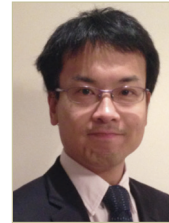


Updated status of Fukushima-Daiichi NPP

Takafumi Ihara*

Recovery operation at Fukushima-Daiichi NPP is steadily on the Roadmap toward decommissioning. Significant amounts of improvements such as enhancing the reliability of core cooling systems, the commencement of fuel removal from spent fuel pools etc. have already been achieved over the last few years and those efforts are being boosted by the establishment of a new entity fully responsible for the decommissioning and decontamination works while many challenges such as much uncertainty in RPV/PCV, increasing water inventory, etc. still exist. Not only the recovery work, but also continuous examination on lessons learned from Fukushima is our first priority so that the knowledge obtained there should be integrated in safety enhancement measures of any NPPs around the world. Two technical reports for this matter have already been issued.



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joined Tokyo Electric Power Company (TEPCO), in April 2005, where he had worked for the first 3 years as a Mechanical Engineer responsible for the reactor island at Kashiwazaki-Kariwa NPP and also as the Licensing Manager at Headquarters with responsibility especially in the last year to prepare safety evaluation documents which is now reviewed by the Regulatory Body. Since July 2013, Takafumi has taken a new role as Nuclear Power Program Manager at the TEPCO London office, where he is responsible for any strategic communication with partners in Europe and the development of international cooperation to introduce the best practice. Before joining TEPCO, Takafumi earned BS and MS in mechanical engineering from Kyoto University in Japan.

A NEW ENTITY RESPONSIBLE FOR DECOMMISSIONING FUKUSHIMA-DAIICHI NPP WAS ESTABLISHED

In April 2014, A new organization within TEPCO, the “Fukushima Daiichi Decontamination and Decommissioning Engineering Company” (FDEC) was established [1].

FDEC has been focusing and providing specialized capabilities to shift efforts at Fukushima Daiichi from the emergency response phase, which began immediately after the accident, to a sustainable approach more suited to long-term decommissioning work.

Its action plan has three main components: (1) Improving the management of water on the site, including reduction of the amount of water that becomes contaminated and reducing the risks associated with stored water; (2) Safely achieving steady progress toward the achievement of middle- and long-term goals, including the safe removal of spent nuclear fuel and, ultimately, the safe removal of fuel debris; and (3) Establishment of an administration and infrastructure sufficient to support and manage those activities [2].

The first Head of FDEC, Naohiro Masuda, whose decisive actions while superintendent of the Fukushima Daiichi plant during the Great Japan Earthquake and tsunami were credit-

ed for preventing any accidents, took on his role as Chief Decommissioning Officer on the 1st of April 2014 and commented “I take this role with full awareness of the great responsibility we have to the people of Fukushima, Japan, and the world to pursue this work diligently and safely through to its conclusion, no matter how long it may take.”

Masuda also expressed his intention to strengthen cooperation with international and domestic experts such as the International Research Institute for Nuclear Decommissioning (IRID), and with the experts already serving on TEPCO’s Nuclear Reform Monitoring Committee, including Dr. Dale Klein, the former chairman of the U.S. Nuclear Regulatory Commission, and Lady Barbara Judge CBE, the former chair of the UK Atomic Energy Authority. The company also includes three vice presidents from nuclear manufacturers Mitsubishi Heavy Industries, Toshiba, and Hitachi-GE Nuclear Energy.

STEADILY ON THE ROADMAP TOWARDS THE DECOMMISSIONING

Mid-and-Long-Term Roadmap was formulated and made effective in December 2011 as the cold shutdown condition and significant reduction of additional radioactive isotopes’ dispersion was achieved at Fukushima-Daiichi NPP [3][4]. It was also revised in June 2013 [5]. This divides

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Figure 1. The Mission of New Entity.

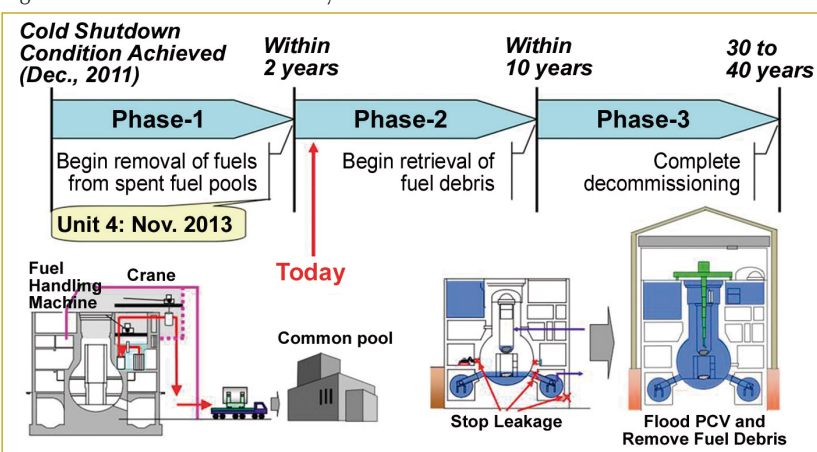


Figure 2. Roadmap for Decommissioning.

the term of decommissioning into the following three phases (Figure 2).

Phase 1: From the initiation of the Roadmap to the start of fuel removal from the spent fuel pool (Target: Should be accomplished within 2 years).

Phase 2: From the end of Phase 1 to the start of fuel debris removal (Target: Should be accomplished within 10 years after the initiation of the Roadmap).

Phase 3: From the end of Phase 2 to the end of decommissioning (Target:

Should be accomplished within 30 to 40 years after the initiation of the Roadmap).

Now the decommissioning work at Fukushima-Daiichi NPP is in Phase 2 of the Roadmap since we successfully started the fuel removal operation from Unit 4 spent fuel pool on the 18th of November 2013 [6]. As of the 25th of November, 1375 of total 1533 assemblies in the pool have been removed from Unit 4 [7]. The fuel assemblies are being removed one by one from a fuel rack inside the Unit 4

spent fuel pool, and being loaded onto the on-premises transportation container, which is capable of holding as many as 22 assemblies, and transported to another pool in the Common Pool Building with the utmost attention paid to safety [8]. No significant change has been observed in the monitoring of radiation level readings in relation to this operation, and neither trouble nor abnormality has been encountered at the site. The fuel removal operation at Unit 4 is targeted for completion by the end of 2014, followed by the fuel removal operation at Unit 1~3 where such preparatory work as decontamination and/or contaminated debris removal on the fuel handling floor in the reactor building is ongoing.

Not only the fuel removal operation from spent fuel pool but also a considerable amount of recovery work has already been fulfilled since the formulation of this Roadmap. First of all, through continuous reactor cooling by water injection, the temperatures of the Reactor Pressure Vessel (RPV) bottom and the Primary Containment Vessel (PCV) gas phase have been maintained within the range of approx. 25 to 45 degrees Celsius stably over the past years, though they vary depending on the unit and location of the thermometer (Figure 3). The reason why the temperatures in the Figure 3 are increasing steadily as a trend is that there is no enough insulation between the RPV/PCV and the air outside, so it reflects the changes of external temperatures.

The redundancy and diversity of the reactor cooling system has been also fulfilled by installing another set of fixed/mobile pumps and water reservoirs. Furthermore, the risk of possible leakage posed by the 3 km long pipes for reactor cooling will be shortened to about 0.8 km by

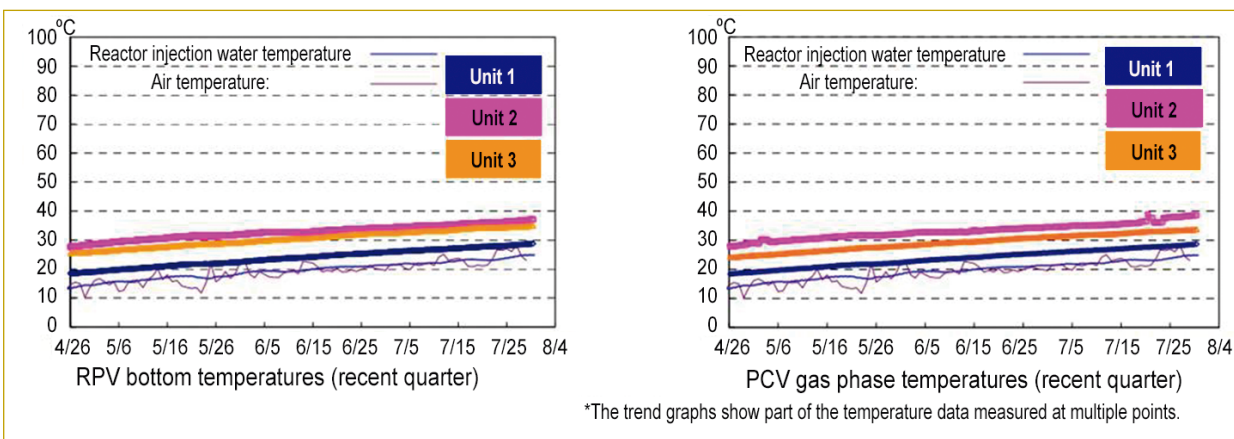


Figure 3. Temperature inside RPV/PCV.

installing a new RO system inside the Unit 4 turbine building and so on at the end of FY2014 (Figure 4).

The amount of radioactive materials (cesium) released from Unit 1-3 PCV additionally has been significantly reduced to and maintained as about 10 million Bq/hr, which has been the calculated value of the total released amount as of May 2013 and is equal to about one-80 millionth compared to the one taken immediately after the accident based on airborne radioactive material concentrations (dust concentration) measured at the top of Reactor Buildings (Figure 5). Accordingly, the exposure dose at the site boundary as of May 2013 was assessed as 0.03mSv/yr at maximum which was significantly lower compared with the 1mSv/yr of exposure limit established by law, although this calculation excludes the effect of already released radioactive materials.

Concentration in the port area also decreased up to one-millionth to one-100 thousandth as compared to the concentration right after the accident and maintained reasonably low compared with the limit value announced by government (Figure 6) [6].

PREPARATION FOR FUEL DEBRIS REMOVAL

The period from now to the completion of fuel debris removal for Units 1 to 3 is estimated to require 20 to 25 years because the large portions from molten fuel have probably leaked from the reactor vessels. Also the Roadmap says that, by the end of Phase 2 (within 10 years from December 2011), R&D activities of remote dismantlement should be complete and methods for dismantling and decontamination for reactors of Units 1 to 4 should be fixed. Also at this point, actual design and manufacture of dismantling equipment/facilities should commence at the site with the full implementation of modified regulatory oversight. One of the biggest challenges for this task is to fill containments with water for maintaining radiation shielding and continuous cooling of the fuel. For the containment filling, a variety of R&D is required to develop the methodology to find all leakage locations on the boundary of containments and to repair those locations with the support from remote robots which can withstand the harsh environmental conditions of high radiation, temperature, humidity, limited space and/or in water environment. Onsite human intervention may be required in some justified cases in

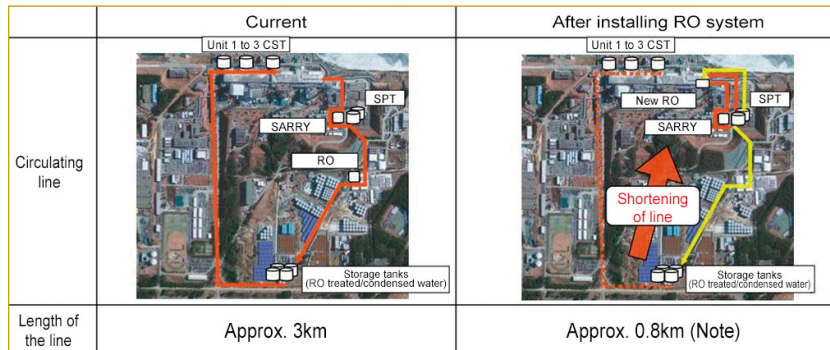


Figure 4. Length Reduction of pipes for Reactor Cooling.

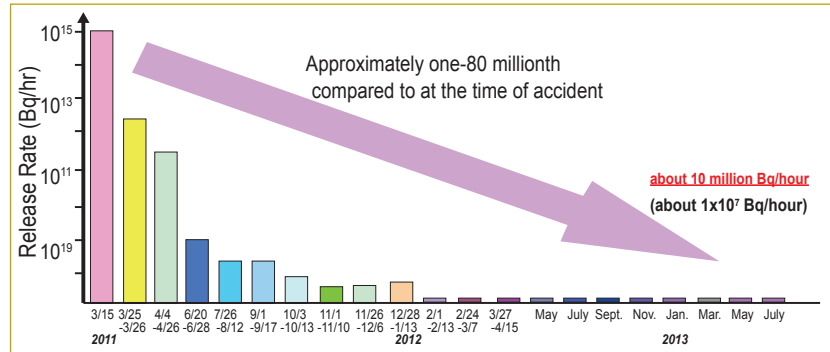


Figure 5. The release amount per hour of the radioactive material (Cesium) from Unit 1~3.

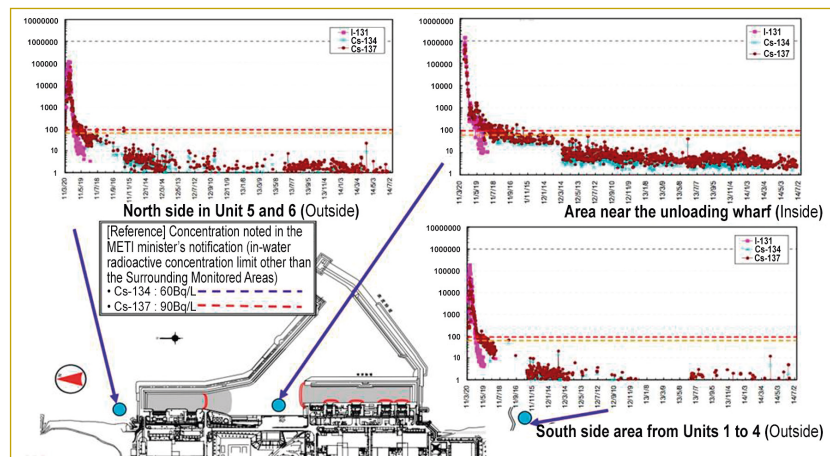


Figure 6. Radioactivity trends in and out of the port area.

accordance with ALARA, so the decontamination work to reduce the dose exposure is also critical work. Thus, the design, manufacture and testing of remote controlled and other equipment for decontamination, repair, survey/monitoring inside the containments are currently one of the most focused R&D activities in the area of fuel debris removal. On the other hand, an innovative approach for fuel debris retrieval without filling containment with water is also under examination in case that containment flooding strategy doesn't work as expected [9].

Remote decontamination work inside the Reactor buildings and Turbine buildings is also prerequisite

and ongoing. Here you can find examples.

One example is a high-tech robot camera built by Hitachi-GE Nuclear Energy. On the 5th of June, it had for the first time obtained clear pictures of places in the damaged Unit 1 reactor at Fukushima Daiichi where coolant water was leaking from the containment vessel into the building's basement [10][11]. The general location of the leakage was first identified last November by a remote-controlled boat that took photographs while floating on the accumulated water in the basement, outside the containment vessel [12]. At that time, it became clear that it would be necessary to examine

more deeply around the suppression chamber, which is the outer part of the containment vessel, to identify the source of the leaks with more precision. Because radiation is high around the vessel, it could only be safely examined by remote control. To meet this need, TEPCO worked with Hitachi-GE Nuclear Energy to develop a robotic camera that could be safely lowered into the suppression chamber and controlled from a separate building hundreds of meters away where workers can safely operate with little or no protective gear. Over a three-day period from May 27-30 2014, the camera was successfully lowered the 2.7 meters down to where the chamber locates and videos were taken of the leaks, using the device's ability to pan, tilt, and zoom. The photographs revealed leakage around an elastic joint ("flexible joint") on the piping coming from the containment vessel. The joint is believed to be suffering from corrosion. A total of .75 to 1.5 tons of water per hour is estimated to be leaking from the area investigated.

As other example, decontamination work inside the Unit 2 reactor building at the Fukushima Daiichi nuclear plant began on the 11th of June 2014, using a remote controlled robot [13]. The robot was manufactured by the Swedish company Husqvarna and modified by Toshiba for use at Fukushima. It was and is being used to decontaminate Unit 2's interior walls and equipment, in preparation for the full-scale decontamination effort. That effort will require further investigation inside the primary containment vessel, and other preparations, before the damaged nuclear fuel can be safely removed from the reactor. The decontamination of Unit 2 began last November with a cleanup of its floor by a different robot called "Raccoon," which was developed by the Japanese company ATOX [14]. That robot snaked along the floor but could not climb walls. But the Husqvarna/Toshiba robot could suction up radioactive dust from walls, cable trays, ducts and the surface of the control panels. The robot could reach as high as five meters, and houses 12 cameras to enable workers to guide it remotely. The robot was controlled from the shielded shed built nearby where radiation is low, a maximum 0.04 mSv/h, well below the permissible limit of 3 mSv per day, set for the work at this time.

Decontamination and investigation works in other units are also underway and TEPCO will continue efforts to identify and ultimately plug all

the leaks. This must be accomplished before the reactor's fuel can be safely removed.

WATER INVENTORY CONTROL

Continuous increase of radioactive water inventory is also a challenging issue at Fukushima. About 400 tons of uncontaminated ground water flows into the buildings of units 1 to 4 per day, producing contaminated water (Figure 7).

The water is transferred to the Cs removal systems and then the desalination systems such as RO type and evaporation type, and then desalinated water is injected into the reactors again. The concentrated water after desalination with still radioactive material is transferred to storage tanks at the rate of about 400 tons per day, a rate we are attempting to reduce by strategies below (Figure 8, 9). This still contaminated water is transferred to an advanced liquid processing system (ALPS) to remove

other radioactive material such as Sr, and then safely stored in tanks. The ALPS system is a sophisticated water processing facility that could remove most remaining radioactive contaminants from water at the Fukushima Daiichi site [15]. Since its installation in October 2012, it has been under test operation, already processing significant amount of water with total treatment capacity of 750 tons per day. Full operation of the facility will represent important progress in water management at the site, where approximately 400 tons of contaminated water is collected from the basements of the reactor facilities every day. In order to increase the processing capacity, we have been constructing the additional ALPS and the high performance ALPS, which are in test for their performance [16][17]. The high performance ALPS is expected to perform well with respect to small quantities of secondary waste, and will provide improved radionuclide removal.

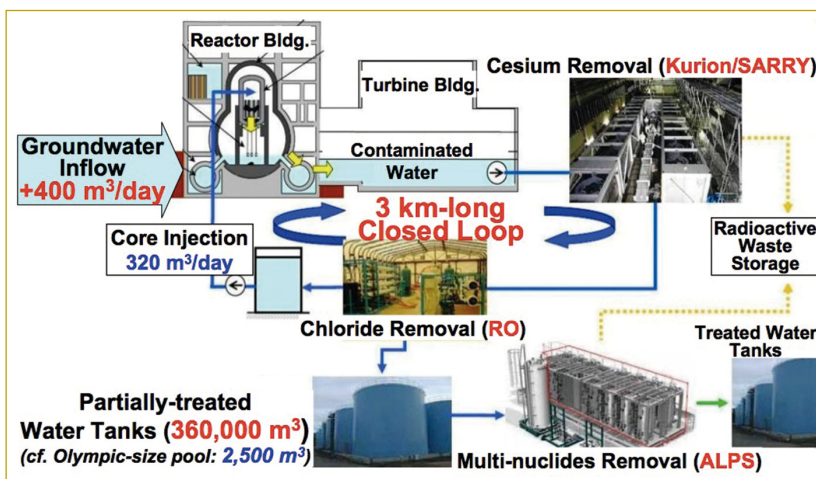


Figure 7. Circulating-Water Core Cooling System.

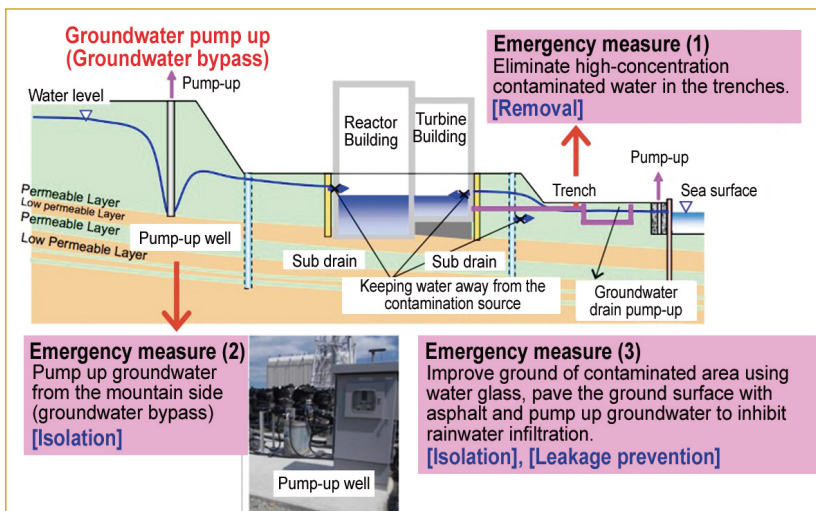


Figure 8. Emergency countermeasures for water inventory issue.

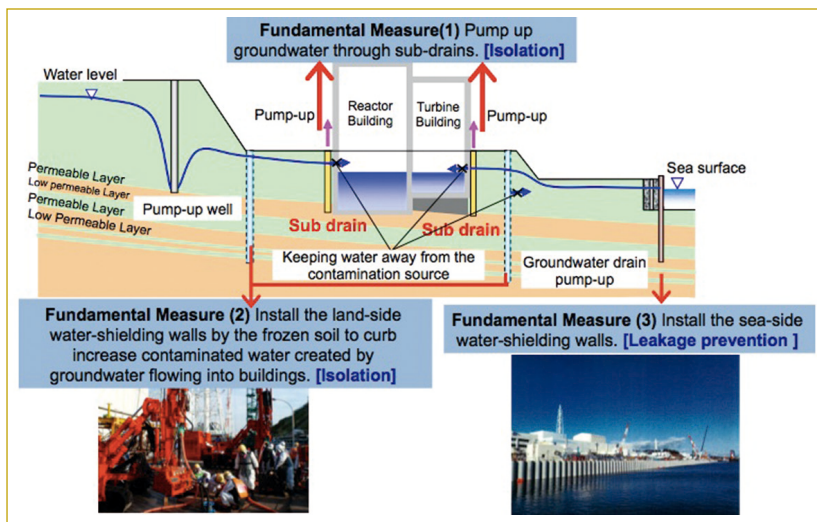


Figure 9. Fundamental countermeasures for water inventory issue.

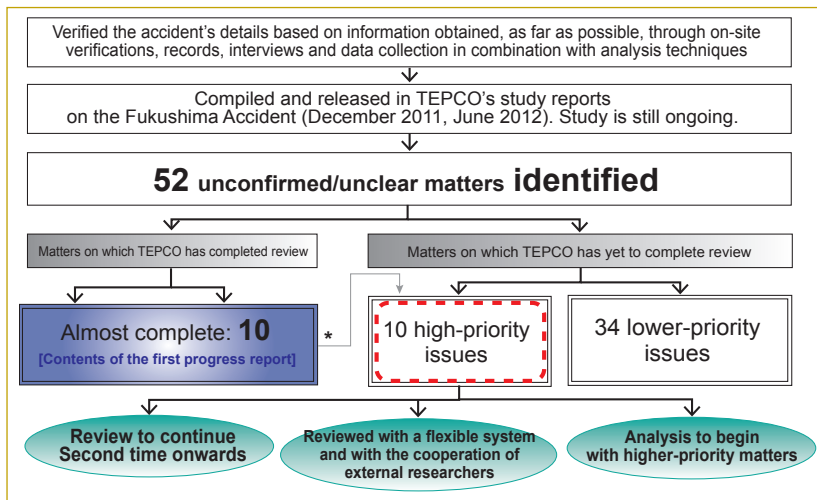


Figure 10. Report on progress made in investigating and studying unconfirmed/unclear matters.

After commission of all ALPSs, the capacity of water treatment will be 2000 ton per day. Beyond the ALPS systems, four other water treatment facilities are now in place to reduce Strontium levels in the water [18]. Kurion's Strontium removal facility has a capacity of 300 tons of water per day [19]. Furthermore, Strontium removal capabilities have been added to two existing Cesium-removal facilities, Toshiba's SARRY and Kurion's system, with capacities of 1,200 tons/day and 600 tons/day, respectively. And a reverse osmosis facility has a capacity of 500-900 tons per day.

As one of options to decrease the amount of groundwater, which is flowing into the basement of the reactor/turbine buildings at Fukushima Daiichi NPS at a pace of approx. 400 tons/day, we already started operating the "groundwater bypass system" [20~25]. The "groundwater bypass sys-

tem" is a system which pumps up groundwater from the upper stream (mountain side of the reactor buildings, from 35 m above sea level), bypassing the reactor/turbine buildings, and deposits it into the ocean, lowering the groundwater level. With this system, the groundwater flowing into the buildings is estimated to be reduced by about 100 tons/day.

We began test operation in April 2013, and have been conducting water quality tests. So far, we have confirmed that the level of radioactive materials contained in the water which is being pumped up is far below our control target of 1Bq/L and now the system is in full operation upon obtaining consensus from the stakeholders [26][27].

As for the other countermeasure for decreasing the amount of groundwater flowing into the basement of the reactor/turbine buildings, a land side impermeable wall is already under

construction and will be completed by March 2015 [28~30]. The land side impermeable wall made of frozen soil (ice Wall) surrounds the buildings of units 1 to 4. We have completed a small scale demonstration test since last year and now for full capacity operation it is under construction of digging 1500 bores of 30 m in depth with 1 m intervals, where the coolant circulating pipes are installed. The barrier is being funded by the government, with construction being undertaken by Kajima Corporation, one of the few entities that has developed the necessary technology, which it has used at numerous construction sites, especially tunnels, to block water penetration. The refrigerant is an environmentally safe and the chilled brine which will flow through the pipes to the depth, freezing the surrounding soil and forming a barrier around the reactor facilities. The circumference of the wall is approximately 1500 meters. The principal benefit of the frozen barrier compared with a physical barrier is that it avoids the challenges of building a wall around such underground obstacles as pipes, and creates a seamless barrier. The wall is also designed to withstand even long-term interruptions of electricity, maintaining its effectiveness for approximately two months after the loss of power.

CONTINUOUS EXAMINATION ON LESSONS LEARNED FROM FUKUSHIMA

Answers to a series of open technical questions about exactly how the Fukushima Daiichi nuclear accident progressed were addressed in a report that TEPCO released on the 6th of August 2014 [31][32].

TEPCO bears a responsibility, as a party who experienced this accident and failed to prevent it, to reveal the complete picture of the accident at Fukushima Daiichi NPP and to contribute to enhancing nuclear power plant safety. In other words, it is critically important to engage as a corporate unit in safety improvement, in order to continue the company's nuclear power business, especially to continue efforts to reveal the process of accident progression and, based upon the findings, to continue implementing further measures for safety enhancement of nuclear power plants. The accident progression processes to the ultimate severe accidents have been interpreted in the response actions to the accident taken so far and the knowledge obtained there has been integrated in safety enhancement measures of the

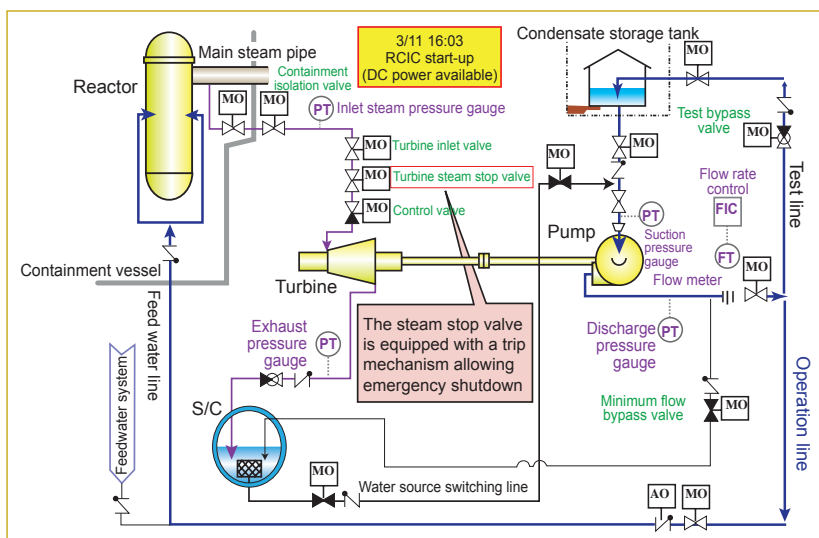


Figure 11. Unit 3 RCIC System.

Kashiwazaki-Kariwa Nuclear Power Plant.

The report, the second in a series of progress reports issued on the inquiry, addresses four issues that had been deemed “high priority” by TEPCO (Figure 10). Although the answers are in some cases more in the nature of hypotheses than definitive resolutions, they bring additional data and a higher degree of confidence to those hypotheses. Two of the four issues addressed in this report is described below.

Unit 3 RCIC System

In the Fukushima Accident, Units 1, 2, and 3 all ultimately suffered the melting of nuclear fuel in the reactor cores as the result of the loss of cooling power following the tsunami and the failure of both the off-site AC electrical power and the backup power that was being produced by diesel generators. But not all reactors behaved identically, and cooling power was lost at different times in different reactors.

In Unit 2, a component of the cooling system known as “reactor core isolation cooling” (RCIC), which is designed to maintain its function for basically four hours continued to operate for several days. But in Unit 3, the same RCIC system failed after 20 hours. Determining the reason for this earlier shutdown was deemed important for its potential to provide information that would improve the design of similar systems elsewhere (Figure 11).

According to the report, the Unit 3 RCIC system failed before its batteries were drained because a safety device designed to prevent the RCIC system from being damaged by high

turbine exhaust pressure seems to have operated exactly as it was designed to shut RCIC down.

Under normal reactor operations, this safety device prevents the RCIC system from being damaged. But in an emergency setting where all other cooling systems have failed, it may be better to let the RCIC continue operating even at the risk of damage. Therefore, the report says, steps will be taken to allow this “interlock” between the RCIC and the turbine exhaust pressure to be released in emergencies. This will enable the RCIC system to continue working in a situation where it is the only system available to protect the reactor core.

The finding should not be construed to suggest that the premature RCIC failure caused Unit 3’s meltdown. As was the case with the other two reactors, given the circumstances at Fukushima Daiichi after the earthquake and tsunami, all cooling systems would have eventually been lost. Its significance, rather, lies in understanding how to prevent premature shutdown of the RCIC system in future emergencies in reactors of similar design, both in Japan and elsewhere.

Extent of Unit 3 core damage

The report helped resolve a discrepancy between what engineers believed had happened inside Unit 3, based on various findings, and the analysis provided by computer programs. Based on the findings, it has been reevaluated that most of the melted core fuel had been dropped from the “Reactor Pressure Vessel” (RPV) to the “Primary Containment Vessel” (PCV) at Unit 3. The reeval-

uation was made after surveys revealed that the emergency water injection system known as “High Pressure Coolant Injection” (HPCI) had not supplied the initially estimated amount of water into the reactor. However, according to the analysis, even if all the melted core fuel had dropped to the PCV, the estimated maximum erosion of concrete mat did not lead to the breach of the PCV boundary. Further precise evaluation is currently being made with government support, to determine how deeply the fuel has eroded the concrete mat.

We will continuously try to 1) reveal the whole pictures of the accident such as figuring out the behavior of the reactors at the point of the accident etc., based on a systematic on-site survey and a simulation analyses, and 2) make use of the whole pictures, in order to enhance the safety, which is our duty as a nuclear operator, and develop the decommissioning of reactors. Also, we will work on the nuclear safety reform, and announce our progress on these approaches on a regular basis.

CONCLUSION

TEPCO are committed to the implementation of decontamination activities including the removal of rubble, and the management of the contamination status through radiation measurement, and reduction, in cooperation with concerned ministries and agencies to restore the environment damaged by the accident as quickly as possible, never wasting a single day.

Keeping firmly in mind that the safety of the workers and employees who are involved in the decommissioning operation is the highest priority, we are addressing the improvement of their work environment to increase efficiency through the reduction of exposure via decontamination, etc. and the reduction of their workload by simplifying protective equipment, and ensuring the thorough provision of facilities to support their physical and mental well being.

Gathering wisdom from various research institutes and companies inside and outside Japan, we are making the utmost efforts in the decommissioning operation, which is the first of its kind in the world. In addition, by leveraging the technologies and knowledge gained from such experience in variety of areas throughout the world, we will ensure that the lessons learned from

the accident continue to provide benefit in the future.

We will perform the decommissioning work seeking the understanding of the international community by ensuring sufficient openness, reflecting the advice and guidance given by international organizations and external experts.

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