

- The 47 prefectures make measurements every hour and present results to MEXT daily. 54 Universities make measurements. The information is publicly available.

- A huge effort is being done by the National Government in cooperation with national and international specialized institutions to perform an efficient environmental monitoring. Recently the Government of Japanhas adopted a resolution to strengthen and to optimize the monitoring capabilities in areas inside the Planned Evacuation Zone (PEZ) and in areas outside this zone with relatively high dose rates. This includes terrestrial and sea monitoring.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

Environmental radiological monitoring is a key element for the management of a nuclear emergency, especially in cases with significant radiological releases.

Environmental radiological monitoring programmes have been enhanced from the beginning of the event to date. Many difficulties were found to start the pre-established monitoring programmes of local governments, most of them due to the damages on the equipments caused by the earthquake and the tsunami. A huge effort is being done by the National Government in cooperation with specialized national and international institutions to perform an efficient environmental monitoring. Recently the Government of Japanhas adopted a resolution to strengthen and to optimize the monitoring capabilities in areas inside the Planned Evacuation Zone (PEZ) and in areas outside this zone with relatively high dose rates. This includes both airborne and sea monitoring.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|

Results of the environmental monitoring programmes should be useful to give feedback to optimize the countermeasure strategy and to inform the public.

Emergency environmental radiological monitoring programmes should be defined and exercised in advance (normal conditions) to assure a fast and reliable deployment when an accident occurs. The design should consider the potential of common cause failures that could affect the equipments simultaneously with the nuclear accident, such as SBO or extreme natural events, and the consideration of all resources available at national and international levels to deal with such cases.

# FINDINGS SHEET

| | | |
|---|---|---|
| **1. FINDING IDENTIFICATION** | Finding Number: | **A3-12** |

| | |
|---|---|
| Assessment Area: | **A3 – RADIOLOGICAL CONSEQUENCES** |
| Facility: | **GENERAL/ FUKUSHIMA DAI-ICHI NPP** |
| Unit: | |
| Finding Title: | **ON-SITE RADIOLOGICAL CONSEQUENCES. RADIATION PROTECTION OF WORKERS** |

## 2. FINDINGS

### 2.1 - FINDING DESCRIPTION: BACKGROUND

- Radiation protection of workers in an accident with serious radiological implications, both on-site and off-site, is a key issue, not only from the view point of preventing radiological diseases to individuals, but to contribute to the proper development of the mitigation activities on-site. While the radiation protection programme is effective, it will reassure workers to assume the radiological risks associated to their tasks in a confident atmosphere of protection.
- The accident of Fukushima Dai-ichi NPP has challenged the development of a proper radiation protection programme of workers, due to several facts, such as the damage of the normal dosimetry system, the loss of dosimeters and especially the extreme radiological conditions in some areas of the plant.

### 2.2. – FINDINGS AT FUKUSHIMA-DAI-ICHI NPP:

- Japanese regulations for Radiation Protection are in line with the recommendations established by ICRP in publication ICRP-60 (1990). Dose limits for workers are established in terms of Effective Dose (ED) in 100 mSv for the period of 5 years, with a maximum of 50 mSv in a single year, and for women 5 mSv/3m.

- For emergency situations predefined individual dose reference levels are used rather than limits. At first, an individual dose reference level of 100 mSv was established. After the assessment of the accidental situation, authorities decided to increase the reference level for individual dose up to 250 mSv ED, for the sum of external and internal exposures during the emergency period. This was to permit the needed activities of mitigation in a compatible way with the protection of workers.

- The operator has established a lesser reference level (200 mSv) to assure the fulfillment of the one determined by authorities. Internal dose is measured by whole body counter (WBC) for those individuals with external doses above 100 mSv.

- During the accident the Management system of individual dosimetry became inoperable:

unable to gather access control information for Radiation Controlled Areas (RCA) and to gather personal dose data. Additionally, the Automatic Personal Dosimeter (APD) System was inoperable and they were unable to use 5,000 dosimeters. At first days, they could gather only 320 APD.

- To deal with that problem, they established a provisional approach that included the use of shared dosimeters for some workers under specific criteria and manual log register of individual doses. Gradually situation has enhanced. Now approximately 2,100 APD units are available.

- NISA has issued instructions on radiation protection to comply with by TEPCO in the specific cases of lack of dosimeters and lack of enough whole body counters.

- Gradually the situation has improved. On 14 April they introduced a simplified access control system, based on combination of APD and bar-code system. A new system has been established on 20 May for the management of radiation exposures of workers, including actions as those defined bellow:
  - Management of exposure doses (reporting on some works by TEPCPO to MHLW)
  - Health checkups establishing a system to connect with individual doses DB
  - Introduction of a system to established priorities for the assessment of internal doses, based on several criteria: accumulated external doses higher than 100 mSv, females involved in operations and especial cases (injuries, psychological symptoms…)

- Monitoring of dose rates in different areas of the plant is done on a continuous basis and results are represented in useful radiation maps.

- Every intervention in RCA is planned. Time of work in RCA for is limited to a maximum of 2 hours for every worker. Gradually especial tools have been introduced to support work in areas with highest radiation levels or serious contamination, such as robots and unmanned equipments.

- A comprehensive protocol between J-Village and Fukushima Dai-ichi has been established for a strong coordination of radiation protection controls of all personnel entering the restricted area and the facility. Around 2,000 workers a day are provided with radiation protection equipment in J-Village.

- As for radiation protection of outside workers and first time interveners, TEPCO provides a short training before entering the NPP on protective clothes, radioactivity and relevant work processes. J-Village is used for this training. Registration is going on for retroactive health care.

- Radiological prophylaxis with Iodine tablets was administered to the personnel working in the facility first days after the accident.

- So far (23 May) 30 workers are over 100 mSv external doses. Until 31 March there were 21 people to receive 100 mSv, the maximum internal dose was less than 40 mSv. Still they remain concerned and want to do the entire WBC evaluation as soon as possible.

- The presence of significant amount of very highly contaminated water in some buildings and trenches continues to be a matter of special concern, both for radiation protection of workers and the potential risks of uncontrolled releases to the sea.

- A number of actions have already been adopted by TEPCO and additional actions are included in the recovery road-map for achieving efficient control of the contaminated water. In this aim additional consideration should be done to some remarkable matters, such as those presented below:

  - Minimization of the inventory and production of contaminated water in a way compatible with the cooling of the Reactors and the Spent Fuel Pools. In minimizing contaminated water, the final objective should be the establishment of close cooling systems, and intermediate objectives should consider the reuse and the recycling contaminated water.

  - The installation of temporary additional storage and decontamination capabilities should strengthen the application of specific safety criteria, both to assure highly reliable and efficient operation of systems and to prevent accidental leaks. The potential of natural events, such as earthquakes and tsunamis, should be considered in the design and operation procedures of those systems.

- At last, TEPCO reported that two workers have received doses that could exceed the established reference dose levels (250 mSv) due to exposure to I-131 during the mitigation activities in Fukushima Dai-ichi. They plan to make an assessment of the internal doses (thyroid gland) received by these workers

- As summary, the established procedures to control the exposure of workers in Fukushima Dai-ichi NPP seem to be efficient in assuring a high level of protection in a context of extreme difficulties.

| **3 –CONCLUSIONS** | | **__/__/2011** |
|---|---|---|

The established procedures and organizations to control the exposure of workers in Fukushima Dai-ichi NPP and J-Village seem to be efficient in assuring a high level of protection in a context of extreme difficulties (areas seriously contaminated and very high dose rate levels). A matter of concern is the presence of significant amount of very highly contaminated water in some buildings.

The individual internal dose controls for all workers are encouraged to be done as soon as possible, especially for those workers involved in the mitigation activities at the beginning of the accident when releases occurred.

| **4 – LESSONS LEARNED** | | **__/__/2011** |
|---|---|---|
| Protection of workers in emergency situations should be considered a key issue to prevent unnecessary exposures and to support the mitigation activities. In the optimisation process for exposure of workers in emergency situations consideration should be done to a flexible application of the dose reference levels and the introduction of practical tools, such as the extensive use of radiological maps of the site or the use of special equipment (robots and unmanned tools). Classification of workers in different groups of risk could help to optimise the dosimetry and protection resources.<br>Especial attention should be paid to the outside workers and first responders, in terms of previous information and training.<br>A number of lessons could be learned for the international community from the experience of Japan in providing large scale radiation protection in response to the accident. | | |

# ANNEXES

# ANNEX I - MISSION PROGRAMME

**Tuesday, 24 May 2011:**

A.M.: Arrival of experts to Tokyo, Narita Airport, transfer to hotel.
09:00 Briefing and discussion @Main Lobby
12:00 Lunch
13:00 Technical Discussion @Banquet room Prominence (B1 floor) ~18:00
16:40 Transport by bus to METI
17:10 Courtesy visit to Mr Banri Kaieda, Minister of Economy Trade and Industry @Minister Kaieda's office (20min)
17:30 Press Contact (doorstep interview) after the courtesy visit (20min)
17:55 Return to hotel by bus
18:10 Working dinner
The room is booked until 24:00

**Wednesday, 25 May 2011:**

08:30 Departure from Hotel ANA by bus
09:00 Arrival at METI
09:00 Technical Discussions @METI conference room (17th floor, Main bldg.) (3h20min)
12:20 Lunch (Lunch box)
13:20 Departure from METI
13:50 Arrival at MOFA
13:50 Courtesy visit to Mr Takeaki Matsumoto, Minister of Foreign Affairs, (MOFA) (30min)
14:20 Press contact (Doorstep Interview) (10min)
14:30 Departure from MOFA
14:40 Arrival at NISA/METI
14:40 Technical Discussions @METI (1h20min)
16:00 Departure from METI to the Prime Minister's Office (PMO)
16:30 Arrival at PMO
16:30 Courtesy visit to Mr Yukio Edano, Chief Cabinet Secretary (30min)
17:00 Press contact (Doorstep interview) (10min)
17:10 Departure from PMO
17:30 Arrival at MEXT
17:30 Courtesy visit to Mr Yoshiaki Takaki, Minister of Education, Culture, Sports, Science & Technology (MEXT) (20min)
17:50 Press contact (Doorstep interview) (10min)
18:00 Departure from MEXT
18:10 Arrival at Hotel
18:10 Working Dinner until 24:00

**Thursday, 26 May 2011:**

07:00 Departure from ANA Hotel
10:00 Arrival at Tokai Dai-ni NPP (Japan Atomic Power Co.)
10:00 Site tour (120min)

12:00 Departure from Tokai Dai-ni NPP
12:00 Lunch on board
14:00 Arrival at J-Village
14:00 Change clothes ~14:30
14:30 Departure from J-Village by TEPCO's bus
15:00 Arrival at Fukushima Dai-ni NPP (Tokyo Electric Power Co.)
15:00 Radiation survey (20min)
15:20 Briefing (30min)
15:50 Plant observation (water intake, heat exchanger building, T/B, R/B from outside) (2hrs 50min)
18:40 Radiation survey (20min)
19:00 Observation of the Joint Conference
19:00 Q&A, Interviews (60min), dinner box (@ TEPCO)
20:00 Departure from Fukushima Dai-ni NPP
20:30 Arrival at J-Village
20:30 Radiation Survey (60min)
21:30 Departure from J-Village
23:00 Arrival and check-in at Hotel Square (Hitachi, Ibaraki Prefecture 0294-22-5531)

**Friday, 27 May 2011:**

07:00 Departure from Hotel Square Hitachi
07:00 Breakfast on board (snack bought in Tokai Dai-ni)
08:30 Arrival at J-Village
08:30 Change clothes ~09:00
09:00 Departure from J-Village by TEPCO's bus
09:30 Arrival at Fukushima Dai-ni NPP (Tokyo Electric Power Co.)
09:30 Radiation survey (30min)
10:00 Briefing, information exchange, interviews, snack lunch (60min)
11:30 Departure from Fukushima Dai-ni NPP
12:00 Arrival at Fukushima Dai-ichi NP
12:00 Plant observation (water intake, other facilities) (2hrs 30min)
14:30 Radiation survey (30min)
15:00 Emergency operation bldg. (seismic isolation bldg.) (30min)
15:30 Departure from Fukushima Dai-ichi NPP
16:00 Arrival at J-Village
16:00 Radiation Survey (60min)
17:00 Departure from J-Village
17:00 Snack on board (bought in Tokai Dai-ni or by stopping at a highway service station)
20:30 Arrival at ANA Hotel
20:30 Screening at hotel @Banquet room 'Aurora' (B1F)
21:00 Working Dinner room 2400hrs

**Saturday, 28 May 2011:**

08:30 Internal IAEA meeting with experts, split-up into 3 groups (37F, 606, 610)
09:00 Informal technical discussions with Japanese institution @ banquet room 'Aries' (37F)

12:00 Lunch @Banquet room 'Aries' (37F)
13:00 Informal technical discussions with Japanese institutions @Banquet room 'Aries' (37F)
18:00 Finish of discussion
18:00 Team meeting
19:00 Dinner @Banquet room 'Galaxy III' (B1F) –working dinner~24:00

**Sunday, 29 May 2011:**
09:00 Informal technical discussions @Banquet room 'Glory' (B1F)
12:00 Lunch
13:00 Preparation of Report @Banquet room 'Glory' (B1F)
17:00 Coordination with Admin
19:00 Submitting the draft report to the Government of Japan
19:00 Working Dinner @Banquet room 'Glory' (B1F) ~24:00

**Monday, 30 May 2011:**
09:00 Departure from ANA Hotel to NISA/METI
09:10 Informal technical discussions
12:00 Lunch
14:00 Review of Report with NISA
18:00 Departure from METI
18:30 Dinner @Hotel, banquet room 'Glory' (B1F)
20:00 Informal technical discussions, review of report

**Tuesday, 31 May 2011:**
09:00 Departure from ANA Hotel to NISA/METI
09:10 Formal technical discussions, review of Report
12:00 Lunch
18:00 Departure from METI
18:30 Cheese & Wine Reception at Mr Taniguchi's
18:30 Dinner @banquet room 'Glory' (B1F)

**Wednesday, 1 June 2011:**
08:30 Departure from ANA Hotel
09:00 Arrival at Prime Minister's Office
09:00 Closing Meeting @Prime Minister's office
09:30 Press contact: Doorstep interviews
18:00 Hospitalities

**Thursday, 2 June 2011:**
A.M. Experts return home.

# ANNEX II - LIST OF PARTICIPANTS

## A.1 IAEA REVIEW TEAM:

| TEAM LEADERSHIP | |
|---|---|
| Mr WEIGHTMAN, Michael William<br>United Kingdom<br>(Team Leader) | Health and Safety Executive (HSE)<br>Office for Nuclear Regulation (ONR)<br>4N.2 Redgrave Court<br>Merton Road, Bootle<br>MERSEYSIDE L20 7HS<br>United Kingdom<br>Tel: +44 151 951 4168<br>Fax: +44 151 951 4821<br>mike.weightman@hse.gsi.gov.uk |
| Mr JAMET, Philippe<br>France<br>(Deputy Team Leader) | Autorité de Sûrete Nucléaire (ASN)<br>6 place du Colonel Bourgoin<br>75572 PARIS Cedex 12<br>France<br>Tel: + 33 1 40 19 86 35<br>Fax : + 33 1 40 19 86 09<br>Mobile : + 33 6 66 40 09 71<br>philippe.jamet@asn.fr |
| **INTERNATIONAL EXPERTS** | |
| Mr GODOY, Antonio *1<br>Argentina<br>(Effect of earthquake, tsunami, explosion and after-shocks on SSCs) | Chivilcoy 1178 Castelar (1712)<br>BUENOS AIRES, Argentina<br>Tel: +54-11-4627-0762<br>Mobile: +43 (664) 41 39 328<br>agodoy@aon.at |
| Mr GUERPINAR, Aybars *1<br>Turkey<br>(External Events Assessment) | Tokoglu Mah.<br>1068 Sok. No. 31<br>Alacati, CESME, Turkey<br>Tel: +90 232 7169879<br>Mobile: +436645385787<br>aybarsgurpinar2007@yahoo.com |
| Mr GORYACHEV, Alexander Valentinovich *2<br>Russian Federation<br>(Spent Fuel Management under severe degradation) | NIIAR<br>Group head, Fuel Research Department<br>JSC “State Scientific Center Research Institute of Atomic Reactors”<br>433510 DIMITROVGRAD-10, Ulyanovsk region, Russia<br>Tel: +7(84235) 65674<br>Mobile +7 9063943686<br>Fax: +7(84235) 65663<br>goryachev@list.ru, jvv@niiar.ru |

| | |
|---|---|
| Mr CHAI, Guohan *2<br>People's Republic of China<br>(Safety Assessment and Defence-in-Depth) | Chief Engineer, Nuclear and Radiation Safety Centre, Ministry of Environmental Protection<br>54 Hong Lian Nan Cun, Haidian District, BEIJING 100082 People's Republic of China<br>Tel: +86-10-8221-2561<br>Fax: +86-10-6225-7804<br>chaiguohan@126.com |
| Ms UHLE, Jennifer *2<br>United States of America<br>(Severe Accident: Analysis) | US Nuclear Regulatory Commission (USNRC)<br>21 Church Street, RACHVILLE<br>MD 20852 USA<br>Tel: +1-301-251-7402<br>Jennfer.Uhle@nrc.gov |
| Mr SUNG, Key Yong *2<br>Republic of Korea<br>(Severe Accident: Analysis) | Head, Risk Assessment Department<br>Korea Institute of Nuclear Safety (KINS)<br>Yousong-ku Kusong-dong 19,<br>DAEJEON, 305-600<br>Republic of Korea<br>Tel: +82-42-868-0158<br>Mobile: +82-10-8247-4543<br>k109sky@kins.re.kr |
| Mr CHANDE, S. K. *2<br>India<br>(Severe Accident: Management Procedures) | Vice-Chairman,<br>Atomic Energy Regulatory Board (AERB),<br>Niyamak Bhavan, Anushaktinagar<br>MUMBAI<br>PIN. 400 094, India<br>Tel: +91-22-2557-4024<br>Mobile: +91-981-983-2100<br>vc@aerb.gov.in |
| Mr LUX Ivan *3<br>Hungary<br>(Emergency preparedness and response: protective actions) | Deputy Director General<br>Nuclear Safety Directorate<br>Hungarian Atomic Energy Authority (HAEA)<br>1539 BUDAPEST, P. O. Box 676<br>Hungary<br>Tel:+36-1-4364-881<br>lux@haea.gov.hu |
| Mr SUMARGO, Dedik Eko *3<br>Indonesia<br>(Emergency preparedness and response: governmental infrastructure and communication) | Head for Sub-directorate of Nuclear Emergency Preparedness<br>Nuclear Energy Regulatory Agency (BAPETEN)<br>P.O. Box 400, JI. Gajah Mada No. 8<br>JAKARTA, Pusat, 10120<br>Indonesia<br>Tel: +62 81382198211, +62 2163856518<br>d.sumargo@bapeten.go.id<br>de.margo@yahoo.com |

| | |
|---|---|
| Mr LENTIJO, Juan Carlos *3<br>Spain<br>(Radiological Consequences) | General Director for Radiation Protection<br>Consejo de Seguridad Nuclear (CSN)<br>c/ Pedro Justo Dorado Dellmans, 11<br>28040 MADRID<br>Spain<br>Tel: +34-91-346-0622<br>Fax: +34-91-346-0528<br>Mobile +34-630-0822-73<br>jcll@csn.es |
| **INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA) EXPERT TEAM** | |
| Mr LYONS, James Edward | Director<br>Division of Nuclear Installation Safety (NSNI)<br>Department of Nuclear Safety and Security<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-22520<br>J.Lyons@iaea.org |
| Mr SAMADDAR, Sujit Kumar | Head, International Seismic Safety Centre (ISSC)<br>Division of Nuclear Installation Safety (NSNI)<br>Department of Nuclear Safety and Security<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-22513<br>S.Samaddar@iaea.org |
| Mr BRADLEY Jr, Edward Eugene | Nuclear Engineer<br>Research Reactor Section (RRS)<br>Division of Nuclear Fuel Cycle and Waste Technology (NEFW)<br>Department of Nuclear Energy<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-22759<br>E.Bradley@iaea.org |
| Ms NAMMARI, Nadia | Project Assistant<br>Safety Assessment Section (SAS)<br>Division of Nuclear Installation Safety (NSNI)<br>Department of Nuclear Safety and Security<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-25557<br>N.Nammari@iaea.org |

| **IAEA PUBLIC INFORMATION TEAM** | |
|---|---|
| Mr WEBB, Gregory Paul | Press and Public Information Officer<br>Media and Outreach Section<br>Division of Public Information (MTPI)<br>Department of Management<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-22047<br>Mobile: 43-699-165-22047<br>G.Webb@iaea.org |
| Mr PAVLICEK, Petr | Video Editor/Cameraman<br>Media and Outreach Section<br>Division of Public Information (MTPI)<br>Department of Management<br>IAEA<br>Vienna International Centre<br>P. O. Box 1400, VIENNA, Austria<br>Tel: +43-1-2600-26390<br>Mobile: +43-699-165-26390<br>P.Pavlicek@iaea.org |
| **IAEA LIASION OFFICER** | |
| Mr MORITA, Shin | Nuclear Safety Officer<br>International Seismic Safety Centre (ISSC)<br>Division of Nuclear Installation Safety (NSNI)<br>Department of Nuclear Safety and Security<br>IAEA<br>Vienna International Centre<br>P. O. Box 140 0, VIENNA, Austria<br>Tel: +43-1-2600-22614<br>S.Morita@iaea.org |

## A.2 JAPANESE ORGANIZATIONS

Officials of the GOVERNMENT OF JAPANand governmental advisory committee members, including from:

- Prime Minister’s Office;
- Ministry of Foreign Affairs (MOFA);
- Ministry of Economy, Trade and Industry (METI)
- Nuclear and Industrial Safety Agency (NISA);
- Ministry of Education, Culture, Sports, Science and Technology (MEXT);
- Ministry of Agriculture, Forestry and Fishery (MAFF);
- Ministry of Health, Labour and Welfare (MHLW);
- Nuclear Safety Commission (NSC);
- Japan Nuclear Energy Safety Organization (JNES);
- Japan Atomic Energy Agency (JAEA);
- Tokyo Electric Power Company Ltd. (TEPCO);
- Japan Electric Power Company Ltd. (JAPC)
- The Committee’s members, academic experts (to be nominated by the Government of Japan).

| **PRIME MINISTER’S OFFICE (PMO)** | |
|---|---|
| **Mr EDANO, Yukio** | Chief Cabinet Secretary,<br>Minister of State for Okinawa and Northern Territories Affairs |
| **Mr HOSONO, Goshi** | Special Advisor to the Prime Minister |

| **MINISTRY OF FOREIGN AFFAIRS (MOFA)** | |
|---|---|
| **Mr MATSUMOTO, Takeaki** | Minister for Foreign Affairs |
| **Mr MIYAGAWA, Makio** | Director General, Disarmament, Non-Proliferation and Science Department |

| | |
|---|---|
| **Mr KOIZUMI, Tsutomu** | Director, Non-Proliferation, Science and Nuclear Energy Division<br>Disarmament, Non-Proliferation and Science Department |
| **Mr ONISHI, Kazuyoshi** | Deputy Director, International Nuclear Energy Cooperation Division, Disarmament, Non-Proliferation and Science Department |

| **MINISTRY OF ECONOMY, TRADE AND INDUSTRY (METI)** | |
|---|---|
| **Mr KAIEDA, Banri** | Minister for Economy, Trade and Industry |

| **NUCLEAR AND INDUSTRIAL SAFETY AGENCY (NISA)** | |
|---|---|
| **Mr TERASAKA, Nobuaki** | Director General |
| **Mr NEI, Hisanori** | Deputy Director General for Nuclear Fuel Cycle |
| **Mr BANNAI, Toshihiro** | Director, International Affairs Office<br>Bannai-toshihiro@meti.go.jp |
| **Mr YAMADA, Tomoho** | Director, Nuclear Power Licensing Division<br>Yamada-tomoho@meti.go.jp |
| **Mr MITA, Shunichiro** | Senior Safety examiner, Seismic Safety Office<br>Nuclear Power Licensing Division |
| **Mr SUGIHARA, Yutaka** | Safety examiner, Seismic Safety Office<br>Nuclear Power Licensing Division |
| **Mr YOSHINO, Masaharu** | Director for Safety Examination,<br>Nuclear Power Licensing Division |
| **Mr OHSHIMA, Toshiyuki** | Director for Safety Examination,<br>Nuclear Safety Regulatory Standards Division |

| | |
|---|---|
| **Mr AOYAMA, Katsunobu** | Deputy Director, Nuclear Power Plant Aging Management Office<br>Nuclear Power Inspection Division |
| **Mr TAKASU, Tsuyoshi** | Safety examiner, Nuclear Power Licensing Division |
| **Mr MAEKAWA, Yukinori** | Director, Nuclear Emergency Preparedness Division |
| **Mr KOSAKA, Atsuhiko** | Deputy Director, Quality Assurance, Nuclear Power Inspection Division |
| **Mr NAKAMURA, Koichiro** | Deputy Director General for Nuclear Safety |
| **Mr TAKABATAKE, Masaaki** | Head of Radiation Group, Emergency Response Centre |
| **Mr ICHIMURA, Tomoya** | Head of Coordination Group, Emergency Response Centre |
| **Mr YONEYAMA, Hiromitsu** | Chief Nuclear Safety Inspector<br>Nuclear Power Inspection Division |
| **Mr ONO, Yuji** | Deputy Director, Nuclear Safety Regulatory Standard Division |

| **MINISTRY OF EDUCATION, CULTURE, SPORTS AND TECHNOLOGY (MEXT)** | |
|---|---|
| **Mr TAKAKI, Yoshiaki** | Minister for Education, Culture, Sports and Technology |
| **Mr SASAKI, Ryuzo** | Senior Vice Minister |
| **Mr GODA, Takafumi** | Director General, Science and Technology Policy Bureau |

| | |
|---|---|
| **Mr WATANABE, Itaru** | Senior Deputy Director General<br>Science and Technology Policy Bureau<br>Exec Director for Nuclear Safety<br>iwatana@mext.go.jp |
| **Mr AKASAKA, Naoaki** | Director, Office of International Relations,<br>Nuclear Safety Division<br>Science and Technology Policy Bureau<br>akasaka@mext.go.jp |
| **Mr TANABE, Kuniharu** | Deputy Head, Residents' Safety Group, Nuclear Sufferers Life Support Team, Cabinet Office |
| **Mr CHAYAMA, Shuichi** | Head of Radiation Group, Nuclear Sufferers Life Support Team, Cabinet Office |
| **Mr FUKUSHIMA, Yasumasa** | Head of Medical Care Group, Nuclear Sufferers Life Support Team, Cabinet Office |

| **MINISTRY OF AGRICULTURE, FORESTRY AND FISHERY (MAFF):** | |
|---|---|
| **Mr AKIYAMA, Noritaka** | Deputy Director, Food Security Division, Secretariat |
| **Mr ENDO, Hisashi** | Director, Ecosystem Conservation Office, Fisheries Agency |
| **Mr MORITA, Takami** | Senior Research Coordinator, Fisheries Agency |
| **Mr SATOH, Yuusuke** | Fisheries Coordination Division Chief, Fisheries Agency |

| **MINISTRY OF HEALTH, LABOUR AND WELFARE (MHLW)** | |
|---|---|
| **Mr MIYAHARA, Shintaro** | Policy Planning Division, Industrial Safety and Health Department, Labour Standards Bureau |
| **Mr MORI, Tadashi** | Industrial Health Division, Industrial Safety and Health Department, Labour Standards Bureau |

| **JAPAN NUCLEAR SAFETY COMMISSION (JNSC)** | |
|---|---|
| **Mr MADARAME, Haruki** | Chair |
| **Mr KUKITA, Yukata** | Deputy Chair |
| **Ms KUSUMI, Shizuyo** | Commissioner |
| **Mr OYAMADA, Osamu** | Commissioner |
| **Mr SHIROYA, Seiji** | Commissioner |

| **JAPAN NUCLEAR ENERGY SAFETY ORGANIZATION (JNES)** | |
|---|---|
| **Mr NAKAGAWA, Masaki** | Director, Emerging Nations Training Centre, Office of International Programmes<br>Nakagawa-masaki@jnes.go.jp |
| **Mr SAITO, Minoru** | Assistant Director General, Nuclear Emergency Preparedness and Response Division |
| **Mr EBISAWA, Katsumi** | Associate Vice President |
| **Mr HAYASHIDA, Yoshihisa** | Director, Radiation Safety and Water Chemistry Evaluation Group, Nuclear Energy System Safety Division |
| **Mr ABE, Hiroshi** | Senior Staff, Seismic Safety Division |
| **Mr CHANGJIANG, Wu** | Senior Researcher, Seismic Safety Division |
| **Mr SUGINO, Hideharu** | Senior Researcher, Seismic Safety Division |

| | |
|---|---|
| **Mr ANZAWA, Tokio** | Principal Staff, Nuclear Energy System Safety Division |
| **Mr MOTOHASHI, Shohei** | Senior Counsellor, Seismic Safety Division |
| **Mr WATANABE, Atsushi** | Senior Staff, Nuclear Energy System Safety Division |

## Representatives of Licensees:

| TOKYO ELECTRIC POWER COMPANY LIMITED (TEPCO) | |
|---|---|
| **TOKYO HEADQUARTERS** | |
| **Mr MASUDA, Naohiro** | Superintendent, Fukushima Dai-ni NPP<br>Masuda.naohiro@tepco.co.jp |
| **Mr KAWANO, Akira** | General Manager,<br>Nuclear Power & Plant Siting Administrative Dept.<br>Kawano.akira@tepco.co.jp |
| **Mr NISHIOKA, Hiroaki** | Overseas Business Development Dept.,<br>International Affairs Dept.<br>Nishioka.hiroaki@tepco.co.jp |
| **Mr TATEIWA, Kenji** | Deputy Manager, Overseas Business Development Dept.,<br>International Affairs Dept.<br>tateiwa.kenji@tepco.co.jp |
| **Mr SUZUKI, Akira** | Group Manager, Nuclear Power Plant Management Dept.<br>Suzuki.akilla@tepco.co.jp |
| **Ms KUMANO, Yumiko** | Transport Engineering Group, Nuclear Fuel Cycle Department<br>kumano.yumiko@tepco.co.jp |
| **Mr ITO, Shinichi** | General Manager, Nuclear Power & Plant Siting Administrative Dept.<br>Ito.shinichi@tepco.co.jp |
| **Mr MIYATA, Koichi** | Group Manager, Nuclear Asset Management Dept.<br>Miyata.koichi@tepco.co.jp |
| **Mr ONO, Masayuki** | Group Manager, Nuclear Quality and Safety Dept.<br>Ono.masayuki@tepco.co.jp |
| **Mr OTSUKA, Yasuyuki** | Deputy Manager, Nuclear Asset Management Dept.<br>Otsuka.yasuyuki@tepco.co.jp |
| **Mr FUKUDA, Toshihiko** | General Manager, Nuclear and Siting Division<br>Fukuda.toshihiko@tepco.co.jp |

| | |
|---|---|
| **Mr SAKAI, Toshiaki** | General Manager, Construction Engineering Center, Construction Dept.<br>Sakai.toshiaki2@tepco.co.jp |
| **Mr ASAI, Satoshi** | Deputy Manager, Nuclear Asset Management Dept.<br>Asai.satoshi@tepco.co.jp |
| **Mr MIZUTANI, Hiroyuki** | Deputy Manager, Nuclear Asset Management Dept.<br>Mizutani.hiroyuki@tepco.co.jp |
| **FUKUSHIMA DAI-ICHI NPP** | |
| **Mr YOSHIDA, Masao** | Superintendent<br>Yosida.masao@tepco.co.jp |
| **Mr YOSHIZAWA, Atsufumi** | Unit Superintendent<br>Yoshizaawa.a@tepco.co.jp |
| **Mr INAGAKI, Takeyuki** | General Manager, Maintenance Dept.<br>Inagaki.takeyuki@tepco.co.jp |
| **FUKUSHIMA DAI-NI NPP** | |
| **Mr MASUDA, Naohiro** | Superintendent<br>Masuda.naohiro@tepco.co.jp |
| **Mr KAWAMURA, Shinichi** | Unit Superintendent<br>Shinichi.kawamura@tepco.co.jp |

| **JAPAN ELECTRIC POWER COMPANY LIMITED (JAPC)** | |
|---|---|
| **Mr ITO, Hiroyasu** | Deputy General Manager, Plant Management Dept, Headquarter |
| **Mr KENDA, Hirofumi** | Station Manager, TOKAI Dai-ni Power Station |