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Volume I

ENGINEERING SAFETY REVIEW SERVICES
SEISMIC SAFETY EXPERT MISSION

"PRELIMINARY FINDINGS AND LESSONS LEARNED FROM THE 16 JULY 2007 EARTHQUAKE AT KASHIWAZAKI-KARIWA NPP"

"The Niigataken Chuetsu-Oki earthquake"

Kashiwazaki-Kariwa NPP and Tokyo, Japan
6 – 10 August 2007

ENGINEERING SAFETY REVIEW SERVICES (ESRS)

DIVISION OF NUCLEAR INSTALLATION SAFETY

DEPARTMENT OF NUCLEAR SAFETY AND SECURITY

REPORT

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"PRELIMINARY FINDINGS AND LESSONS LEARNED FROM THE 16 JULY 2007 EARTHQUAKE AT KASHIWAZAKI-KARIWA NPP"

REPORT TO
THE GOVERNMENT OF JAPAN

Kashiwazaki-Kariwa NPP and Tokyo, Japan

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Mission date: 6 – 10 August 2007

Location: Kashiwazaki-Kariwa NPP and Tokyo, Japan

Facility: Kashiwazaki-Kariwa NPP, Units 1 – 7

Organized by: International Atomic Energy Agency

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CONTENTS

SUMMARY

Upon request from the Government of Japan an IAEA expert mission was conducted at the Kashiwazaki-Kariwa NPP following a strong earthquake that affected the plant on 16 July 2007. The objective, as agreed with the Japanese counterpart, was to conduct a fact finding mission and to identify the preliminary lessons learned that might have implications for the international nuclear safety regime.

Although the Niigataken Chuetsu-Oki earthquake on 16 July 2007 significantly exceeded the level of the seismic input taken into account in the design of the plant, the installation behaved in a safe manner, during and after the earthquake. In particular, the automatic shutdown of the reactors of Units 3, 4 and 7, which were operating at full power, and of the reactor of Unit 2, which was in the start up state, were performed successfully.

Based on the reports from experts from the Tokyo Electric Power Company (TEPCO) and the limited but representative plant walkdowns and visual observations performed by the IAEA team, safety related structures, systems and components of the plant seem to be in a much better general condition than might be expected for such a strong earthquake, and there is no visible significant damage. This is probably due to the conservatisms introduced at different stages of the design process. The combined effects of these conservatisms were apparently sufficient to compensate for uncertainties in the data and methods available at the time of the design of the plant, which led to the underestimation of the original seismic input.

However, important components like the reactor vessels, the core internals and the fuel elements have not yet been examined and in-depth inspections are still to be performed. On the other hand, non-safety related structures, systems and components were affected by significant damage such as soil and anchorage failures and oil leakages.

A re-evaluation of the seismic safety the Kashiwazika-Kariwa NPP needs to be done with account taken of the lessons learned from the Niigataken Chuetsu-Oki of earthquake and using updated criteria and methods. Detailed geophysical investigations are foreseen both on land and offshore for defining the new seismic input to the plants. In particular, these investigations should address the issue of the potential existence of active faults underneath the site.

Another consideration is the possibility that long term operation of components could be affected by hidden damage from this event. Thus, the potential interaction between large seismic events and accelerated ageing may be an important topic to consider in future inspection programmes.

Throughout the mission, the attitude of the Japanese counterpart was open and cooperative. It was felt that this search for openness was shared by all the individuals with whom the team interacted.

In addition to the more detailed and comprehensive inspections and analyses to be performed by the Japanese and their commitment to present a report at the Regulator's Meeting during the 51st IAEA General Conference in September 2007, the IAEA will follow this mission with extensive international cooperation, including technical assessments and studies, as well as communicating the findings and lessons learned to nuclear operators, regulators and technical support organisations.

1. BACKGROUND, OBJECTIVES AND SCOPE OF THE MISSION

1.1. BACKGROUND

Upon request from the Government of Japan through the Nuclear and Industrial Safety Agency (NISA), an IAEA expert mission was conducted at the Kashiwazaki-Kariwa Nuclear Power Plant following the strong Niigataken Chuetsu-Oki earthquake that affected the plant on 16 July 2007.

Kashiwazaki-Kariwa nuclear power plant is the biggest nuclear power plant site in the world. It is operated by Tokyo Electric Power Company (TEPCO). The site has seven units with a total of 7965 MW net installed capacity. Five reactors are of BWR type with a net installed capacity of 1067 MW each. Two reactors are of ABWR type with 1315 MW net installed capacity each. The five BWR units entered commercial operation between 1985 and 1994 and the two ABWRs in 1996 and 1997 respectively.

At the time of the earthquake, four reactors were in operation: Units 2, 3 and 4 (BWRs) and Unit 7 (ABWR). Unit 2 was in start-up condition but was not connected to the grid. The other three reactors were in shutdown conditions for planned outages: Units 1 and 5 (BWRs) and Unit 6 (ABWR).

A strong earthquake with a moment magnitude of 6.6 (M_{JMA}=6.8 according to the Japanese Meteorological Agency) occurred at 10:13 h local time on 16 July 2007 with its epicentre about 16 km north of the site of the Kashiwazaki-Kariwa NPP and its hypocentre below the seabed of the Jo-chuetsu area in Niigata prefecture (37° 33' N, 138° 37'E).

The earthquake caused automatic shutdown of the operating reactors, a fire in the in-house electrical transformer of Unit 3, release of a very limited amount of radioactive material to the sea and the air and damage to non-nuclear structures, systems and components of the plant as well as to outdoor facilities, as reported by TEPCO on their web page.

Preliminary data indicated that the design basis ground motion for the plant may have been exceeded, with possible significant effects on the behaviour of the plant systems, structures and components.

The IAEA was informed of this event on the same day and in view of subsequent information on its severity, the IAEA expressed on 18 July its readiness to send to Japan an international team of experts to join the Japanese government in assessing the event and its consequences and to share the findings and lessons learned with the international nuclear community.

Thus, on 23 July, NISA requested the IAEA that a team of international experts be sent to Japan observe the current conditions at the Kashiwazaki-Kariwa nuclear power plant. In addition, Japan undertook to report on the latest information regarding the impact of the earthquake on the plant at the Senior Regulators' Meeting planned to be held during the 51st IAEA General Conference in September 2007. It was also indicated that Japan will host an IAEA international workshop on this matter after all safety assessments have been conducted.

The IAEA welcomed this proposal and informed Japan that it was ready to send the expert team in a few weeks; the mission date was fixed for 6 – 10 August 2007.

1.2. OBJECTIVES

The objectives, as agreed with the Japanese counterpart organization, were to conduct a fact finding mission in relation to the current conditions at the nuclear power plant and to identify the preliminary lessons learned from the event that might have implications for the international nuclear safety regime.

Thus, the mission complemented the ongoing safety evaluations of the incident as they are currently being performed by Japan's Nuclear and Industrial Safety Agency, Japan's Nuclear Safety Commission and the plant operator, the Tokyo Electric Power Company.

Specifically, the IAEA team discussed the performance of the nuclear power plant units during and after the earthquake, in particular, the fulfilment of the fundamental safety functions which are required to be maintained at a nuclear power plant immediately following such an event, as follows:

1) control of reactivity;
2) removal of heat from the core; and
3) confinement of the radioactive materials and control of operational discharges, as well as limitation of accidental releases.

1.3. SCOPE OF THE MISSION

The scope of the mission was limited to three subject areas:

Area 1: Seismic design basis – design basis ground motions

Preliminary investigations of the actual earthquake and its ground motions and comparison with the design basis ground motions for the plant seismic design.

Area 2: Plant behaviour – structures, systems and components

Observation of the damage that occurred as a consequence of the earthquake of 16 July 2007 to the seven units at Kashiwazaki-Kariwa nuclear power plant site on the basis of the information gathered and made available by TEPCO and by performing limited but representative plant walkdowns.

Area 3: Operational safety management

Preliminary investigations of the operational safety management response and releases of radioactive material during and after the earthquake, on the basis of the examination of documents and of discussions with TEPCO.

It should be pointed out that an important limiting condition was the short time for performing the mission, with only three days available for conducting the in-plant walkdowns of seven units including access to the controlled areas in each of them.

Taking all this into consideration, a detailed description of the three areas covered within the scope of the mission was established and communicated to the Japanese counterpart in advance to the mission.

2. CONDUCT OF THE MISSION

The mission was conducted by a team composed of a leader and five international experts well recognized in this domain:

1.	*Team Leader*:	Philippe Jamet, IAEA, Director of Division of Nuclear Installation Safety (NSNI).
2.	*Deputy Team Leader*:	Antonio R. Godoy, IAEA, Acting Head of Engineering Safety Section (ESS)/NSNI, responsible for the programme of external and internal events and site evaluation.
3.	*Team Members:*	

1) Gunsell, Lars: Sweden/Swedish Nuclear Power Inspectorate SKI/BWR engineering specialist
2) Gürpinar, Aybars: Turkey/private consultant (former Head of IAEA/ESS and Acting Director of NSNI)
3) Johnson, James J.: USA/James J. Johnson & Associates/expert on earthquake engineering in nuclear installations
4) Kostov, Marin: Bulgaria/Risk Engineering/expert on earthquake engineering for nuclear installations

The mission was conducted through meetings and walkdowns of the NPP units at the Kashiwazaki-Kariwa site, with the final closing meetings in Tokyo.

The three areas that were addressed by the IAEA team are indicated in Section 1.3 above. The members of the team for each of the areas were as follows:

Area 1 – Seismic design basis: Mr. A. Gürpinar and Mr. A. Godoy

Area 2 – Plant behaviour–Structures, Systems and Components: Mr. A. Godoy, Mr. L. Gunsell, Mr. P. Jamet, Mr J. J. Johnson and Mr. M. Kostov.

Area 3 – Operational Safety Management: Mr. Lars Gunsell and Mr. P. Jamet

Owing to the short time available for conducting the mission, the walkdowns of the seven units by the IAEA team had to be performed on a very tight schedule. TEPCO organized the programme activities in a very efficient and effective manner, facilitating all logistical aspects and providing all necessary facilities and means.

The IAEA team split in groups for performing the plant walkdowns as indicated in the table below.

The mission report is composed of two volumes, Volume I and Volume II which contain all supporting documentation and information collected during the mission and provided by the counterpart to the IAEA team.

The detailed mission programme and the list of participants are included in Appendices I and II of this mission report (Volume I).

Table: General programme of the in-plant walkdowns

Units	Members
Outdoor facilities: Monday afternoon	• All IAEA team members
- Unit 4: Tuesday morning - Unit 7: Tuesday afternoon	• Antonio Godoy • James J. Johnson • Lars Gunsell
- Unit 6: Tuesday morning - Unit 3: Tuesday afternoon	• Philippe Jamet • Marin Kostov
- Unit 1: Wednesday morning - Unit 2: Wednesday afternoon - Outdoor facilities – intake structures	• Antonio Godoy • James J. Johnson
- Unit 5: Wednesday morning - Outdoor and Radwaste facilities	• Marin Kostov

3. MAIN FINDINGS AND LESSONS LEARNED

3.1. GENERAL

Although it appears that the Niigataken Chuetsu-Oki earthquake on 16 July 2007 significantly exceeded the design basis ground motion as indicated by the response spectra comparison at the level of the foundation base mat in all units, the operating plants were automatically shutdown and all plants behaved in a safe manner, during and after the earthquake.

The three fundamental safety functions of (a) reactivity control, (b) removal of heat from the core and (c) confinement of radioactive materials were ensured with the exception of very minor radioactive releases which occurred shortly after the earthquake. The radioactive releases to the environment were estimated to result in an individual dose well below the authorized limits established by the regulatory authority for exposure of the public for normal operating conditions.

Based on the reports from TEPCO experts and the limited in-plant walkdowns and visual observations performed by IAEA experts, safety related structures, systems and components of the plant seem to be in a general condition much better than expected for such a strong earthquake, with no visible damage. This is probably due to the conservatisms introduced at different stages of the design process. The combined effects of these conservatisms were apparently sufficient to compensate for uncertainties in the data available and the methods applied at the time of the design of the plant, which led to the underestimation of the original design basis ground motions.

However, observations and conclusions relating to the behaviour of structures, systems and components require validation from the results of the ongoing investigations. Further and thorough inspections and evaluations of all critical structures, systems and components of the seven units have not been completed and important components like the reactor vessels, the core internals and the fuel elements have not yet been examined. TEPCO is accomplishing what is to be the first stage of a more comprehensive inspection plan, namely visual observations. Presently, detailed checks of the integrity and operability of all safety systems and components of the frontline and supporting safety related systems are ongoing even though no apparent damage has been sustained. All these activities should be thoroughly and fully documented.

Due to proper functioning of the automatic seismic scram system, the Kashiwazaki-Kariwa nuclear power plant units that were in operation (i.e. Units 3, 4 and 7), as well as Unit 2 which was in start-up state, shut down safely when the earthquake occurred. In accordance with Japanese safety regulations, in order to restart plant operation TEPCO needs the permission of the regulatory authority.

Furthermore, in accordance with the new seismic guidelines of the Nuclear Safety Commission (NSC) (issued in September 2006) a re-evaluation of the seismic safety needs to be done taking into account the effects of the Niigataken Chuetsu-Oki earthquake. Any re-evaluation of the seismic safety of the plant, including possible upgrades, requires the input from a new seismic hazard evaluation, seismic analysis and comparison of results with the original seismic design, including also the need to address the issue of the potential existence of active faults underneath the site.

Another consideration is the possibility that a component remains functionally available under normal operating conditions but sustains hidden damage. This could affect the capability of the component to function as required during potential accidents and its safe long term operation.

Therefore, the potential interaction between large seismic events and full functionality also under accident conditions should be analysed and inspected prior to restart of the plant, and accelerated ageing may be an important topic to consider in future inspection programmes.

3.2. SPECIFIC

Exceedance of the Design Basis Ground Motion by the Observed Earthquake

Comparisons of the seismic response spectra used for the design of structures, systems and components with the response spectra that were obtained from the time histories recorded by the installed site accelerometers during the 16 July 2007 Niigataken Chuetsu-Oki earthquake show that at the base mat elevation (which is considered as input for the seismic analysis) there is significant exceedance of the design basis levels by the observed values for a very wide range of spectral frequencies.

In spite of the exceedance of the seismic input, from the presentations made by TEPCO experts as well as from reports by the regulatory authority (NISA), and as was confirmed by the plant walkdowns performed by the IAEA team, it is indicated that the safety related structures, systems and components of all seven units of the plant (in operating, start-up and shut down conditions) demonstrated good apparent performance in ensuring the basic safety functions concerning control of reactivity, cooling and confinement.

Therefore, it is important to understand all the elements involved in the derivation of the seismic design basis and identify the sources of conservatism as well as sources that contributed to the exceedance of the seismic design basis by the observations from the earthquake. The chain that makes up the process of the derivation of the seismic design basis and the actual design of the plant structures, systems and components has a multitude of links that have varying degrees of uncertainty and that are evaluated by earth scientists, hazard analysts, geotechnical, civil, mechanical, electrical and systems engineers. As the design basis response spectra and thus the seismic design are composite products, a systematic approach is needed for this process to identify the sources of uncertainties and conservatisms.

Re-evaluation of the Seismic Hazard

In September 2006, i.e. before the 16 July 2007 earthquake occurred, NSC issued guidelines for the conduct of the reviews of the seismic design of all nuclear power plants in Japan with significant recommendations relating to the identification and characterization of capable and active faults as well as the deterministic and reference probabilistic evaluations of the seismic hazard at nuclear power plant sites. The September 2006 guidelines issued by NSC are very much in line with the recommendations of the IAEA Safety Guide NS-G-3.3 on Evaluation of Seismic Hazards for Nuclear Power Plants issued in 2002.

With the occurrence of the 16 July 2007 earthquake, the investigations carried out by TEPCO at the Kashiwazaki-Kariwa nuclear power plant site are extended. According to the programme developed by TEPCO in response to the need to perform seismic hazard re-evaluation at the site, detailed geophysical investigations are foreseen both on land and offshore with the aim of identifying and characterizing capable and active faults in the site vicinity, the near region and the region. These investigations are also to address the issue of the potential existence of active faults underneath the site and, consequently, the possibility of surface faulting. The attenuation relationships to be used for faults in the near region should include both empirical methods based on observed seismic data as well as analytical methods producing synthetic seismograms compatible with the fault mechanism and the travel path. It is expected to be able to address directivity issues using this methodology.

It is also recommended by the Guidelines to conduct both deterministic and probabilistic seismic hazard assessments (PSHAs). The results of the PSHAs would be used for seismic probabilistic safety assessment (PSA) studies that are now foreseen for nuclear power plants operating in Japan. The new NSC guidelines also address the issues related to uncertainties and recommend that these are treated appropriately.

Off-Site Power

Observations from past earthquakes have demonstrated that a loss of off-site power (LOSP) occurs due to earthquakes with peak ground accelerations (PGAs) greater than about 0.25g. However, Kashiwazaki-Kariwa nuclear power plant did not lose off-site power during and after the 16 July 2007 event. A lesson of this earthquake is that the assumption of loss of off-site power for earthquake events with peak ground accelerations greater than about 0.25g may be conservative in countries like Japan where the seismic design of electrical facilities is relatively advanced. Therefore, detailed evaluations of the off-site power generation, transmission lines and switchyard may provide justification for raising the threshold of LOSP to earthquakes greater than 0.25g PGA in other nuclear power plants.

Common-Cause Failures

The Niigataken Chuetsu-Oki earthquake of 16 July 2007 provided practical examples of the common cause nature of an earthquake excitation and fully correlated failures, e.g. identical failure modes of the fluorescent light fixtures of control rooms in Units 6 and 7, damage to the ducts connected to each of the stacks for Units 1 – 5 and damage of ducts due to settlement and soil failure inducing damage in structures and components interconnected but founded on separate foundations. The common cause nature of the earthquake should be taken into account for all seismic evaluations of nuclear power plants.

Fire Safety

Seismically induced fires are frequent events after an earthquake in urbanized areas but are relatively rare at a nuclear power plant. Although not directly related to nuclear safety, the Unit 3 in-house electrical transformer fire, reported as one of the consequences of the earthquake of 16 July 2007, demonstrated problems in the fire fighting capability of the plant. The analyses made by TEPCO and the regulatory authority show that there is a clear understanding of the root technical cause of the fire problems and the ways for improvement.

Common cause failure should be avoided in any case. Failure of the fire fighting system (tanks, pumps, piping, distribution system) and its consequences can be minimized by providing adequate seismic capacity, redundancy and diversity of the system.

Seismic Systems Interaction

Seismic systems interaction refers to the induced effects of falling, proximity impact, and spray and flooding hazards on seismic category I (SC-I) structures, systems, and components (SSCs); most often due to the effects of non-seismic category items on SC-I items. The walkdowns of the Kashiwazaki-Kariwa nuclear power plant demonstrated that:

- Generally, the extensive use of strong anchorage of non-safety category items prevented falling hazards from occurring during the earthquake.

- Extensive good housekeeping and maintenance practices were observed.

In spite of these positive features, the Niigataken Chuetsu-Oki earthquake of 16 July 2007 demonstrated the phenomena of seismic systems interaction with regard to falling (platforms in spent fuel pools, light fixtures in the control rooms of Units 6 and 7, HVAC diffusers in control room of Unit 3, and cabinets in control room of Unit 2) and flooding (sloshing of the spent fuel pool, fire suppression piping failure outside the Unit 1 reactor building and flowing in through cable penetrations, and condenser flexible connection failure). Flooding failures led to water flow to various portions of the structures that could have caused SSC functional failures.

For all nuclear power plants:

- Diligence is required in the design, construction, and operational phases of all plants to ensure that seismic systems interaction issues are minimized, as observed in the case of Kashiwazaki-Kariwa nuclear power plant;
- Plant walkdowns performed to evaluate conditions for potential seismic vulnerabilities should extensively consider the potential consequences of failures due to non-seismically designed conditions.

Soil Failures

Many of the problems on the Kashiwazaki-Kariwa nuclear power plant site were induced by large soil deformations. In case of strong earthquakes, soil failures often cannot be avoided. Nevertheless, measures to limit their effects should be taken. Such measures include the use of proper soil materials for backfill and proper soil compacting, protection of the penetrations of distribution systems (piping, cable trays, ducts) by expansion joints that can allow large displacements and/or concrete channels to protect the underground piping, drainage of the site in order to reduce the underground water level as well as proper handling of precipitation water. Use of a combination of most of these measures may help to reduce damaging effects of large ground deformation.

Anchorage Failures

There were a limited number of anchorage failures mainly on transformers and water tanks that are not safety related equipment. The failure of anchorages of the heat exchangers at the turbine building of Unit 4 is another example. The long term behaviour of anchorages should be assured by a proper ageing management programme that considers the safety importance of equipment as well possible interaction effects. Because of the lack of experience for anchorage behaviour after a strong earthquake that exceeds the design values, the anchorages should be subjected to a detailed evaluation and a properly documented long term monitoring and inspection plan.

Operational Safety Management

The management of the event in all units was successfully carried out with respect to the operation of the reactor safety systems. The availability of both operating and safety systems and the existence of applicable operating procedures ensured the safety of the units and demonstrated the strength of maintaining several levels in the defence in depth.

Verification of readiness for operation of the safety systems that were not activated was carried out through visual inspection. It should be carefully analysed if this procedure is sufficient or if it should be the accepted practice to test with full activation of the safety systems without substantial delay after the occurrence of an earthquake.

There was a time delay in reporting the leakage of radioactive material to the authorities. The information from the plant should have been issued more promptly. It is of key importance to preserve the integrity of the communication and monitoring systems in order to report the information on releases of radioactive material to the authorities as soon as possible to provide guidance for off-site emergency organizations, even if no significant releases have occurred or are expected to occur as result of the event.

Releases

Two minor releases of radioactive material occurred after the Niigataken Chuetsu-Oki earthquake of 16 July 2007.

The first one was a release of radioactive material through the main stack of Unit 7. The release came from the main turbine condenser and the root cause was the delay by the operator in manually stopping the turbine gland steam ventilator, thus breaking the condenser vacuum and allowing the radioactive material normally present in the condenser to leak through the seals.

The second release of radioactive material was due to a leak of a cable penetration which allowed contaminated water that had spilled over from the spent fuel pool to drip down to a discharge water pit into a non controlled area from where it was pumped into the sea.

In both cases, the path and causes of the releases were well understood by TEPCO and it was shown that the radioactivity released was extremely small and was estimated to result in an individual dose well below the authorized limits set by the regulatory authority for normal operating conditions.

Significant displacements were observed on the ducts connected to the main exhaust stacks of Units 1, 2, 3, 4 and 5. These displacements could have resulted in limited leakages and releases of contaminated air at the ground level instead of such contaminated air being exhausted and monitored at the top of the stack. TEPCO is still investigating this issue.

4. ACKNOWLEDGEMENTS

Throughout the mission, the IAEA team received good cooperation from all the Japanese counterpart. All questions asked by the expert team were addressed with precision and, when needed, accompanied by adequate documentation. The programme of the plant walkdowns was discussed in detail with the counterpart who showed flexibility and constantly did their best to respond to all the requests from the experts. During the plant walkdowns, supplementary demands of the team were systematically satisfied so that experts could go anywhere they wanted and ask all the questions considered necessary which, if so needed, were later answered, corrected or expanded, during the daily wrap-up meetings. It could be said that the only limitation was the short time available (two and a half days) for conducting the plant walkdowns of seven units.

5. FINDINGS SHEETS

In following pages the findings sheets for each of the three areas covered by the mission are attached.

FINDINGS SHEET

1. FINDING IDENTIFICATION	Finding Number: A.1-01
NPP:	**KASHIWAZAKI-KARIWA NPP**
Unit:	**UNITS 1 TO 7**
Assessment Area:	**A.1 – SEISMIC DESIGN BASIS, INSTRUMENTAL RECORDS AND RE-EVALUATION OF SEISMIC HAZARD**
Finding Title:	**A1-01 – EXCEEDANCE OF THE DESIGN BASIS GROUND MOTION BY THE EARTHQUAKE**

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

- Recent studies for the evaluation of seismic hazard for new and operating nuclear facilities have consistently shown significantly higher values compared to those evaluated in previous decades. Also in the past two years, two nuclear power plants in Japan experienced earthquakes that exceeded the design basis response spectra without any damage to safety related structures, systems and components.

- As a result of this, the IAEA started an extra-budgetary programme on the seismic evaluation of existing nuclear power plants (hazard and design evaluation) supported by, among other Member States, Japan where TEPCO is a major contributor. Therefore, although the 16 July 2007 Niigataken Chuetsu-Oki was a major earthquake that exceeded very significantly the design basis response spectra of the plant at the base mat level, its occurrence was not totally unexpected by the plant because of the awareness brought by earlier events and the related ongoing international interaction.

2.2. – FINDINGS AT KASHIWAZAKI-KARIWA NPP:

- There are a multitude of reasons for the exceedance of design basis ground motions and for these reasons the Niigataken Chuetsu-Oki earthquake needs to be studied in detail for a thorough understanding of the event in question and to share feedback on the experience with the international nuclear safety community. From the discussions and documents presented to the IAEA team, some of the reasons seem related to the identification and characterization of the seismogenic sources (e.g. among others, the estimate of potential maximum magnitudes) of the seismotectonic model in the near region of the site, while other reasons concern the validation of the attenuation relations for areas close to the epicentres.

- TEPCO experts have made and presented comparisons of the seismic response spectra used for the design of structures, systems and components with the response spectra that were obtained by site accelerographs during the 16 July 2007 Niigataken Chuetsu-Oki earthquake. As the records from the free field accelerographs were overwritten by aftershock records it was not possible to have a comparison of these. Instead comparisons were calculated for records that were obtained at the base mat levels for all seven units. These are provided in Volume II of this report. These comparisons show that there was significant exceedance of the design basis levels by the observed values for a very wide range of spectral frequencies. From the presentations made by TEPCO experts as well as reports by the regulatory authority NISA, and as was confirmed by plant walkdowns performed by IAEA experts, it is indicated that the safety related structures, systems and components of all seven units of the plant (in operating, start-up and shut down conditions) demonstrated exceptionally good apparent performance in ensuring the basic safety functions concerning control of reactivity, cooling and confinement.

- Therefore, it is important to understand all the elements involved in the derivation of the seismic design basis and to identify the sources of conservatism as well as sources that contributed to the exceedance of the design basis ground motions.

- The chain that makes up the process of the derivation of the seismic design basis and the actual design of the plant structures, systems and components has a multitude of links that have varying degrees of uncertainty and that are evaluated by earth scientists, hazard analysts, geotechnical, civil, mechanical, electrical and systems engineers. As the design basis response spectra and thus the seismic design is a composite product, an analytical approach is needed for this process.

3 – LESSONS LEARNED:		10/08/2007

1. Fault mechanism and directivity:

When there are significant contributions to the seismic hazard by active faults in the site vicinity or the near region (see the IAEA Safety Guide NS-G-3.3 for definitions of the terms site vicinity and near region), source parameters such as the fault mechanism and directivity effects may play an important role. This may cause variations in the hazard even within areas very close to each other. Ways of including these effects in seismic hazard studies need to be considered when such active faults are present in close proximity to NPP sites.

2. Local Geological Conditions:

The Kashiwazaki-Kariwa nuclear power plant has seven operating units, with four units located in one part of the site and the other three units about one and a half kilometers away. However, both the intensity of damage (to non safety items) and the levels of free field acceleration are quite different at the two locations – higher in the part of the site where the four units (1 to 4) are located. Part of the explanation may be due to the differences in the age and the depth of the underlying geological formations. At the site of Units 5 – 7 the Pliocene formations has a thickness of about 120 m above the Upper Miocene to Lower Pliocene formations, while at the site of Units 1 – 4 the Pliocene formations have a thickness of over 300 m, with an anticline separating the two sites.

Such differences need to be taken into account in seismic hazard evaluations.

3. Attenuation relationships:

Attenuation relationships generally play an important role in seismic hazard assessments. They have always received much attention and the data on which they are based have steadily and exponentially increased. Until about ten years ago the number of accelerograms recorded in the near vicinity of an epicentre was relatively small. For this reason this part of the attenuation relationship had large uncertainties and some extrapolation from other parts of the curve was needed. With the deployment of dense networks in some parts of the world, e.g. K-NET in Japan, there has been a dramatic increase in the records of near field earthquakes and in general these records have shown larger than expected peak and spectral accelerations compared to earlier derived attenuation relationships. When seismic sources are present in the near region or the site vicinity of a nuclear facility, it is necessary to take into consideration the recent records that have been obtained in the near field.

4. Energy contents of the ground motion

In general, response spectra may not be representative of the energy content of the ground motion. It may be possible to have the same response spectrum for ground motions with significantly different energy content. For this reason additional representations of the earthquake ground motion are needed to account for these differences. Generally, power spectral density functions and cumulative absolute velocities (CAV) may be used to check and compare the energy content which may have played a role, as a metric of the potential of the earthquake to cause damage.

5. Soil structure interaction

The deeply embedded structures of the Kashiwazaki-Kariwa nuclear power plant showed interaction with the soil. Especially for the aftershock record (16 July 2007, 15:37) the reduction in the peak ground acceleration is remarkable (from 298 Gals[1] free field to 60 Gals at the base mat level). This difference is much less for the main shock, possibly owing to saturation of the free field acceleration because of soil non-linearities. It should be noted that this soil structure interaction took place for the local geological conditions at Kashiwazaki-Kariwa nuclear power plant which varies from hard soil to soft rock.

6. Conservatism of the design

Although the design basis response spectra and the observed response spectra at the base mat level show significant differences (i.e. exceedance of the observed values) the fact that design basis response spectra are not necessarily representative of the final seismic design is once again confirmed. Volume II of this report contains a comparison of the maximum response acceleration values observed at each floor where records are available with the values estimated at the design stage for the S2 earthquake level. It can be observed here that there is very little difference between the design response acceleration and the observed acceleration values. It is also noted that in Japan the design of nuclear power plants is often governed by requirements that are related to multiples of static

[1] 1 Gal = 0.01 m/s^2.

design coefficients of the building code. It is important to understand and document the conservatism at different steps of the design process.

7. Accounting for uncertainties

Regardless of the method used (deterministic or probabilistic) each step of seismic hazard evaluation contains both uncertainties that are random (i.e. aleatory) and uncertainties that are related to the modelling (i.e. epistemic). Identification and quantification of these uncertainties is very important and is usually not straightforward. The data used needs to be qualified in terms of its reliability and the method needs to allow for alternative models that are in agreement with the data. Japan has a wealth of seismic data that may be used to decrease uncertainties associated with seismic hazard evaluation.

8. Importance of seismic instrumentation

Although part of the free field records of the 16 July 2007 earthquake were lost due to overwriting by aftershocks in the process of transmitting these to TEPCO headquarters in Tokyo, there is still considerable data that will facilitate the understanding of this earthquake at the Kashiwazaki-Kariwa nuclear power plant. Free field, downhole, base mat and in-structure records have been obtained and these are used for comparing with the response spectra and time histories used as basis for the design.

For the future, redundancies should be considered in the processing of data so that plant personnel have immediate access to this information and that loss in transmission is avoided. Experience from modern instrumentation installed in nuclear power plants in the world that provides immediate indication to the operator of the severity of earthquake using updated criteria needs to be considered.

FINDINGS SHEET

1. FINDING IDENTIFICATION	Finding Number: A1-02
NPP:	KASHIWAZAKI-KARIWA NPP
Unit:	UNITS 1 - 7
Assessment Area:	A.1 – SEISMIC DESIGN BASIS, INSTRUMENTAL RECORDS AND RE-EVALUATION OF SEISMIC HAZARD
Finding Title:	A1-02 – RE-EVALUATION OF THE SEISMIC HAZARD.

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

- Any action relating to the seismic re-evaluation or upgrading of the structures, systems and components of the Kashiwazaki-Kariwa nuclear power plant needs to be preceded by a seismic hazard re-evaluation to re-define the ground motion parameters. In September 2006, i.e. before the earthquake of 16 July 2007 earthquake occurred, NSC issued guidelines for the conduct of reviews of the seismic design of nuclear power plants in Japan with significant recommendations relating to the identification and characterization of capable and active faults. Deterministic evaluation of seismic hazards at the sites of the existing nuclear power plants will be followed by a reference probabilistic analysis (PSHA). With the occurrence of the 16 July 2007 earthquake, the investigations carried out by TEPCO at the Kashiwazaki-Kariwa nuclear power plant site have taken a new direction.

2.2. – FINDINGS AT KASHIWAZAKI-KARIWA NPP:

- The September 2006 guidelines issued by NSC are very much in line with the recommendations of the IAEA Safety Guide NS-G-3.3 Evaluation of Seismic Hazards for NPPs issued in 2002. According to the programme developed by TEPCO in response to the seismic hazard re-evaluation requirement at the Kashiwazaki-Kariwa nuclear power plant site, detailed geophysical investigations are foreseen both on land and offshore with the aim of identifying and characterizing capable and active faults in the site vicinity, the near region and the region.
- The attenuation relationships to be used for faults in the near region include both empirical methods based on observed seismic data as well as analytical methods producing synthetic seismograms compatible with the fault mechanism and the travel path. It is expected to be able to address directivity issues using this methodology. It is also recommended to conduct a deterministic seismic hazard evaluation followed by a reference PSHA.
- The results of the PSHA would be used for seismic PSA studies that are now foreseen for NPPs operating in Japan. The new guidelines also address the issues relating to uncertainties and recommend that these are treated appropriately.

3 – LESSONS LEARNED:		10/08/2007

1. **Need for strengthening of the database to decrease uncertainties:**

   A significant amount of investigations both on land and offshore are foreseen in the upcoming programme for the re-evaluation of the seismic hazard at the Kashiwazaki-Kariwa nuclear power plant site. It is expected that these investigations will provide information relating to the identification and the characterization of the faults in the region. This would significantly enhance the geological database and help in reducing uncertainties regarding their existence, location and characterization.

2. **Use of deterministic and probabilistic methods**

   Both deterministic and reference probabilistic methods will be used in the re-evaluation of seismic hazard. Probabilistic seismic hazard analysis will be needed for the seismic PSA study. It is important to conduct both studies for this site in order to understand the different ways of quantifying uncertainties. There is worldwide interest in conducting seismic PSA and PSHA studies are needed for this purpose for a variety of seismotectonic settings. A site such as Kashiwazaki-Kariwa nuclear power plant will attract attention owing to the close proximity of active faults to the site (16 km) and the way these are treated in a seismic hazard evaluation.

3. **Faults in the near region**

   The faults in the near region of Kashiwazaki-Kariwa nuclear power plant site will also be of interest for the modelling of the attenuation relationship and how new methods such as empirical Green's functions can be applied within the context of a nuclear power plant seismic hazard evaluation. Source related parameters such as fault mechanism and directivity were observed to play an important role in the recent earthquake. It is expected that new methods may provide more information relating to these issues.

4. **Local geological conditions**

   The variations of the geological conditions at the Kashiwazaki-Kariwa nuclear power plant site both in terms of age and depth seem to have played a role in the damage patterns to non-safety related items. Modelling of these characteristics in the seismic hazard analysis (with the knowledge of the actual damage distribution) will be a very interesting study to follow for the international nuclear safety community.

FINDINGS SHEET

1. FINDING IDENTIFICATION	Finding Number:	A2-01
NPP:	**KASHIWAZAKI-KARIWA NPP**	
Unit:	**UNITS 1 TO 7**	
Assessment Area:	**A.2 – PLANT BEHAVIOUR – STRUCTURES, SYSTEMS AND COMPONENTS**	
Finding Title:	**A2-01 – OFF-SITE POWER**	

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

- It is common practice to assume that off-site power is lost when evaluating nuclear power plants for earthquakes with peak ground acceleration (PGA) values greater than about 0.25g, owing to the common cause nature of the earthquake. Even though conventional power generation plants may be operational and transmission lines may be intact, the transformer substations are vulnerable to failure during earthquakes, making power unavailable to the nuclear power unit being evaluated. This assumption has been confirmed in many observations over the past decades. In some cases, especially when applying methods to address earthquakes beyond the design basis, it has been permitted to take credit for off-site power if it can be shown with high confidence that power generation, transmission lines and substation functions are demonstrated to be operable.

2.2 FINDINGS AT KASHIWAZAKI-KARIWA

- At Kashiwazaki-Kariwa nuclear power plant, off-site power was maintained during and after the 16 July 2007 earthquake even though recorded ground motion on the surface of soil at the site had peak ground acceleration values approaching 1g, affecting the switchyard.

3. LESSONS LEARNED

1. A lesson of this earthquake is that the assumption of loss of off-site power (LOSP) for earthquake events with peak ground accelerations greater than about 0.25g may be conservative in countries like Japan where the seismic design of electrical facilities is relatively advanced. Detailed evaluations of the off-site power generation, transmission lines and switchyard may provide justification for raising the threshold of LOSP to earthquakes greater than 0.25g PGA.

FINDINGS SHEET

1. FINDING IDENTIFICATION		Finding Number: A.2-02
NPP:	KASHIWAZAKI-KARIWA NPP	
Unit:	UNITS 1 TO 7	
Assessment Area:	A.2 – PLANT BEHAVIOUR – STRUCTURES, SYSTEMS AND COMPONENTS	
Finding Title:	A2-02 – SEISMIC SYSTEMS INTERACTION	

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

The major seismic systems interaction issues are described as follows:

- Falling interaction is a structural integrity failure of a non-safety or safety related item that can impact and damage an item classified as seismic category I (SC-I) (or in the nomenclature of Kashiwazaki-Kariwa, as seismic class A or As). In order for the interaction to be a threat to a SC-I item, the impact must contain considerable energy and the target must be vulnerable.
- A light fixture falling on a 10 cm diameter pipe may not be a credible damaging interaction to the pipe. However, the same light fixture falling on an open relay panel is an interaction, which can cause failure of the device to perform its required function. A light fixture or a series of connected light fixtures can be hazardous to personnel and structures, systems and components (SSCs). Examples of other types of falling hazards include structural or non-structural elements failing and falling on SC-I SSCs.
- Proximity interactions are defined as conditions where two or more items are close enough together that any unsafe behaviour of one of them may have consequences on the other one. The most common example of proximity interaction is the impact of an electrical cabinet containing sensitive relays by items adjacent to it that were not secured against seismic loads.
- Spray and flood can result from failure of piping, systems or vessels that are not properly supported or anchored. Inadvertent spray hazards to SC-I SSCs arise most often from the failure of non-seismic category I items containing a liquid such as water. Fire protection systems using water may also cause spray of flooding issues. Inadvertent actuation of fire protection piping systems is one such cause. If spray sources can spray equipment sensitive to water spray, then the source should be modified. For fire protection piping, this usually is accomplished by adding support to reduce deflections and impacts or stresses. Large tanks may be potential flood sources. If a flood source can fail, an assessment should be made of the potential consequences taking into account the flow paths and dispersion of the liquid through penetrations, drains, etc. Flow paths may be difficult to assess and can most

appropriately be performed in the plant rather than only relying on drawings.

- Seismic systems interaction is one of the most repeatable phenomena resulting from earthquake events.

2.2 FINDINGS AT KASHIWAZAKI-KARIWA

The walkdowns of the Kashiwazaki-Kariwa nuclear power plant demonstrated that:

1. Anchorages:

Generally, the extensive use of strong anchorages for non-safety and non-seismic category items prevented falling hazards from occurring during the earthquake.

2. Housekeeping:

A general observation is that the Kashiwazaki-Kariwa units have very good housekeeping procedures, i.e. items used for maintenance or other similar activities are tied down and in designated areas even for those units under maintenance or outage conditions.

3. Falling hazards:

Examples of falling hazards during the earthquake were:

- Failure of the connection of the work platform as observed in the spent fuel pools for Units 4 and 7. Although no damage is believed to have occurred, potential consequences of this failure would be damage to the spent fuel or the support structure within the fuel pool.
- Failure of the attachments of the interconnecting multiple fluorescent light fixtures to the ceiling of the control room as observed in Units 6 and 7. No significant consequences were observed, but adverse effects to the control room electrical equipment or to the operators could have occurred. As an example, it was reported in the course of the plant walkdown that in Unit 6 a control room operator suffered a minor shoulder injury due to a falling light fixture.
- Failure of the attachments of the ventilation air conduit diffusers to the ceiling of the Unit 3 control room – partially dropped. There were no adverse consequences, but adverse effects to electrical equipment or to the operators could have occurred.
- Tipping/falling of a cabinet in Unit 2 control room impacting a non-safety related cabinet. The tipped cabinet was attached to the raised control room floor – the cabinet and a small portion of the raised floor tipped.

4. Spray or flooding hazards:

Examples of flooding hazards during the 16 July earthquake were:

- Sloshing of the spent fuel pool water onto the reactor building operating floor of Unit 6 and leakage through cable penetrations in the floor leaking water to lower elevations.
- Failure of the rubber flexible connection of the condenser B seawater box and connecting valve in Unit 4 leaking sea water onto the turbine building floor at lower elevations. The flexible connection that failed had originally been installed 13 years ago –plant personnel stated that the normal replacement schedule was 10 to 15 years – and so ageing of the flexible connection was a factor in its failure.

- Localized soil failure caused failure of fire suppression piping at a cable penetration to the Unit 1 reactor building. Water (about 2000 m^3) and soil entered the reactor building at grade elevation and flowed through floor penetrations and stairwells to lower levels, finally reaching the B5 level at about 38 m below the plant grade level. A 40 cm deep puddle of water formed at the B5 level. It seems that this water and soil did not produce adverse consequences to SSCs. The total evaluation by TEPCO is not completed yet.

3. – LESSONS LEARNED:		10/08/2007

For all nuclear power plants:

1. Diligence is required in the design, construction and operational phases of all plants to assure that seismic systems interaction issues are minimized, as observed in the case of Kashiwazaki-Kariwa nuclear power plant.

2. Plant walkdowns performed to evaluate conditions for potential seismic vulnerabilities should extensively consider the potential consequences of failures due to non-seismically designed conditions.

FINDINGS SHEET

1. FINDING IDENTIFICATION		Finding Number:	A2–03
NPP:	KASHIWAZAKI-KARIWA NPP		
Unit:	UNITS 1 TO 7		
Assessment Area:	A.2 – PLANT BEHAVIOUR – STRUCTURES, SYSTEMS AND COMPONENTS		
Finding Title:	A2-03 – FIRE PROTECTION		

2. FINDINGS

2.1 - FINDING DESCRIPTION-BACKGROUND

Background:

- One of the first announcements to the public after the earthquake of 16 July 2007 that affected the Kashiwazaki-Kariwa nuclear power plant concerned the fire in the in-house electrical transformer of Unit 3. The fire was initiated by sparks from a short circuit caused by large ground displacements (settlements) of the transformer foundation (see Appendix V of Volume II of this mission report). The spark caused the ignition of oil leaked from the transformer. The fire was extinguished by the local municipality fire brigade approximately 2 hours after it began.
- Although the transformer was separated by a firewall, active actions for extinguishing the fire were not possible because the outdoor fire protection system of Units 1-4 was damaged.

Safety Significance:

- The particular fact of the fire in the in-house transformer has no safety significance for the plant. The in-house transformer is not an item of safety related equipment and does not affect the nuclear safety of the unit. Nevertheless, the fact is significant from the broad point of view of safety due to seismically induced events.
- Frequently fire protection systems are not seismically qualified and may suffer seismic damage. However, the IAEA Safety Guide NS-G-1.6 recommends that seismically induced events, such as fires, be carefully considered in the plant safety analyses and adequate counter measures be taken.
- The damage of the outside water fire protection system of Units 1 to 4 is a cause of serious concern.

2.2. FINDINGS AT KASHIWAZAKI-KARIWA NPP	Date:	10/08/2007

- The multiple failure of the fire protection system was caused mainly due to large ground deformations produced by the earthquake. The fire protection piping was not seismically qualified because this is not required by current codes. It was indicated by TEPCO that the code requires only the installation of fire protection walls and that has been provided.

  An upgrade of the fire extinguishing system is planned with increased capacity. The source of water is the filtrated water tank that is shared by Units 1 to 4. The indoor and outdoor fire systems have a total capacity of $350m^3/h$ and they are driven by motor and diesel pumps, respectively. Although the present capacity might be sufficient, the effects of the earthquake showed that the outdoor system has been affected by a common cause failure.

- The underground piping is very vulnerable to large soil deformations such as those that occurred at the Kashiwazaki-Kariwa nuclear power plant and this should have been considered as a weak link in the analyses of the fire extinguishing system. Associated counter measures should have been properly taken.

3 – LESSONS LEARNED:

1. Seismically induced fires are frequent events after an earthquake in urbanized areas but are relatively rare at a nuclear power plant. Although not directly related to nuclear safety, the fire in the in-house electrical transformer started as result of the 16 July 2007 earthquake demonstrated problems in the fire fighting capability of the plant. The analyses made by the plant personnel and the regulatory authority show that there is a clear understanding of the root cause of the fire, of the deficiencies in the fire management system and of the ways for improving them.

2. In any case, common cause failure should be avoided. Failure of the fire fighting system (tanks, pumps, piping, distribution system) and its consequences can be minimized by providing adequate seismic capacity, redundancy and diversification of the systems.

3. Large soil settlements often cause piping failure, as was the case at the Kashiwazaki-Kariwa nuclear power plant when subjected to the 16 July 2007 earthquake. Flexible joints, flexible penetrations, protective buried channels and other means could be used in order to minimise probability of failure.

FINDINGS SHEET

1. FINDING IDENTIFICATION		Finding Number:	A2-04
NPP:	**KASHIWAZAKI-KARIWA NPP**		
Unit:	**UNITS 1 TO 7**		
Assessment Area:	**A.2 – PLANT BEHAVIOUR – STRUCTURES, SYSTEMS AND COMPONENTS**		
Finding Title:	**A2-04 – SOIL DEFORMATION**		

2. FINDINGS

2.1 - FINDING DESCRIPTION - BACKGROUND

Background:

- TEPCO personnel reported several instances of damage caused by large soil deformation: the station road was cut off, liquefaction of soil occurred in a large area of the site, fire in the in-house transformer of unit 3 occurred due to large settlements, the fire extinguishing system was cut at five locations due to settlements, the bank protection of the north-south discharge outlet sank, the north slope of the soil disposal area collapsed, etc.

Safety Significance:

- None of the seismically induced ground failures on the Kashiwazaki-Kariwa nuclear power plant site are having any safety significance. The behaviour of the safety related structures was not affected by the settlements and the liquefaction.

- The IAEA Safety Guide NS-G-1.6 recommends attention and prevention of the seismically induced ground deformations as excessive settlements, liquefaction, etc. Although the safety related structures of Kashiwazaki-Kariwa nuclear power plant are either founded directly on base rock or on piles that reach the base rock, the large ground deformation of the near surface deposits should be taken into account.

2.2. FINDINGS AT KASHIWAZAKI-KARIWA NPP	Date:	10/08/2007

- Although not of safety significance, the large ground deformations blocked the road to the plant at a critical moment when any delay in help and access was of importance.

- The ground failures caused a common failure of the outdoor fire extinguishing system that prevented quick and immediate response to the fire in the in-house transformer of Unit 3.

- The large ground settlements caused the oil leak of several transformers on the site, as well as the fire in the in-house electrical transformer of Unit 3.

- The large ground deformations around the safety related buildings most probably have caused damage in most of the piping penetrating the building walls.

3 – LESSONS LEARNED:

1. In case of large seismic shaking, as was the case during the earthquake of 16 July 2007 that affected the Kashiwazaki-Kariwa nuclear power plant, large ground deformations are frequently inevitable. Nevertheless measures to limit their effects could be taken.

2. Such measures include the use of proper soil materials for backfill and proper soil compacting, protection of the penetration by expansion joints that can allow large displacements and/or concrete channels to protect the underground piping, drainage of the site in order to reduce the underground water level as well as proper handling of precipitation water, etc. The use of a combination of most of these measures may help to reduce damaging effects of large ground deformation.

FINDINGS SHEET

1. FINDING IDENTIFICATION		Finding Number:	A2-05
NPP:	**KASHIWAZAKI-KARIWA NPP**		
Unit:	**UNITS 1 TO 7**		
Assessment Area:	**A.2 – PLANT BEHAVIOUR – STRUCTURES, SYSTEMS AND COMPONENTS**		
Finding Title:	**A2-05 – ANCHORAGE BEHAVIOUR**		

2. FINDINGS

2.1 - FINDING DESCRIPTION -BACKGROUND

- The seismic qualification of nuclear power plants requires analyses, testing and care for the anchorage. Anchorages frequently shows brittle seismic behaviour. In the case of the earthquake on 16 July 2007 that affected the Kashiwazaki-Kariwa nuclear power plant some anchorage failures were reported. All reported cases refer to equipment that is not safety related; in particular anchorage failures were found for transformers (Units 1, 2 and 3) and water tanks (Units 5, 6 and 7) as well as at a heat exchanger in the turbine building of Unit 4 (walkdown finding).

Safety Significance:

- The anchorage failures found have no safety significance for the Kashiwazaki-Kariwa nuclear power plant. As the plant had been subjected to moderate earthquake in 2004, the question arises of whether the anchorages were properly investigated after that earthquake and if the ageing management programme was updated.

2.2 - FINDINGS AT KASHIWAZAKI-KARIWA NPP	Date:	10/08/2007

- Some of the failed anchorages of the service water tanks (Units 5, 6 and 7) show signs of corrosion. That may have been caused by minor cracks from previous heavy loadings. As the earthquake on 16 July 2007 exceeded the design values, it could be expected that some of the anchorages might have suffered micro damage. A proper ageing management programme should be established to prevent sudden and abrupt changes in the anchorage behaviour.
- There are long embedded anchorages where some minor longitudinal cracks in the reinforced concrete have been observed (e.g. on the turbine condenser of Unit 5). After examination, those cracks need to be properly closed as they may affect the long term behaviour of the anchorages.

3. <u>LESSONS LEARNED</u>		**10/08/2007**
1. The long term behaviour of anchorages should be guaranteed by a proper ageing management programme reflecting the safety significance of the equipment as well as the possible interactions. Because of the lack of experience for anchorage behaviour after a strong earthquake that exceeds the design values, the anchorages should be subjected to detailed evaluation and long term monitoring.		

FINDINGS SHEET

1. FINDING IDENTIFICATION	Finding Number:	A3-01
NPP:	**KASHIWAZAKI-KARIWA NPP**	
Unit:	**UNITS 1 TO 7**	
Assessment Area:	**A.3 – OPERATIONAL SAFETY MANAGEMENT**	
Finding Title:	**A3-01 – OPERATIONAL SAFETY MANAGEMENT RESPONSE AFTER SHUTDOWN**	

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

- Operational safety management includes actions taken by the management of the power plant and the operating staff at a specific unit. Important elements in managing the response to an event are to ensure control of reactivity, removal of the decay heat from the core and confinement of radioactive material. Accident management also includes necessary communication to authorities and other organisations involved in emergency planning.

2.2 FINDINGS AT KASHIWAZAKI-KARIWA NPP:

- All units in operation (Units 3, 4 and 7) and in start up (Unit 2) scrammed automatically on experiencing high seismic acceleration, as intended. For the scrammed units, the main feed water and turbine condensers were initially available as heat sinks and water make-up. The main steam isolation valves were closed manually for Unit 2 after 50 minutes and for Unit 7 after 7 hours and 55 minutes, which made the condensers unavailable in each case. The normal feed water systems were operating for all units at least the first day for all units, except for Unit 5 where the normal feed water system was stopped after 6 hours.
- The safe conditions of the plant were verified in the control room. Readiness for operation for all safety systems in all plants was first verified through visual inspection. Full testing of the safety systems with emergency diesel began on July 25.
- Operating procedures exist and were applicable, and consist of emergency operating procedures, accident operating procedures and dedicated instructions for walkdown of plant safety systems after an earthquake.
- Assistance from other units, which is usually available at unplanned unit automatic shutdown, was not possible at this time, owing to the fact that all units were affected by the earthquake and the fire at Unit 3. Resources from the technical support centre and maintenance group were also limited.
- The reporting to the authorities of the leakage of radioactive material at Unit 6 was carried

out at 18:52, whilst the earthquake occurred at 10:13. The reason for taking such a long time has been explained by TEPCO. The delay was mainly caused by a lack of personnel after the earthquake due to evacuation and other priorities. Preserving of the integrity of the communication systems is also a key issue in this respect.

3. LESSONS LEARNED		10/08/2007

1. The accident management of the event in all units was successfully carried out with respect to the operation of the reactor safety systems. The availability of both operating and safety systems and the existence of applicable accident procedures ensured the safety of the units and demonstrated the strength of maintaining several levels of defence in depth.

2. Verification of readiness for operation of the safety systems that were not activated was carried out through visual inspection. It should be carefully analysed if this procedure is sufficient or if it should be the accepted practice to test with full activation of safety systems without substantial delay after the occurrence of an earthquake.

3. There was a time delay in reporting the leakage of radioactive material to the authorities. Information from the plant should have been issued more promptly. It is of key importance to report information on releases of radioactive material to the authorities as soon as possible to provide guidance for off-site emergency organizations, even if no significant releases have occurred or are expected to occur as a result of the event.

FINDINGS SHEET

1. FINDING IDENTIFICATION	Finding Number:	**A3-02**
NPP:	**KASHIWAZAKI-KARIWA NPP**	
Unit:	**UNITS 1 TO 7**	
Assessment Area:	**A.3 – OPERATIONAL SAFETY MANAGEMENT**	
Finding Title:	**A.3-02 – RELEASES**	

2. FINDINGS

2.1 - FINDING DESCRIPTION: BACKGROUND

- Confinement of radioactive materials and control of operational discharges, as well as limitation of accidental releases is a fundamental safety objective in nuclear safety. It is important to detect and correct uncontrolled releases and possible pathways to the environment, even if the actual releases are very limited.

2.2 FINDINGS AT KASHIWAZAKI-KARIWA NPP:

TEPCO reported detection of iodine particulate material (Cr-51 and Co-60) during a weekly periodic measurement performed at the main exhaust stack at Unit 7. The detected radioactivity ($4x10^8$ Bq of iodine and $2x10^6$ Bq of other substances) was estimated to result in an individual dose well below the authorized limits for normal operating conditions. The release of radioactivity was found to come from the exhaust fan in the turbine gland steam ventilator. It was due to a mistake of an operator who failed to turn off a ventilator when the gland steam was no longer available. Under these circumstances, the ventilator continued to propel steam and incondensable gases from the turbine condenser to the main stack, which underwent further contamination.

- A small discharge of contaminated water into the sea occurred after the earthquake. The water spilled over from the spent fuel pool to the reactor building refuelling floor, where it filled up a cable chase. It then leaked into an uncontrolled area on the lower floor through a cable penetration that had a defective sealing. The water dripped down one additional floor along cables and a penetration. It finally collected one floor down in a pit of discharged water. The contaminated water was then sent to the sea by the discharge pump through the discharge outlet.

  The volume of discharged contaminated water was estimated by TEPCO using the records of the pump activation. The activity of the discharged water was directly measured on samples of water from puddles in rooms above the pit. It was found out that the activity released was extremely small and it was estimated to result in an individual dose well below the authorized limits for exposure of the public under normal operating conditions. The phenomenon of water spilling over from the spent fuel pool is now well known and had already been observed during previous earthquakes. It seems therefore important to devote special attention to the leak-tightness of penetrations on the floor of the reactor building where the spent fuel pool is located.

- Significant displacements were produced by the earthquake in the ducts connected to the main exhaust stacks at Units 1, 2, 3, 4 and 5. These displacements could have resulted into limited leakages and releases of contaminated air at the ground level instead of such contaminated air being exhausted and monitored at the top of the stack.
- TEPCO considered that the events had a very low impact on the plant safety and individual radiation dose. The IAEA team finds this conclusion reasonable.

3. LESSONS LEARNED		**10/08/2007**

1. Although no releases of radioactive material from the reactor core due to the earthquake were detected, careful attention should be paid to other possible sources of releases, even if the releases are of limited low amounts.

APPENDIX I - MISSION PROGRAMME

The mission programme was as follows:

1. **Sunday, 5th August:**

Arrival of experts to Tokyo, Narita Airport.

Transfer from Narita Airport to Tokyo Station by Express Train

Travel from Tokyo to Nagaoka: by train, arrival on Sunday afternoon.

Transfer to the Hotel at Nagaoka

17:00 – 18:30: Meeting with NISA/JNES, at the Hotel

18:30 – 19:30: IAEA Team – Internal Meeting

2. **Monday, 6th August: Kashiwazaki-Kariwa NPP – *"Overall Picture"***

Morning: Opening remarks

Presentations by TEPCO:

- The earthquake – general information and records at free field and at the plant buildings/structures.
- KK NPP seismic design basis: seismotectonic model, design spectra, time histories, control point, etc.
- KK NPP – Plant behaviour – damage – incidences.
- KK NPP Operational response

Organization of the plant walkdown (A walkdown was being performed in all Units, with the IAEA team organized in two groups):

- Review of layout drawings;
- Select of walkdown paths;
- Logistical aspects: access to controlled areas/protocol of walkdown records (photos, notes)

Afternoon: Continuation of presentations and discussions. Review of documentation by IAEA Team.

Plant general tour / outside areas – all members of the IAEA team

Late afternoon: IAEA internal meeting (at hotel meeting room)

3. **Tuesday, 7th August: Kashiwazaki-Kariwa NPP – *"Plant Walkdown"***

Morning: Plant walkdown – Groups 1 and 2

Area 1 – Meeting NISA/JNES/TEPCO and IAEA expert: Mr A Gürpinar.

Afternoon: Plant walkdown – Groups 1 and 2

Late afternoon: IAEA internal meeting: discussion and documentation of observations - preparation of Draft Mission Report (at hotel meeting room)

4. **Wednesday, 8th August**: **Kashiwazaki-Kariwa NPP – *"Plant Walkdown"***

Morning: Plant walkdown – Groups 1 and 2

Meeting with NISA/JNES/Experts on Seismic Design Basis – IAEA/Mr Gürpinar.

Meeting with TEPCO Experts on Area 3 - Operational Management – IAEA/Mr Gunsell

Afternoon: Plant walkdown – Groups 1 and 2

(Cont.) Meeting with NISA/JNES/Experts on Seismic Design Basis – IAEA/Mr Gürpinar.

(Cont.) Meeting with TEPCO Experts on Area 3 - Operational Management – IAEA/Mr Gunsell

Late afternoon:	IAEA internal meeting: discussion and documentation of observations - Preparation of first version of Draft Mission Report (at hotel meeting room)
24:00	Handing over of first version of Draft Mission Report to NISA

5. **Thursday, 9th August**: **Kashiwazaki-Kariwa NPP – *"Discussion on Findings"***

09:00 – 15:30:	Discussions on first version of Draft Mission Report with participation of NISA/JNES/TEPCO.

Handing over of second version of Draft Mission Report.

Closing Remarks.

15:30 – 16:30:	Transfer to Nagaoka Station
17:06:	Departure to Tokyo by Shinkansen (Max Toki 338)
19:00:	Arrival at Tokyo Station.
19:30:	Check-in at Excel Tokyo Hotel

6. **Friday, 10th August: Tokyo – "*Closing meeting*"**

09:30 – 10:30:	TEPCO – Presentation of Draft Mission Report – Findings and lessons learned.
10:45 – 11:45:	NISA – Presentation of Draft Mission Report – Findings and lessons learned.
12:00 – 12:45:	NSC – Presentation of Draft Mission Report – Findings and lessons learned.

Saturday, 11th August: Departure of Experts from Tokyo to home countries.

APPENDIX II - LIST OF PARTICIPANTS

A.1 IAEA REVIEW TEAM:

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A.2 JAPANESE ORGANIZATIONS

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Mr. NAGAMOTO, Masaki	Official, Nuclear Safety Public Relations and Training Division
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Mr. INUFUSA, Kazuo	Safety Examiner, Seismic Safety Office, Nuclear Power Licensing Division
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