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Fukushima Dai-ichi Nuclear Accident

This edition of the ISOE NEWS is dedicated to the people of Japan and especially to radiation protection issues of those who have responded heroically to the nuclear accident at Fukushima. The combined effects of the earthquake and tsunami have led to the loss of thousands of lives and to the destruction of the main infrastructures in north-eastern Japan, ranging from entire towns and industrial installations to roads, bridges, power lines and water systems. As a result of these natural disasters, the Fukushima Dai-ichi site including six boiling water reactors has also been seriously damaged.

Figure 1 shows crippled Dai-ichi NPP Units 4-3-2-1, from left to right. During the early hours of the accident, core meltdown happened in Units 1, 2 and 3, as they were in operation before the earthquake. It is assumed that most of the radioactive noble gases were released from the damaged reactor cores to the atmosphere and about 10 % of iodine-131 and cesium-137 (from Japanese SEEDI -*Radiation Dose from Plume Release in Nuclear Accident*- software results) or at least 1 % (from TEPCO report). Unit 4 was not in operation due to outage but it is assumed that hydrogen generated in Unit 3 leaked through the connection piping of gas treatment system to the ventilation stack exhaust, and a hydrogen explosion also damaged the roof of Unit 4 reactor building.

Figure 1: Fukushima Dai-ichi NPP (after earthquake and tsunami)

This report of the ISOE concentrates on occupational exposure control of emergency response workers at Fukushima and implementation of radiation protection and individual monitoring related issues of the road map issued by TEPCO. Only information from the Japanese utility and official Japanese Government sources, including "Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety" dated 7 June 2011, "Status of the Fukushima Dai-ichi Nuclear Power Plant and Related Environmental Conditions" issued in August 2011 by the IAEA Incident and Emergency Center and relevant OECD Nuclear Energy Agency reports are included.

Radiation dose control measures at the Fukushima Dai-ichi NPP after the accident

During the early hours of the subsequent events, nearly 1 hour after the earthquake, tsunamis reached to the turbine- generator buildings and also other buildings facing the sea which provide access to the controlled areas depriving the function of the control system, and rendering many of the electronic alarm personal dosimeters (APD) and dose reading devices unusable as they became submerged in seawater. Also, due to the increase of radiation and contamination levels in the power station site, it was decided that workers should

conduct their preparation in the response headquarters established in the quake-proof building (main anti-earthquake building located at the site in the direction of the upper right corner of Figure 1), and that distribution of APDs and recording of doses were performed in this building.

From March 11, shortly after the earthquake, dose management of workers had to be performed manually by recording the names of individuals and their daily dose values on paper to accumulate data. Moreover, such daily individual doses were manually recorded and input into PCs (using Excel sheets) and saved in a database. Since many APDs became unusable not every worker was able to wear an APD and TEPCO has thus been managing radiation doses of all the personnel by making leaders of operational groups wear APDs on behalf of the entire group.

As controlling workers' radiation exposure is extremely important to ensure safety on the site, the Nuclear and Industrial Safety Agency (NISA) gave oral instructions to make every effort to manage its workers' radiation exposure and dose. After receiving these instructions, TEPCO procured the necessary dosimeters by April 1 so that all the workers conducting operations were able to carry portable individual dosimeters. Furthermore, the evaluation of external exposure during work in the quake-building was based on the length of the period of stay because workers didn't wear APDs when working inside the building.

Moreover, shortly after the earthquake, appropriate protection equipment such as protective masks were not worn even though the calculation of radioactive materials within the air of the quake-proof building exceeded the allowable limits of radioactive concentration in the air, resulting in workers staying in the building inhaling radioactive materials.

On April 14, about one month after the accident occurred, radiation control measures similar to that of the previous dose management (the system in which individual names and dose readings are automatically recorded) became available since the system of radiation control measures was nearly completely restored.

Revision of dose limit in emergencies in Japan

The dose limit for radiation workers in Japan is set prior to the accident at an effective dose of 100 mSv over 5 years and 50 mSv per year. In addition to this limit, the dose limit for women is regulated at 5 mSv over 3 months. The dose limit for radiation workers engaged in emergency work is regulated by the relevant laws at 100 mSv for an effective dose, at an equivalent dose of 300 mSv for eye lenses, and at an equivalent dose of 1 Sv to the skin.

With the Declaration of a Nuclear Emergency issued according to the Act on Special Measures Concerning Nuclear Emergency, the effective dose of 100 mSv was raised to 250 mSv in the event of an unavoidable emergency, which took effect on March 14. In determining the basis for the 250 mSv dose limit, the ICRP 1990 Recommendations (Pub. 60) that stipulate a dose limit of 500 mSv for persons voluntarily engaged in emergency rescue operations in order to avoid definitive impact, a primary objective of radiation protection, was taken into consideration.

System of radiation control measures in J Village

Shortly after the accident from March 17, J Village, a soccer training facility located at a point about 20 km south of Fukushima Dai-ichi NPP, was utilized as a place for preparing workers for entry into Fukushima Dai-ichi NPP, where they put on their protective equipment, and performed decontamination tests when leaving, etc (Figures 2 and 3).

A system was established for radiation workers in Fukushima Dai-ichi NPP who don't go through the quake-proof building to attach ADPs (there are several kinds of dosimeters due to hasty procurement and assistance received from a variety of organizations) at J Village before going to work at the site in Fukushima Dai-ichi NPP, and to record doses for the day when returning dosimeters upon finishing work for the day. For this reason, dose readings in J Village continue to be manually calculated since the beginning of the accident. TEPCO is planning to introduce an individual recognition system using bar codes in J Village.

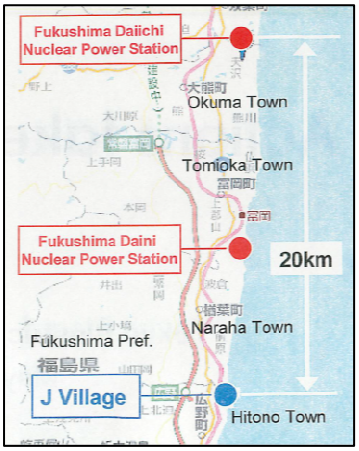


Figure 2: Location of J Village

Radiation protection equipment, work management, and early countermeasures

Due to the high concentration of radioactive materials over the entire site of Fukushima Dai-ichi, TEPCO requires workers to wear Tyvek and other protection clothes, gloves, and protection masks. It also requires appropriate protective clothes (anoraks, etc.), rubber gloves, and shoe covers taking into consideration weather conditions and contamination levels of the work sites (Figure 3).

As for the quake-proof building, it was difficult to prevent the inflow of radioactive materials because the entrance door was not an airtight structure, and the door was slightly damaged by the hydrogen explosions of Units 1 and 3, leaving a gap, and as there is no particular protective equipment installed in the building. Therefore, in the event of such an accident, the inhalation of radioactive materials by workers occurred.

Countermeasures were taken to decrease the concentration of radioactive materials in the air of the building such as connecting a unit house installed with an ambient air filtration system with charcoal filters at the entrance of the quake-proof building. As a result, the concentration of radioactive materials has been kept at low levels to the extent that it has been unnecessary to implement further protective measures.

In addition, a preliminary survey is conducted so that workers are informed of the situation in developing a work plan in areas such as high radiation areas.

Figure 3: Arrangements for workers at J Village

Figures 4 to 6 show workers engaging in supportive radiation work, temporary indicator set-up at Unit 2 and installation of a shielding wall at the same unit.

Figure 4: Supportive work

Figure 5: Temporary indicator set-up at Unit 2

Figure 6: Installation of a shielding wall at Unit 2

Review of radiation exposures

The status of radiation doses for the workers engaged in emergency work at Fukushima Dai-ichi NPP as of May 23 is that there were approximately 7,800 people who entered the site and were exposed to approximately 7.7 mSv on average. Thirty people were recorded as receiving doses over 100 mSv.

TEPCO has been evaluating exposures dose of the workers continuously during last months. These exposures are in two categories: internal (due to inhalation) and external. The last report on exposure status was issued on August 31 and periodic updates are available for downloading from TEPCO's web site at http://www.tepco.co.jp/en/press/corp-com/release/index-e.html.

TEPCO submitted a number of reports to the Ministry of Health, Labor and Welfare on the dose evaluation of workers engaging in emergency work at Fukushima Daiichi. Number of workers exceeding total dose of 100 mSv was reported to be 81, and 6 are exciding 250 mSv (in 5 cases internal dose exceeds 250 mSv). In April, still 3 workers exceeded 50 mSv of external dose. No workers exceeded 50 mSv of external dose which had engaged in emergency work since May 2011.

Detailed presentation of preliminary dose reports for the first months

March 2011: The workers received in average 22,40 mSv of total dose and the maximum dose was 670,4 mSv. There was a total of 3 751 workers, 1 653 of them TEPCO employees.

Internal exposure was assessed by whole body contamination measurement later on and by evaluation of a behavior survey. Maximum internal dose was 590 mSv for TEPCO and 98,5 mSv for the contractors. Maximum external dose component was 199,4 mSv. Average external dose was 13,50 mSv.

April 2011: Radiation exposures at the site were lower. Average external exposure was 3,2 mSv, average total exposure was 3,9 mSv. There were altogether 3 650 workers, 621 of them are TEPCO employees. Maximum external dose was reported as 65,9 mSv and maximum total dose was 69,3 mSv.

May 2011: Newly engaged workers at the site received an average external dose of 2,66 mSv and the maximum dose was 41,6 mSv of external radiation. Maximum total exposure was also 41,6 mSv, maximum internal dose was 10,1 mSv. There were all together 3 143 workers, 279 of them TEPCO employees. In the interval from 20 to 50 mSv the number of exposed workers was 21. These doses are related only to work activities, not include after-work time or transfer to the workplaces.

June 2011: There were 1 981 workers at the site, 183 of them TEPCO employees. Average total dose was 2,35 mSv and internal exposures became less important with average dose of 0,03 mSv. Maximum total dose was 38,7 mSv and maximum internal dose was 1,7 mSv.

Other exposures

On March 24, it was confirmed that two out of three workers involved in work for laying electric cables on the first and basement floors of the turbine building of Unit 3 had radioactive materials attached to the skin of their feet when stepping into puddles of radioactive water wearing low-cut shoes. Although TEPCO decontaminated their exposed skin, it was decided that there was a possibility of beta ray burns, and the two workers were transported to Fukushima Medical University Hospital. After examination on March 25, all three workers including the two that were exposed to the puddle were transported to an independent administrative institution, the National Institute of Radiological Sciences (NIRS). Immediately after their arrival, NIRS performed checkups, etc. The workers were also re-examined on April 11 for follow-ups and it was confirmed that these three workers were not suffering any health issues. From the results of the evaluations of the equivalent doses of their skin, it is estimated that they were exposed to less than 2 to 3 Sv.

Moreover, on April 27, in the course of confirming radiation exposures over a period of three months, TEPCO confirmed that a female employee had been exposed to more than 5 mSv over a period of 3 months, which is above the legally stipulated dose limit. Meanwhile, some of the people engaged in work were not designated as radiation workers. For this reason, NISA gave a strict warning to TEPCO, and instructed it to investigate the cause of the exposure, to develop measures to prevent any recurrence, to verify the system of radiation control measures in Fukushima Dai-ichi NPP, and to develop appropriate countermeasures based on their findings.

Besides radiation control measures, as it is important to establish and maintain the working environment of workers, TEPCO is working to improve the occupational safety, health management and the living environment for workers at Fukushima Dai-ichi NPP and Fukushima Dai-ni NPP. Also, the government has issued instructions to TEPCO regarding (i) exposure dose management for workers, including internal exposure, thorough implementation of temporary health examinations, and reporting. In addition, (ii) certain emergency operational works are required to be reported in advance to the Labor Standards Inspection Office to have their exposure control for workers, etc. confirmed. Moreover, the policy requires (iii) creating a database capable of tracking exposure doses, etc. over the long-term for all the workers engaged in emergency work even after they leave their current jobs, and conducting long-term health management.

Radiation control measures for employees of the government engaged in restoration work

Radiation control measures for the Self-Defense Forces of Japan (SDF)

Self-Defense Force members working within 30 km of Fukushima Dai-ichi NPP were informed in advance about their expected exposure dose from the latest monitoring results for the planned activity area or surrounding points and planned time of the activity, and also advised to take necessary appropriate measures such as wearing simple protection clothes (such as Tyvek) and so on.

The SDF members also monitor their exposure using individual monitors and confirm their cumulative dose during their active duty. The upper limit of the cumulative exposure dose for an individual member is 50 mSv (the limit for exposure of radiation workers), but for female members, it is 5 mSv over a 3-month period, and if there is a possibility that exposure will exceed 30 mSv (or 3 mSv for female workers) during their activity, members temporally suspend their activity considering a turn back dose for returning (a dose capable of returning within the limit of cumulative exposure dose).

As mentioned earlier, for emergency and other unavoidable lifesaving operations, the upper limit of the cumulative dose is 250 mSv (excluding female workers). As of May 31, there is no SDF member whose exposure exceeds the above mentioned limit.

Radiation control measures for firefighting teams

Firefighting team members working within 20 km of Fukushima Dai-ichi NPP were equipped with simple protection clothes. The dose rate was measured and cumulative dose was calculated during their operations to minimize the exposure doses as much as possible, with the upper limit having been decided by individual Firefighter Headquarters, taking into account the exposure dose limit in the Operation Measure Manual of the Fire and Disaster Management Agency. The Manual sets the exposure dose limit as 100 mSv for emergency operations such as lifesaving activities (alarm is set at ranges from 30 to 50 mSv), and 100 mSv over five years for those who repeatedly engage in the operations (it should not exceed 50 mSv in any given year). Fire fighting team members working within 20 km of Fukushima Dai-ichi NPP have their exposure doses measured after the operations, and as of May 31, there is no member whose exposure exceeds the limit.

Evaluation of radiation exposure control measures

In principal, the operator is primarily responsible for the appropriate performance of radiation control measures for its radiation workers based on a predetermined plan. Performing precise control of dosages is the basis of performing appropriate radiation control measures for radiation workers. However, because of the insufficient number of dosimeters due to above mentioned reasons, actions such as equipping only work unit leaders in relatively low environmental doses were taken. Dose evaluations are based on behavior records because measuring the doses of each individual with an APD was impossible. It took considerable time to establish a system for radiation control measures equivalent to the system which was in place before the tsunamis. Early respiratory protection measures also seem to be insufficient.

In addition, delay in management to prevent radioactive materials from entering the quake-proof buildings and that of measuring the concentration of radioactive materials in the air within the building resulted is increasing the risk of internal exposure. Evaluation of management or control of respiratory protection programme is not reported.

At Fukushima Dai-ichi NPPs, whole body counters (WBC) became unusable due to the increase of the background level. Therefore, vehicle-mounted WBCs were procured and have been used for measurements. Due to a large number of workers, TEPCO decided to perform WBC measurement and evaluated dose rates preferentially to workers with high external exposure doses and to those who were engaged in emergency operations in March. However, at present, two workers were confirmed to have high internal radiation doses (iodine 131) in their thyroid glands in the evaluation of internal exposure doses. Currently, dose evaluation has been performed on those two workers and their dose may exceed the limit of 250 mSv for emergency operations. Furthermore, there is a possibility that some workers engaged in emergency operations right after

the accident in March may be evaluated as having doses close to the limit or doses that may exceed the limit in line with the progress of internal exposure dose evaluation.

Evaluation of emergency medical system for exposures

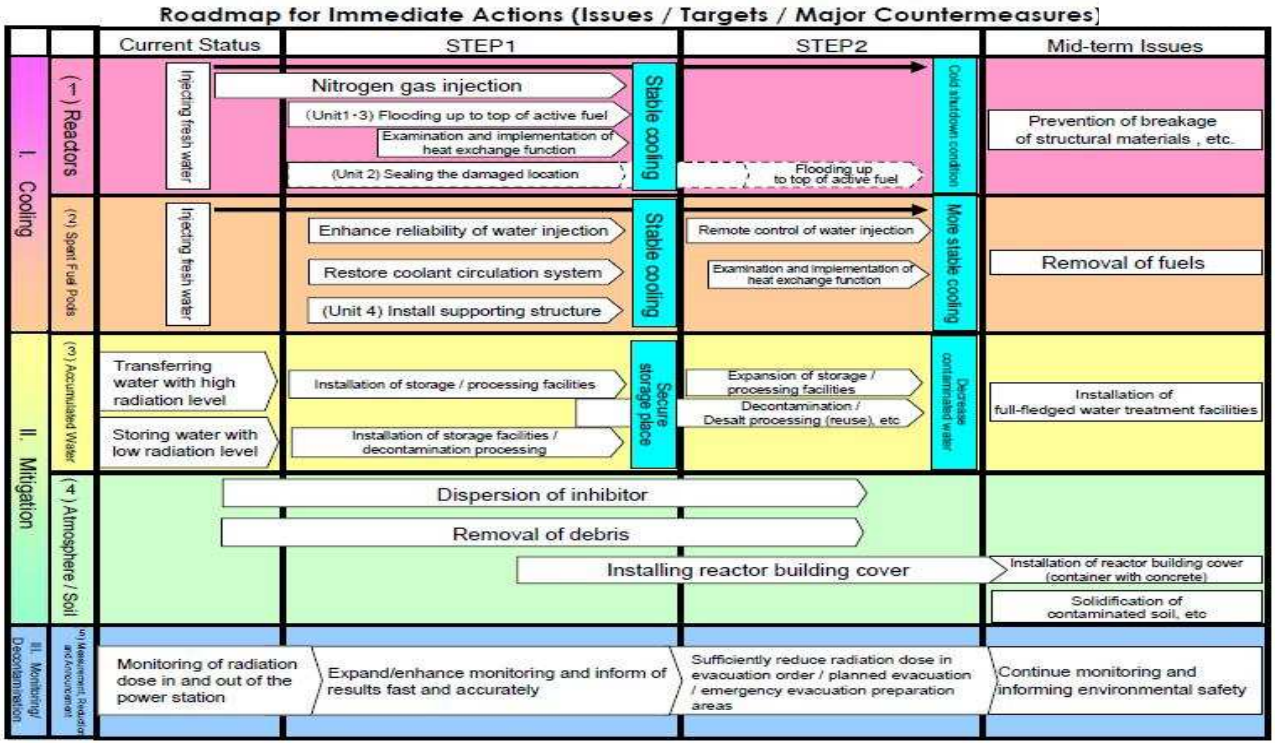
As a precaution, there were some cases, in which some people engaged in emergency work for this accident at Fukushima Dai-ichi NPPs were transported to an independent administrative institution, NIRS, which is a tertiary emergency medical institution for exposure, but there were no cases serious enough to be treated as tertiary exposure.

As this nuclear disaster caused by the Great East Japan Earthquake, it was a disaster beyond the assumptions of conventional nuclear disaster countermeasures that required responses to earthquakes and tsunamis at the same time. The local governments first strengthened their systems by co-ordinating with medical institutions such as university hospitals nationwide on such issues as how to cope with the high numbers of injured or sick patients.

As such, the Fukushima Medical University, an institution for secondary exposure, and other medical institutions in the prefecture, were obliged to work under complex emergency conditions such as simultaneously performing disaster medical measures including dispatching on-site disaster medical care. Therefore there is a possibility that these institutions could not sufficiently respond when emergency response against radiation exposure was really needed compared to the anticipated response in the field by the regional disaster prevention plans, which were planned in advance. However, as the Nuclear Emergency Response Local Headquarters led the immediate restructuring of the medical system for exposure and strengthened the response system in cooperation with related institutions such as university hospitals including tertiary medical institutions for exposure, the medical system for exposure is considered to be performing its necessary functions.

TEPCO Road Map

With regard to the accident at Fukushima Daiichi Nuclear Power Station, TEPCO issued a road map in April 2011. Related predefined issues are given below.



1. Basic Policy

By bringing the reactors and spent fuel pools to a stable cooling condition and mitigating the release of radioactive materials, TEPCO plans to make every effort to enable evacuees to return to their homes and for all citizens to be able to secure a sound life.

2. Targets

Based on the basic policy, the following two steps are set as targets: "Radiation dose is in steady decline" as "Step 1" and "Release of radioactive materials is under control and radiation dose is being significantly held down" as "Step 2." Target achievement dates are tentatively set as follows: "Step 1" is set at around 3 months and "Step 2" is set at around 3 to 6 months after achieving Step 1.

3. Immediate Actions

Immediate actions were divided into three groups namely, Cooling, Mitigation and Monitoring and Decontamination. For the following five issues "Cooling the Reactors," "Cooling the Spent Fuel Pools," "Containment, Storage, Processing, and Reuse of Water Contaminated by Radioactive Materials (Accumulated Water)," "Mitigation of Release of Radioactive Materials to Atmosphere and from Soil," and "Measurement, Reduction and Announcement of Radiation Dose in Evacuation Order/Planned Evacuation/Emergency Evacuation Preparation Areas" targets are set for each of the five issues and various countermeasures are going to be implemented simultaneously.

Brief description of operations at Fukushima Dai-ichi during July-August 2011

As reported in August, the core cooling has become stable. TEPCO is making a lot of efforts to stabilize Fukushima accident. The target of the Step 1 was to reduce the radiation release to the atmosphere which is 1/1000 compared with the worst burst situation. Right now the target of the Step-2 is to stabilize the core cooling. They have almost achieved the target. The temperature of the core in Unit 1 is about 80 °C and the temperature of the core in Unit 3 became 98 ℃ whic h is less than the target of the boiling temperature 100 ℃. The remaining issue is Unit 2 whose core temperature is 120 ℃. F igure 7 shows the control room of unit 2 after the accident. More details are given in TEPCO's web site (http://www.tepco.co.jp/en/press/corp-com/release/index-e.html).

Figure 7: Control room of Unit 2

Installation of the cover for Unit 1

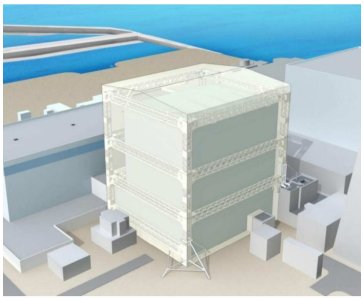


Figure 8: Picture of the cover, Unit 1

In August 2011, the construction started on the iron frame for the cover of the Unit 1. Figure 8 shows the model of the planned cover for Unit 1 and figure 9 shows the crane moving components to work area.

Figure 9: Crane work, Unit 1

Hot spot identification

Figure 10: Measuring hot spots

At the beginning of August, two localized very high radiation fields were identified in the range of 10 Sv/h. Figure 10 shows a RP worker taking measurements of high dose area at the main exhaust tower between Unit 1 and 2, the location of the stack drain pipe. At the bottom of the stack drain pipe the dose rate was measured by telescopic detector to be 3,6 Sv/h.

Another hot spot was detected in Unit 1. The dose rate around the entrance to the Train Room for the Standby Gas Treatment System on the second floor of the turbine building was determined to be greater than 5 Sv/h.

Management of on-site contamination

The accumulated water in the trench of the turbine building of Unit 2 was transferred to the Radioactive Waste Treatment Facilities (RWTF). TEPCO installed a second cesium removal system called Simplified Active Water Retrieve and Recovery System (SARRY), within the water treatment and waste removal system. The systems are using a combination of absorption towers and oil separators. Figures 11 and 12 show the final lay-out and site installation works of SARRY.

On August 23, it was announced that a dose rate of 3 Sv/h had been measured at an isolated point within the operating SARRY system. At this location there is an air vent with a float. During the exchange of vessels radioactive material passed the float and accumulated in the piping. After dissolving this material back to the vessel the system was activated again.

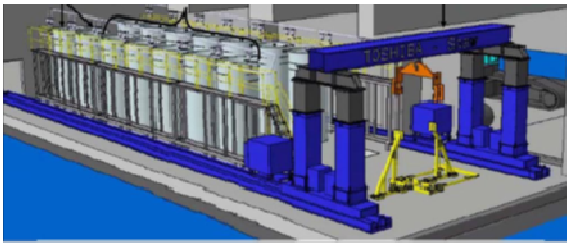


Figure 11: Cesium removal system-SARRY

Figure 12: SARRY installation work

Waste management and reactor cooling of Unit 3

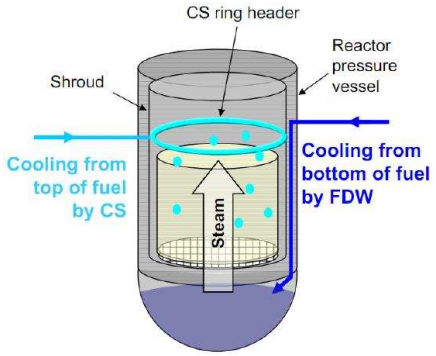


Figure 13: Reactor cooling system- Core Spray (CS) and Feed Water (FW)

The accumulated water in the basement of the turbine building Unit 3 was transferred to the RWTF.

In addition to the feed water (FW) system providing water to the bottom of the reactor and cooling via steam, the cooling system for the reactor is planned to be diversified with a core spray (CS) system line (Figure 13).

The CS system is scheduled to be in operation in August/September. The flow rate from CS will be 3 m^3/h as well as the flow rate of FW system.

Spent fuel pool of Unit 4

The supporting structure for the spent fuel pool of Unit 4 was completed by the end of July after the injection of concrete and grouting into installed structures of steel support pillars and within the rooms below the pool.

Progress status classified by issues directly related with the workers and the work environment

Figure 14: Training of radiation workers

From August 16, TEPCO introduced a system which can output radiation exposure data on receipts and at the same time automatically acquire individual radiation exposure data of workers. Protective equipment appropriate to the work environment is provided to workers in order to improve safety during radiation related work, such as air filtering personal protection suits and masks (Figure 14).

On-site radiation monitoring

Radiation monitoring of dose rates and airborne contamination is performed continuously at the locations presented by Figure 15.

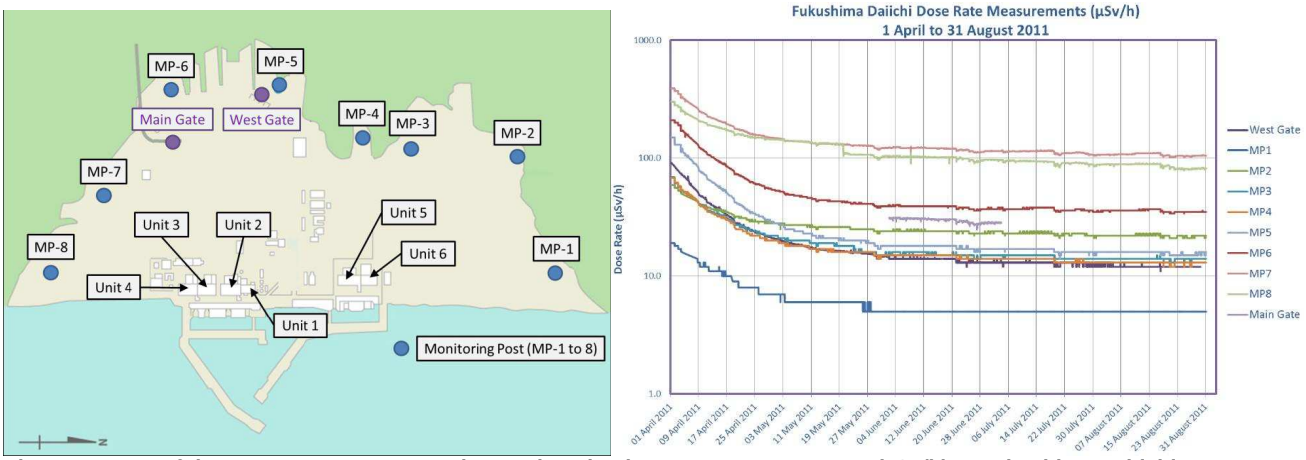


Figure 15: Map of dose rate measurement points and onsite dose rate measurements (µSv/h) at Fukushima Dai-ichi

On-site measurements of airborne contamination have been taken by an air sampler inside a vehicle. This vehicle would drive to each measurement point and take a sample of 1,7 m^3 in 40 min. In August, TEPCO tested a timer-controlled dust sampler that could be installed at monitoring points for the sampling of 15 m^3 of air in 300 min. This new method has a lower limit of detection: Cs-137 volatile 0,43 Bq/m^3, particulates 0,24 Bq/m^3.

ISOE Network Website (www.isoe-network.net) and the Severe Accident Management

A specially designed web page in the ISOE Network has been created after the Fukushima NPP accident to collect relevant information from ISOE partners and to exchange this information with Japanese colleagues. In addition, the results of a survey which was conducted by the ISOE NEA Secretariat in April 2011 to collect some specific information on dose management criteria for high dose/ dose rate areas, recommended protective equipment for emergency response workers and etc. is available for downloading from the web site (http://www.isoe-network.net/index.php/rp-library-mainmenu-104/severe-accident-management.html).

In addition, some specific documents on severe accident management from ISOE participants are also available for downloading.

Upcoming ALARA Symposium

2012 ISOE International ALARA Symposium

The 2012 ISOE International ALARA Symposium, organized by the ISOE North American Technical Centre (NATC), will take place 8-11 January 2012 in Fort Lauderdale, USA.

2012 ISOE Regional ALARA Symposium

The 2012 ISOE European ALARA Symposium, organized by the European Technical Centre (ETC), will be held 20-21 June 2012 in Prague, Czech Republic.

The meeting will be preceded on 19 June 2012 by the Radiation Protection Managers (RPM) and a Regulatory Body Representatives meeting.

The Symposium announcement, call for papers and registration form are available on the ISOE Network.

More information on all ISOE Symposia, including papers and presentations from previous symposia, can be found on the ISOE Network.

Schedule of Meetings for 2011

- 4-5 October 2011: Expert Group on Occupational Exposure - EGOE (OECD, Paris / France)
- 7-8 November 2011: Working Group on Data Analysis- WGDA (OECD, Paris / France)
- 8 November 2011 (afternoon): ISOE Bureau/TC meeting (OECD, Paris / France)
- 9-10 November 2011: ISOE Management Board (OECD, Paris / France)

For further information, please visit the ISOE Network: *www.isoe-network.net*