Results of Deliberation to Formulate a Mid- and Long-Term Strategy for Cleaning Up the Fukushima Dai-ichi Nuclear Power Plant

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Advisory Committee for Formulating Mid- and Long-term Strategies to
Clean up the Fukushima Dai-ichi NPP of TEPCO
Atomic Energy Commission

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1. Introduction

The Tohoku District-Off the Pacific Ocean Earthquake and subsequent tsunami on March 11 2011 caused extensive damage to the reactor cores and reactor buildings of Units 1 to 4 at the Fukushima Dai-ichi Nuclear Power Plant of Tokyo Electric Power Company (TEPCO). Massive amounts of radioactive materials were released in the air from the damaged reactor cores, and contaminated vast areas mainly in Fukushima prefecture, and forced the residents in these areas to evacuate under the instruction of the Nuclear Emergency Response Headquarters to prevent radiation exposures. Many of them are still unable go back to their hometowns and have to live inconvenient and uncomfortable lives in various evacuation areas. Radioactive contaminations have been expanded since then, and great many people affected socially, economically and mentally by the accident. What is more, such a serious accident which has never seen on the light water reactors (LWR) has a much greater impact on global communities for uses of atomic energy.

This Advisory Committee expresses its heartfelt sympathy to the people affected by the accident, and taking these situations serious, recognizes an urgent need for the prompt and assured cleanup of the accident site.

The Government-TEPCO Integrated Response Office, set up by the government and TEPCO, announced the "Roadmap towards restoration from the accident at the Fukushima Dai-ichi Nuclear Power Plant of TEPCO" (hereafter referred to as the "Roadmap") in April. Since then, it has made decisions on various operations for an early restoration of the plant from the accident based on the Roadmap, including the installation of a stable reactor core cooling system and continuation of safe shutdown. The target of Step 1 in the Roadmap, "the radiation dose is in steady decline," has been achieved in July, and various efforts have been made to achieve the target of Step 2, "the release of radioactive materials is under control and the radiation dose is being significantly held down" within the year. If the Step 2 target is achieved, the reactor facilities (plant) will be in a stable condition, sufficiently decreasing the effects of radiation on the outside of the plant premises.

After the completion of Step 2, therefore, the efforts will be shifted from the stabilization of the plant to the assured continuation of the stabilized condition. The efforts will also made for cleanup operation including the repair of the damaged buildings, transfer of the spent fuel stored in the reactor buildings to safe places, and removal and disposal of damaged core fuel in the reactors. After that, the operation of decommissioning these units is to be evaluated. The related parties have to devote themselves with unflagging resolve to the planning and assured promotion of the mid- and long-term efforts which are essential to ease the uncertainties of local residents and restores the credibility of nuclear power generation in Japan.

Considering the cleanup work following the accident causing a serious damage to the reactor at the Three

Mile Island Nuclear Power Plant Unit 2 (hereinafter referred to as “TMI-2”) as a reference, it will take a fairly prolonged period of time to accomplish the cleanup operation at Fukushima with a prospected need for using highly advanced and world's first technologies.

The government, which has promoted the nuclear policy, should play a leading role to ensure the progress of this operation, and support the achievement of the mid- and long-term measures as early as possible in light of the importance of the assured implementation of difficult but crucial tasks of restoring the plant from the accident by TEPCO. In this context, the Atomic Energy Commission set up this Advisory Committee on July 21, 2011 for allowing the government to share a roadmap for the mid- and long-term efforts with TEPCO and determine the theses of technological development potentially effective for the promotion of the roadmap as early as possible. According to these objectives, the Advisory Committee started its activities on August 3, studied the roadmap for mid- and long-term efforts, selected the research and development (R&D) theses required for the promotion of the roadmap, and investigated into the allocation and system of R&D for seeking solutions. On November 11, the Advisory Committee made a draft of report summarizing the results of its investigation, and presented it for public comment.

In this report, created as described above, Chapter 2 provides, by making reference to the restoration work at TMI-2, a summary of the program for the mid- and long-term measures that can be assumed at present for the Fukushima Dai-ichi NPP where the situation is more serious than that of TMI-2 in that a multiple number of reactors had been severely damaged and contaminated with highly radioactive materials. Chapter 3 identifies the technological issues to be solved for conducting the restoration work, and selected the R&D theses potentially effective for solving these issues. Chapter 4 covers the implementation system of R&D for the mid- and long-term measures. Chapter 5 addresses the international cooperation in R&D for the mid- and long-term measures. Chapter 6 presents the recommendations across the mid- and long-term measures, and Chapter 7 the conclusion.

The Advisory Committee expects TEPCO, the government, industry and research institutions to make preparations as early as possible based on this report to adequately carry forward the difficult and long-term tasks at the Fukushima Dai-ichi NPP, conduct timely R&D, which will lead to the enhancement of nuclear safety in the world by gathering expertise and technologies at home and abroad, and promote effective collaboration and joint R&D with foreign countries. The R&D efforts presented in this report are prerequisite for implementing the mid- and long-term restoration measures at the Fukushima Dai-ichi NPP, and should therefore be promoted with firm resolve to produce useful results.

In addition, the Advisory Committee expects sustained communications among related parties for obtaining the consent of municipalities and local residents which is vital for implementing the mid- and long-term measures.

2. Mid- and Long-term Operation at the Fukushima Dai-ichi NPP

2-1. Basic Concept of Mid- and Long-term Operation

The Fukushima Dai-ichi NPP has been controlled to some extent in terms of thermal hydrodynamic behaviors after the completion of Step 2 of the Roadmap, but still in highly exceptional as a nuclear plant in that so many reactor facilities and parts of buildings were seriously damaged. Especially at Units 1, 2 and 3 which underwent core melting, it is likely that nuclear fuel had melted down with part of the in-vessel structures, and hardened again (becoming “fuel debris”) at the bottom of the reactor pressure vessel (RPV) with part of the fuel debris dropped from the RPV into the primary containment vessel (PCV). In addition, large amounts of spent fuel assemblies[1] and new fuel assemblies remain in the spent fuel pools (SFPs) at Units 1 to 4. The mid- and long-term operation is therefore aimed at removing these highly radioactive fuel assemblies and fuel debris from the reactors and storing them at safe places as early as possible to stabilize the plant facilities in safer conditions.

To promote the removal operation, thorough decontamination of the site is required to minimize potential risks to the public and job safety, as well as the technologies to meet the requirement of highly advanced remote control, and a complete simulation of work using mockups to cope with the situations that access to the work areas is extremely difficult due to extensive damage to the reactor buildings in hydrogen explosions, the presence of highly radioactive rubble inside and outside the buildings, high radiation inside the buildings due to diffusion of radioactive materials, and accumulation of highly radioactive waste water in basement areas. The policies on the control of exposures of workers to radiation and the assurance of occupational safety and health should be clarified to ensure the health of the workers on site, and meticulous management plans provided based on the policies.

At TMI-2, as the accident caused radioactive materials to diffuse in the reactor building, the building was contaminated with high levels of radioactivity and the basement areas were submerged in highly radioactive waste water. In these circumstances, access to the damaged areas was extremely limited. The initial efforts were, therefore, focused on decontamination. The reactor core was seriously damaged as in the case of the Fukushima Dai-ichi NPP, but most of nuclear fuel remained in the RPV in the form of fuel debris, which was eventually taken out from the RPV in about eleven years.

The Fukushima Dai-ichi NPP is of the boiling water reactor (BWR) plant, which has a markedly different structure from the pressurized water reactor (PWR) at TMI-2, especially the containment vessel.

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[1] A bundle of fuel rods injected with uranium pellets

Damage to the buildings and facilities by the accident is more serious in Fukushima Dai-ichi than in TMI-2. Taking in account the core melting in the reactor vessels at both plants, however, it might be of some help to review the restoration work at TMI-2 in pursuit of the ways of successful completion of the mid- and long-term measures at Fukushima Dai-ichi NPP as safely, surely and promptly as possible. The operation at TMI-2 is reviewed in Section 2.2, and based on this review, the mid-term operation at Fukushima Dai-ichi NPP is outlined in Section 2.3. The analysis of the major work of this operation, removing fuel assemblies and fuel debris from SFPs, is summarized in Section 2.4.

2-2. Cleanup Program at TMI-2 in the United States

(1) Outline of Cleanup Program at TMI-2

In the accident at TMI-2 in March 1979, primary cooling water was lost causing a meltdown of the core fuel and damage across the reactor. Soil contamination due to radioactive materials released from the building did not occur because the RPV and PCV, as well as the facilities and equipment of TMI-2 did not suffer serious damage.

Sequences of cleanup activities at TMI-2 were reviewed in various documents including the EPRI report[2]. The contents of the program were examined based on these documents.

The Cleanup Program at TMI-2 was divided into three phases: “Stabilization: Reactor core control, access to the PCV, water treatment, etc.,” “Fuel Removal: Reduction in the radiation exposure of workers, core dismantlement, waste management, etc.” and “Decontamination: Decontamination and disposal of wastes, etc.”

After the accident, the surface of equipment, floors and walls of the reactor building of TMI-2 were highly contaminated with the leaked primary coolant during the accident, and the radiation dose was especially high in the basement areas where contaminated water was accumulated. Accordingly, the first work was to decontaminate the reactor building. Since the RPV and PCV were not damaged, and most of fuel debris was accumulated inside the RPV, the RPV was submerged with water, and the RPV was opened from the top to remove the fuel debris.

The removal of fuel debris was comprised of the following steps: (1) Decontamination of the building, (2) Inspection of the reactor core using a fiberscope, etc., (3) Opening of the RPV from the top, (4) Sampling of fuel debris, (5) Inspection of the bottom of RPV, (6) Removal of in-core structures, and (7) removal of fuel debris. The operation was commenced in 1979, the in-core inspection was conducted about three and a half years later, the RPV was opened from the top about five and a half years later, the

[2] EPRI “The Cleanup of Three Mile Island Unit 2 – A Technical History: 1979 to 1990”

removal of fuel debris was started about six and a half years later, and completed in 1990, about 11 years later. The removed fuel debris was stored in specially designed containers, and loaded on the casks which provide double containment. The casks were transported by rail to the Idaho Nuclear Engineering Laboratory (INEL), and safely stored in the laboratory to the present. After the completion of the Cleanup Program TMI-2 has been put in the monitoring storage, and the condition will be maintained until TMI-1, now in operation, comes to the decommissioning stage.

The Cleanup Program started in March 1980 after an agreement of cooperation through the GEND (a four-organization implementation system) by GPUN (the electric power company owning TMI-2), EPRI (Electric Power Research Institute), NRC (U.S. Nuclear Regulatory Commission), and DOE (Department of Energy). The roles of these organizations are outlined below.

1) GPUN was responsible for determining the Cleanup Program, reconstructing the site, gathering data, developing systems and equipment, and performing related engineering.
2) NRC reviewed the technical evaluation reports and safety evaluation reports submitted from GPUN, examined the final safety analysis report, opened an on-site office where a full time staff monitors the work, and held the Advisory Panel for exchanging opinions with local communities, engineers and politicians in order to mitigate psychological effects of the accident on local residents and politicians.
3) EPRI supported R&D efforts for decontamination technologies, remote control technologies and analysis and assessment for clarifying the cause of accident, and worked on the industry for feedback of the results.
4) DOE was responsible for handling high level radioactive wastes, gaining access to the reactor vessel, removing fuel debris, and conducting R&D including the clarification of the course of accident. The important cause of giving approval to R&D theses was, it said, not to support the electric power company, but to think of national interests first. DOE accepted fuel debris removed from the reactor and certain radioactive wastes, which did not meet the acceptance criteria stipulated for the commercial repositories of radioactive wastes, for future R&D. This decision was said to have rescued the TMI nuclear power plant from being a long-term dump yard, and helped a smooth implementation of cleanup projects.
5) GPUN constantly changed its implementation system from the very beginning of the occurrence of the accident up until the removal of fuel debris to meet varying situations. A technical assistance and advisory group, consisting of third parties, was also set up for technical review and support, and a safety advisory board for review of the health and safety of workers.

(2) Funds for TMI-2 cleanup projects

After the restoration from the accident, GPUN spent 180 million dollars out of the casualty insurances of around 300 million dollars for decontamination by December 1981, but did not yet begin the decontamination of the reactor containment vessel. DOE gathered information concerning the nuclear accident since 1980 in cooperation with GPUN, NRC and EPRI. It also proposed a R&D project in the 1982 budget mainly aiming at 1) developing apparatuses and methodologies to examine fuel debris in the reactor vessel, 2) removing and examining fuel debris, and 3) conducting experiments about purifying radioactive waste water and solidifying collected radioactive waste. For this project of removing fuel debris to complete cleanup, GPUN required providing at least 600 million dollars, but this might result in the bankruptcy of GPUN if it failed to provide the fund and no help was offered. Finding the financial resources therefore was the crucial issue. Since power generation is a public utility, the bankruptcy of GPUN meant a reorganization of power companies, including the GPUN, in this area, and the dominant opinion was that this might delay various restoration tasks and increase the burden of consumers who paid the electric bill. Thus the other ways of finding the financial resources including the following were discussed[3]:

1) Raising the charge of uranium enrichment by the federal government and allocating the surplus.
2) Increasing the insurance payment by reassessing the nuclear insurance to increase the premium.
3) Raising the electric bill in the service areas, namely, Pennsylvania and New Jersey, and decreasing dividends to the shareholders of GPUN.
4) Support by the federal government, which has encouraged nuclear power generation by private utilities, through adequate R&D contributing to the acquisition of expertise on the operation of nuclear reactors and the disposal of high-level radioactive wastes from the accident, facilitation of cleanup activities, improvements in the safety and reliability of future nuclear power generation and decreases in the cost of nuclear power generation.
5) Funding by the group of utilities most affected by the accident in consort according to their commitment to continue nuclear power generation in the future, and supply manpower.

To avoid a stalemate of the discussion, then Pennsylvania Governor Thornburgh suggested in July 1981 that the federal government, the states of Pennsylvania and New Jersey, power suppliers, GPUN and its customers share the remaining cost. This suggestion was accepted, and a support scheme

[3] USGAO: EMD-81-106: Greater Commitment Needed To Solve Continuing Problems AT Three Mile Island, August 26, 1981.

combining the measures described above was determined. Accordingly, GPUN took charge of $367 million, the power suppliers $171 million, the state governments $42 million, the insurance $306 million, and DOE $76 million. The funds spent on the Cleanup Program totaled $973 million.

The Japanese version of the Cleanup Program, a Japan-U.S. WR (water reactor) Study Committee was set up mainly by electric utilities and nuclear power plant manufacturers[4], and the task force in Japan dispatched personnel and provided partial funding ($18 million) upon agreement with DOE..

NRC reported in May 2011 that the evaluated cost of decommissioning TMI-2 was about $837 million (about 660 million yen/10MWe).[5]

(3) Reflection of operation at TMI-2 into the mid- and long-term measures at the Fukushima Dai-ichi NPP

The damage at the Fukushima Dai-ichi NPP extended to the reactor cores and PCVs of Units 1 to 3, and the reactor buildings of Units 1, 3 and 4 were damaged in hydrogen explosions. The extent of damage at the Fukushima Dai-ichi NPP is more seriously than that at TMI-2, but some conditions such as high levels of dose in the reactor building, accumulation of contaminated water in basement areas, severe damage to reactors, and presence of fuel debris at the bottom of the RPV are similar at both plants. This suggests that the methodologies and technologies used at TMI-2 could also be used to the Fukushima Dai-ichi NPP. There should be many other lessons that can be learned from the entire operation at TMI-2 including the systems, costs and relations with local communities. Key items deprived from TMI-2 are listed below.

・ In addition to the nuclear operators, all related organizations participated in the Cleanup Program under the active leadership of the federal government (DOE).
・ Special techniques including remote control were employed for decontamination and removal of fuel debris.
・ The costs of removing fuel debris were shared by the responsible nuclear operator, the power suppliers and the federal and local governments concerned.
・ R&D projects which contributed to national profit when accomplished were financed by the federal government. The projects also received international cooperation and funds.
・ A special conference was established for support and reviews by third parties.

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4 The manufacturers which have experienced to built nuclear power plants.
5 http://www.nrc.gov/info-finder/decommissioning/power-reactor/three-mile-island-unit-2.html (Exchange rate: \76/dollar)

- The federal government provided the opportunities of exchanging opinions with local communities as part of its endeavor to ease the citizen's apprehension.
- To share the lessons learned from the accident with the nuclear operators in the world, and transfer them down to future generations, detailed reports addressing the whole incident, including the progress of discussions about the cause of accident, methods of removing fuel debris and handling wastes and cost sharing were issued and widely released to the public.

2-3. Setting Targets and Tasks in the Mid- and Long-term Measures

The reactor buildings and facilities inside at Units 1, 3 and 4 of the Fukushima Dai-ichi NPP were damaged in hydrogen explosions. The presence of highly contaminated water in the turbine buildings of Units 1 to 3 was confirmed. It was estimated that the circulated cooling water leaked out from the RPV into the bottom of the reactor building through the PCV and further to the turbine building.

Repairs of damaged facilities are prerequisite for restoring the building's characteristics of confining radioactive materials and allowing the work under water in the same manner as TMI-2. In the sequence of work, highly radioactive materials have to be handled in unusual and severe conditions. Minimizing potential risks to the public safety such as unexpected accidents, and providing sufficient measures to ensure the safety of workers must be taken into consideration.

Many works are presumed to be done in highly radioactive conditions. In order to reduce the radiation exposure of workers, remote controlled equipment and robot technology need to be developed depending on the level of work or as common basic technologies.

The operation from the completion of Step 2 up to the beginning of decommissioning (dismantlement) was investigated based on the Cleanup Program at TMI-2 and the above perspective, and five tasks (1) to (5) listed below were determined to be carried out in sequence or concurrently. It should be noted that these tasks are subject to review according to the on-site conditions or progress of R&D in the future.

(1) Discharge of fuel assemblies from SFPs

- The SFP is installed at the top floor of the reactor building. A total of 3,108 fuel assemblies (of which 2,724 are spent fuel assemblies) are stored in the SFPs of Units 1 to 4.
- Results of investigation to date indicate that the ceilings and walls around the SFP were severely damaged, the fuel handling machine (FHM) was inoperable due to hydrogen explosions, and all reduced to rubble (Units 1, 3 and 4), but the analysis of pool water shows that most of fuel assemblies are undamaged, and the structural strength of the pool is retained. Considering the long-term integrity of fuel assemblies, which have been exposed to seawater

(Units 2, 3 and 4), and damage to the reactor buildings (Units 1, 3 and 4), it is crucial to remove these fuel assemblies as early as possible.

- The discharged fuel assemblies are stored in transport containers, and moved to and stored in the common spent fuel pool in the premises of the Fukushima Dai-ichi plant (hereinafter referred to as the “common pool”). To make space for the discharged fuel assemblies, the normal fuel assemblies held in the common pool at present are loaded to dry casks and moved to elsewhere in the plant premises for the time being.
- Long-term effects of being exposed to seawater are taken into account in handling the fuel assemblies transferred to the common pool.
- The discharge of fuel assemblies from SFPs is done in five steps of work: 1) removing rubble at the top floor of the reactor buildings, 2) installing a crane and a cover (or container) as an infrastructure for minimizing the release of radioactive materials and discharging fuel assemblies, 3) producing or procuring transport containers and storage canisters for discharged fuel assemblies, 4) carrying out and temporarily storing the fuel assemblies held in the common pool at present for making space for the discharged fuel assemblies and remodeling the common pool, and 5) discharging fuel assemblies from SFPs for storage in the common pool.
- TEPCO plans to start discharging fuel assemblies from SFPs after the completion of Step 2, and accomplish the work within three years.

(2) Preparatory work for removing fuel debris

- The preparatory work is required for Units 1 to 3. Unit 4 is excluded because all reactor fuel had been transferred to the SFP for annual outage before the accident. A total of 1,496 fuel assemblies were loaded in the reactor in three units, and all reactors were damaged to their core. Part of the core was likely to have turned into re-solidified debris (fuel debris) after in-core structures had melted with fuel assemblies. Moreover, part of molten debris seemed to have flowed out from the bottom of the RPV to the PCV and accumulated at the bottom as fuel debris. There are presumably large amounts of fuel assemblies which have not been melted but extensively damaged. The in-core structures and control rods are also assumed to have been seriously damaged or melted.

- All of the preparatory work required to start the removal of fuel debris is conducted in the highly radioactive reactor buildings. There are so many technical issues to be solved, and the selection of the decisive methodologies is difficult at present, but similar to the methods used in the Cleanup Program at TMI-2, preparations for the removal of fuel debris under water, which provides good shielding against radiation, seems to be most realistic.
- Preparatory work for removing fuel debris consists of eight steps: 1) decontaminating the reactor buildings, 2) identifying leak locations in the PCV and inspecting internal conditions of the PCV from outside, 3) stopping water leak from the reactor building and repairing the lower part of the PCV, 4) flooding part of the PCV with water, 5) inspecting the inside of the PCV and sampling, 6) repairing the upper part of the PCV, 7) flooding the PCV and RPV with water, and 8) inspecting the inside of the RPV and sampling.
- There was no problem to fill the RPV with water (water flooding) in case of the Cleanup Program at TMI-2, but at Units 1 to 3 in the Fukushima Dai-ichi plant, a considerable difficulty is predicted in flooding the RPV with water. This is because the presence of water highly contaminated with radiation was confirmed in the turbine buildings. It was hypothesized that the circulated cooling water leaked from the PCV flowed into the bottom of the reactor building and further to the turbine building. R&D is planned for stopping leaks of the contaminated water and fill the PCV with water, but in case that water flooding is unsuccessful, additional R&D is required to solve problems such as the way to restrict extremely strong radiation from fuel debris. By sufficiently recognizing the need for changing the plan when the method considered as applicable now is found to be difficult for implementation in the future, alternative methods should also be investigated as early as the R&D stage.

(3) Development of fuel debris removing techniques and procedures

- Similar to the methods employed in the Cleanup Program at TMI-2, a technique to install a shielded platform above the RPV to remove fuel debris will be developed. The technique is applied to remove fuel debris after the RPV/PCV is filled with water. The removed fuel debris is stored in specially designed containers and loaded on dry casks for transfer to the common pool.
- At TMI-2, the removal of fuel debris was started about six and a half years after the accident, and completed about eleven years later. Considering the level of accident at the Fukushima Dai-ichi NPP, which is more serious than that of TMI-2, it may take more time to complete

the removal of fuel debris.

- Handling and disposal of removed fuel debris should be examined from various perspectives including the discussions of how the nuclear fuel cycle in Japan should be in the future. The involvement of the government for enforcing safety regulations is also essential.

(4) Assurance of public and job safety

- The efforts of Step 2 should be continued from the mid- and long-term perspective. This includes sustained and stable cooling of the reactor vessels (cold shutdown condition), prevention of hydrogen explosions, sustained and stable processing of contaminated water, reduction of the total amount of accumulated water, prevention of contamination from spreading to the ocean, reduction of radioactive materials released in the air, and preparations against natural disasters (earthquake, tsunami, etc.) to minimize damage.
- The potential risks to the public in individual tasks, such as the release of radioactive materials from the removed rubble or the recurrence of criticality accident caused by a decreased level of cooling water for fuel debris should be considered, and suitable means to reduce these risks taken. The authorities enforcing safety regulations require ensuring the adequacy of the measures taken by the nuclear operators in time.
- Issues such as the maintenance of the integrity of RPVs and PCVs, investigations into stabilized storage, treatment and disposal of secondary wastes produced by the treatment of contaminated water, treatment and disposal of radioactive wastes produced in the course of work, and disposal of radioactive wastes stored in the plant premises should also be studied. The involvement of the government in making policies and regulations concerning radioactive wastes is essential.
- There are many high dose spots at present both inside and outside of the reactor buildings, and countermeasures such as decontamination and shielding, and remote operation techniques using robots have been taken for decreasing the effects of radiation. Improvements in these techniques are desired for use in the operation of the mid- and long-term measures which is expected to be performed in the same severe, highly radioactive conditions.
- It is also essential to decontaminate the reactor buildings and improve the work conditions. Remote control is used in principle for the work in high radiation dose and high contamination, but manpower is used for the work in which remote operation is difficult. Measures to protect workers are needed. To reduce the radiation exposure of workers, it is necessary to simplify the work procedure and shorten the working time.

(5) Investigation of the cause of accident, evaluation of reactor behaviors in the course of damage, etc.

- Clarification of the progress of the severe accidents at Units 1 to 3 will significantly help evaluate the conditions and properties of fuel debris in the reactors, and make the work procedure including the removal of fuel more appropriate.
- This will also contribute to the investigation of the cause of accident at the Fukushima Dai-ichi Nuclear Power Plant, as well as improvements in the safety and reliability of nuclear power generation at home and abroad.

2.4 Analysis of Discharge of Fuel Assemblies from SFPs and Removal of Fuel Debris from RPV/PCV

The previous sections give as much detail as can be assumed at present concerning the discharge of fuel assemblies from SFPs and removal of fuel debris from RPV/PCV, which is the major work in the mid- and long-term measures, and this section addresses the concept of the work, the flow of work, potential issues in each process, techniques and data to solve these issues, and important notes for ensuring safety. Tables 1 and 2 show the results.

(1) Procedure of discharging fuel assemblies from SFPs

1) Removing rubble scattered at upper part of the reactor buildings

The upper part of the reactor buildings of Units 1, 3 and 4 were destroyed in hydrogen explosions, and rubble scattered on the refueling floor[6]. It was confirmed that part of rubble had dropped into SFPs. The removal of rubble is required prior to the discharge of fuel assemblies. Heavy equipment such as a large crane is installed outside the building for lifting the rubble, mainly consisting of fractures of steel beams and concrete structures of the roofs and walls of the building, from the top of the building.

Adhered radioactive materials are likely to be released in the air as the rubble is removed. To prevent this, anti-diffusion measures and monitoring of radiation are required. To minimize the exposure of workers to highly radioactive rubble, countermeasures such as remote operation or shielding of the operator's seat are also required.

2) Installing a cover (or container) and crane, etc.

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[6] Refueling floor: A work area at the top floor of the reactor building. Facilities such as the spent fuel pool are installed there.

Installing a cover or container over the reactor building improves the work conditions, ensures the safety of workers during the removal work, and eliminates the effects of the weather. Inside the cover/container, an FHM and a crane are installed for handling fuel assemblies and carrying the transport container in which fuel assemblies are stored. The FHM and crane need to be designed to provide a drop prevention mechanism to prevent the fall of fuel assemblies and transport containers.

3) Producing/procuring transport containers/canisters for removed fuel

The existing cask loading system is used for transferring fuel assemblies from SFPs to the common pool, but the transport containers, canisters and other required facilities are to be designed and produced.

4) Keeping space for storage in the common pool and remodeling

The normal fuel assemblies stored in the common pool are loaded in the dry casks and kept temporarily in the plant premises to make space for the discharged fuel assemblies. It is likely that the fuel assemblies taken out of the SFP contain salt, and are physically deformed or damaged. To avoid negative effects of these fuel assemblies on normal ones and the common pool facilities, countermeasures and remodeling of the pool structure are required as appropriate before putting the discharged fuel assemblies into the common pool.

5) Discharging fuel assemblies from SFPs

Installing an FHM and a crane for discharging fuel assemblies from the SFP is the same procedure as used in the normal operation at BWR[7]. The discharged fuel assemblies need to be checked for their integrity by means of visual inspection and loading tests before being stored into the transport container. The fuel assemblies which fail the inspection or test are put into a canister and loaded onto the transport container for transfer.

(2) Preparations for removing fuel debris and removal of fuel debris

1) Decontaminating the reactor building

The results of investigations into the inside of reactor buildings to date confirmed the existence

[7] Normal procedure of removing fuel assemblies at a BWR:
The crane lifts the transport container up to the refueling floor, and lowers it into the pool. The FHM stores fuel assemblies into the transport container under water. The crane lifts the transport container from the pool, and lowers it to the ground. The container is then carried out from the reactor building.

of high dose spots ranging from 100 to 1000 mSv/h and rubble scattering inside the buildings. To allow workers to go in the reactor building which is highly likely from time to time in the course of removing fuel debris, the removal of rubble and decontamination of the work areas are essential. The most suitable decontamination method, such as high pressure water injection, coating or surface chipping, is used according to the level of contamination. Workers are assumed to go in comparatively low dose areas, but remote control is required for high dose areas. In this case, the remote control technique is used with the state of rubble taken into consideration. Shielding and other means are required to minimize the radiation exposure of workers during decontamination with anti-diffusion measures to prevent the likely release of radioactive materials from the rubble.

2) Investigating leak spots and internal state of the PCV from outside

Removing fuel debris under water is the most effective way in terms of shielding as used at TMI-2. Identification of leak spots on the RPV and sealing them are difficult if the RPV is inaccessible, and part of the fuel debris is likely to accumulate in the PCV. Taking these into account, repairing the PCV and flooding water in the PCV with the RPV in it are considered most effective for removing fuel debris. The leak spots are assumed to be narrow and submerged in high dose water. Techniques for remote access to the right locations and leak detection are required.

3) Sealing leaks of the reactor building and repairing the lower part of the PCV

When the leaks from the PCV to the reactor building, and from the reactor building to the turbine building are located in the previous step, the technique to seal the leaks under water with water flowing is required. Before the leaks from the reactor building are sealed, the source of water for circulating injection cooling needs to be switched from the basement of the turbine building to the basement of the reactor building. Technical difficulty of sealing leaks on the PCV is predicted, and depending on the leak conditions, other means such as filling part of the reactor building including the leak spots and surrounding areas with sealing materials may be needed.

Alternative ways should always be considered in case of failure to stop leaks from the reactor building or PCV.

4) Flooding part of the PCV with water

After the leaks from the lower part of the PCV are sealed in the previous step, the source of water for circulating injection cooling is switched from the lower part of the reactor building to the PCV, and water is filled in the PCV gradually while the water level is controlled. When the PCV is filled with water, the relative amount of water moderator to fuel debris, presumably having flowed into the PCV, may change and the potential risks of fuel debris leading to a criticality accident increase. Techniques to prevent and monitor criticality accidents are required.

5) Investigating the inside of PCV and sampling

Following the partial flooding of the PCV with water in the previous step, the inside of the PCV is investigated. It is predicted that the inside of the PCV is highly radioactive, and the contaminated water in the PCV is cloudy. Under these conditions, a remote inspection technique is required to understand the distribution of fuel debris inside the PCV. This requires a through-hole drilled on the PCV from outside with a technique to prevent the water inside the PCV from spattering through the hole.

When the location of fuel debris is identified in the above inspection, the fuel debris is sampled for examining its properties. A remote sampling technique is required as in the in-vessel inspection.

6) Repairing the upper part of the PCV

Flooding the PCV with water is assumed to submerge the RPV for removing fuel debris. The preparation work includes repairs of the upper part of the PCV. The areas requiring repairs are narrow, and remote control is used for repairing high dose sections. This means a remote repairing technique is required. Workers are assumed to go in comparatively low dose areas. Shielding or other means to minimize radiation exposure of workers is required.

7) Flooding the PCV/RPV with water

Following repairs of the upper part of the PCV in the previous step, the RPV and PCV are filled with water. This process may change the relative amount of water moderator to fuel debris in the RPV and increase the potential risks of fuel debris leading to a criticality accident. A technique to prevent and monitor criticality accidents is required. After water is filled to a level of sufficiently shielding radiation from fuel debris, the PCV and RPV are opened from the top to remove the steam separator and free moisture separator. To prevent the release of radioactive materials in the air in the sequence of opening of the PCV and RPV, a cover (or container) is installed on the reactor building.

8) Investigating the inside of RPV and sampling

After flooding with water, opening the RPV from the top, and removing in-core structures in the previous steps, a work platform is installed on the refueling floor to investigate the inside of the RPV. It is predicted that the inside of the RPV is highly radioactive, and the water contained in the RPV is cloudy. Under these conditions, a remote inspection technique is required to understand the distribution of fuel debris inside the RPV. Sampling of fuel debris follows the confirmation of the state of fuel debris in the in-vessel inspection for examining its properties, and as in the in-vessel inspection, a remote sampling technique is required. The work on the platform is assumed to be done by workers. Sufficient shielding of workers is required to minimize the exposure of workers to radiation from the fuel debris.

9) Providing techniques and procedure of removing fuel debris

Fuel debris is removed from the work platform installed on the refueling floor. The removed fuel debris is stored in specially designed storage canisters and transferred to a specified place. The record at TMI-2 indicates that the fuel debris has hardened. In this case, various processes are assumed. The hardened fuel debris may need to be crushed into pieces with a drill or cutter and carried into the canister with a holder or suction apparatus. A remote control technique is required for this work. There is a possibility that part of fuel debris has flowed out from the RPV into the PCV. A technique to collect this portion of debris is required. There is also a possibility that the removal of fuel debris may change the relative amount of water moderator to fuel debris and increase the potential risks of fuel debris leading to a criticality accident. A technique to prevent and monitor criticality accidents is required.

3. R&D Theses Useful for the Mid- and Long-term Operation at the Fukushima Dai-ichi NPP

3-1. Selection and Classification of R&D Theses

Based on the analysis in Section 2.4 of every possible process assumed at present for the removal of fuel assemblies from the spent fuel pool and preparation and removal of fuel debris, the issues on every step of work were identified based on the data required for the work, risks caused by the work, problems not directly relating to the work but to be solved in the long run, and nuclear nonproliferation, in addition to the issues which may disturb the work. The issues to be discussed throughout the mid- and long-term measures are classified as the risk management issues on the public and job safety. Issues on the clarification of the cause of accident were also identified.

The technologies and data required for solving the issues identified were discussed, and application of existing technologies and data was assessed. Table 3 lists the resulting R&D theses.

Table 3 suggests that the remote controlled equipment and robot technology need to be developed for various purposes to minimize the radiation exposure of workers. Development of special tools may also be needed according to the purpose, type and condition of remote operation. Common element and basic technologies, applicable to various fields and meeting various needs, are to be identified to raise the effectiveness of the development activities by taking into account the modularity and standardization of general-purpose functionality that can be used for various applications. When the vertical axis represents the work processes, the horizontal axis may represent the common technologies developed for remote control in these processes (cross sectional technologies). From this point of view, common issues were identified for effective development. Table 4 summarizes the result.

With the progress of work, other issues may come into existence or switching to alternative methods may be required. The R&D theses are therefore reviewed as needed.

3-2. Mid- and Long-term Roadmap on R&D

The R&D theses selected in the previous section can be classified as those to be started in early stages, those to be started from the basic R&D as long-term issues, and those to be discussed as the R&D theses following the results of the precedent R&D based on the level of technological difficulty and other factors. To apply the R&D results to on-site work in an efficient way, the schedule of on-site work and that of R&D are coordinated according to their correlation.

Taking these matters into account, the required time to start the R&D theses, identified in the previous section, was assessed, and the mid- and long-term roadmap for the R&D towards the start of the removal of fuel debris was determined as shown in Table 5. There are many uncertainties in determining targets along the time table based on the concrete ground at present, but from the above perspective, the targets were set for starting the discharge of fuel assemblies from the SFP in three years, and starting the removal of fuel debris in 10 years in this roadmap.

Even if the removal of fuel debris is started as scheduled, it is estimated to take more than 30 years to complete the decommissioning of all reactors, considering that the fuel debris has to be removed from three reactors, Units 1 to 3, before decommissioning can be started, and the normal decommissioning of a reactor usually takes 15 years even in the standard processes.

In carrying out the roadmap, the parties concerned should be fully aware of the presence of many uncertainties from the beginning up to the removal of fuel debris as described above, carry forward in stages based on the results of site analysis and R&D, provide alternative methods, and flexibly change the direction according to the circumstances. For these purposes, the roadmap sets the hold points for verifying the results of technological development applied to the subsequent processes from time to time, determining when to start the next process, checking the progress of R&D, and reviewing or evaluating the processes including the subsequent processes and the flow of work. To promote the operation, a research management system will be set up for coordinating on-site work and R&D activities to implement flexible and accurate R&D through the “check and review” of the one-site conditions and technological forecast at each hold point.

3-3. Basic Policies on R&D

The previous section describes the creation of a roadmap and sets the target time to start removing fuel debris within 10 years from the completion of Step 2. To make efforts to proceed steadily and achieve the target according to the roadmap, the engineers engaged in R&D must be clearly aware of and observe the basic policies shown below.

(1) Efficiency

- Make the best of existing technologies and expertise to save the time and resource, actively acquire and utilize advanced technologies at home and abroad, and seek advice from overseas engineers having similar experience and knowledge especially at TMI-2.
- Conduct preliminary tests using mockups to prevent on-site do-over.

(2) Flexibility

- Stand on the “analysis and judgment” basis to keep the judgment up to date while reflecting the results of on-site investigations into the application of element technologies.

- Provide alternative methods in a flexible and impromptu manner if the planned method is not applicable, and use available facilities as far as appropriate.

(3) Priority

- Give priority to R&D required for on-site work, and start R&D for enhancing technologies in parallel to the commencement of on-site work.

(4) Contribution

- Improve Japan's technical strength and foster engineers through R&D.

(5) Protection of intellectual properties

- Protect intellectual properties in handling the results of R&D while ensuring transparency.

4. Promotion of R&D

4-1. Basic Concept

It is very important to establish an appropriate system of conducting R&D according to the basic policies described in Section 3-3. The basic concept for establishing the system was examined and the results are summarized as follows:

- Establish a system not bound by tradition and open to the world to allow flexible and prompt progress of work by gathering knowledge and expertise from specialists and industries at home and abroad (including the adjustment of international cooperation programs) to address extremely difficult and unusual situations in the world.
- Establish an organization responsible for supervising and promoting the whole R&D, and define the responsibility and authority of subordinate organizations.
- Review the programs and systems in a flexible manner according to the progress of the entire operation, and use the PDCA cycle including partial revision and abolition across the R&D program.
- Feed back on-site needs at Fukushima Dai-ichi NPP and results of application of developed techniques and processes into R&D promptly and properly, and review related R&D activities in a flexible manner. From this perspective, the TEPCO engineers should take the primary role in the execution of individual R&D activities.

4-2. The framework of R&D Promotion

Based on the concept in the previous section, setting up a hierarchical administration system for management by layers is effective for reviewing a large number of R&D activities according to their progress and adjust the related R&D activities in a flexible manner.

The hierarchical system may be comprised of three layers: 1) "Team" to conduct an R&D activity, 2) "Project" for adjusting the teams that interact with one another, and 3) "R&D Promotion Office" to supervise the projects and manage the whole R&D program. These layers can be defined as follows:

(1) R&D Promotion Office

1) Purpose and responsibility

The R&D activities relating to the mid- and long-term measures are promoted by the teams domestically and internationally considered as most suitable to acquire the maximum outcome with least cost, and the results fed back directly and indirectly to the field operation for a prompt and assured transition of work to the decommissioning of reactors at the Fukushima Dai-ichi NPP. To achieve this, it is extremely important to promote effective R&D in a comprehensive and systematic manner based sufficiently on the total on-site condition and schedule, and inhibit individual researchers to pursue the result for their own sake or research for the sake of research. The R&D Promotion Office which exercises the leadership is specifically responsible for the following:

- Determine the entire planning including the revision and abolition of individual R&D theses.
- Formulate and consolidate the budget for the total R&D program relating to the mid- and long-term measures, and make requests for required budgetary allocation to the related ministries and agencies.
- Set up most suitable projects to assure effective and quick execution (including the selection of project leaders).
- Accept international cooperation offered by distinguished and prominent overseas R&D institutions for effective operation.

2) Organization

The members of the promotion office include the government (Ministry of Economy, Trade and Industry, Ministry of Education, Culture, Sports, Science and Technology), Tokyo Power Electric Co., Inc., experts who have in-depth knowledge of the design and construction of Fukushima Dai-ichi Nuclear Power Plant, Japan Atomic Energy Agency (JAEA) and academic experts, etc.

- The government appoints an adequate person as the general manager of the R&D Promotion Office who is responsible for the entire R&D program.
- The required staff is assigned to the R&D Promotion Office to work on the above-mentioned R&D project management.

(2) Project

1) Purpose and responsibility

The project is comprised of relating R&D teams for keeping R&D issues in order and managing the teams, and responsible for:

- Inspecting the progress of the teams on a regular basis, coordinating the work across the teams, and checking the hold points to determine the technologies to use and evaluate them on the actual equipment.
- Determining the need of using alternative methods based on the progress of R&D and

application and evaluation of actual equipment.

- Setting up a sub-project for cross sectional management as appropriate including the development of remote control equipment and robots.

2) Organization

- Adequate members are selected according to the nature of the project.
- The project leader is responsible for the whole project.

(3) Individual R&D activities (team)

The body of execution for the selected R&D theses may differ according to the objective. The teams were divided into two categories according to their objectives, and the execution system of these teams was examined:

A) R&D closely relating to actual operation of the plant

The development of individual methods and equipment required for the processes of work up to the removal of fuel debris is classified into this category. As R&D is conducted based on the site information, TEPCO, the owner of the plant responsible for on-site work, and the manufacturers who are familiar with the power plant and own advanced technologies (hereinafter referred to as the "manufacturers in charge of development") may undertake the central role.

B) Basic R&D conducted concurrently with the above R&D

The basic R&D, conducted concurrently with the R&D closely relating to on-site work at the plant, is required for solving various problems, and acquiring data useful for the studies contributing largely to the nuclear energy field and for the development of national policies.

Expertise of engineers and resources of the R&D organizations which have own infrastructures can be used for these purposes. Although the basic R&D is aimed at studying basic and core technologies, cooperation with TEPCO is required for taking on-site needs into account in assessment.

Figure 1 shows the conceptual diagrams of execution systems for promoting R&D.

The R&D Promotion Office is expected to be operated as one of specialized organizations for achieving an effective and integrated management for a prolonged period of time. It makes use of the framework of the existing organizations for its activities for the time being, but flexible arrangements of the organization is required as early as possible without being constrained by convention to obtain the maximum outcome.

5. International Cooperation

As described before, gathering knowledge and expertise at home and abroad is required for effective and efficient operation of the mid- and long-term measures at the Fukushima Dai-ichi NPP. In addition to obtaining technological perspectives in various fields in Japan, international cooperation is also crucial for utilizing the overseas knowledge and experience including the countermeasures for the accidents at TMI-2 and in Chernobyl.

The overseas technologies available at present have already been used for processing the contaminated water on the commercial basis, and it is also important for the government to actively disclose information in Japan and across the world for international cooperation in broader sense. The government is expected to take a leading role in this activity by keeping the following notes in mind:

- Many issues are the first kind in the world and difficult to handle. To make use of knowledge and expertise gathered from around the world, disclose the information on all programs and efforts in the mid- and long-term measures including R&D issues widely on time to keep the public informed.
- Establish a system of evaluating accurately the possibilities of cooperation, including information, advices and money, by the government agencies in the world, international bodies and private industries, and conducting effective and efficient R&D, and incorporate the useful equipment and systems in the world into R&D flexibly and promptly. Avoid an easy procurement of the equipment and systems from abroad, and consider a long-term reliability and compatibility of these equipment and systems with domestic technologies
- The expertise and know-how accumulated as a result of R&D will result in the improvement of technical capabilities of the participating companies and laboratories in Japan, and contribute not only to the response to the accident at Fukushima Dai-ichi NPP, but also to the future nuclear safety both in Japan and abroad. In light of this perspective, carefully handle the results of R&D including the intellectual properties.

6. Recommendations throughout the Mid- and Long-term Measures

This Advisory Committee was set up for organizing the roadmap for the mid- and long-term operation and identifying the R&D issues. Chapters 3, 4 and 5 mainly deal with R&D issues and partially provide the recommendations for assuring safety. Many opinions on the system of operation and on-site work were presented in the course of discussion. As described in Section 2 of Chapter 2, the results of investigating TMI-2 were examined to feed back not only to the R&D issues but also to the whole operation of the mid- and long-term measures.

In this context, the Advisory Committee determined to present the following recommendations relating not only to the R&D issues but the issues to be tackled throughout the mid- and long-term measures:

- The government shall be aware of its responsibility for the safe and secure execution of mid- and long-term measures including the treatment and disposal of radioactive wastes until the completion of decommissioning operation, make utmost efforts to provide all necessary means including manpower, funds, materials and resources for conducting the mid- and long-term measures, build necessary institutions and systems for assuring the public and job safety, and supervise and give appropriate guidance to business operators. It shall also keep not only the municipalities concerned but the people across the nation informed on the current efforts and prospects of the mid- and long-term measures in a straightforward manner.
- The business operator shall built a complete system of operation that includes radiation prevention measures to conduct the mid- and long-term tasks, many of which are the world first challenges, safely and promptly, make a work plan through sufficient consultation with the safety regulation bodies at an early stage before beginning the operation, and provide information on time to set up rational regulations and judgment.
- The government shall provide security in sufficient coordination with related organizations including the IAEA.
- It is important for the government to ensure transparency of the whole operation through the mid- and long-term measures for maintaining the safety and adequacy from the viewpoint of experts, municipalities concerned and general public. The government shall therefore establish an organization comprised of third parties to assess the state of operation. The said organization shall take the opinion of the local residents concerned into the assessment through public hearings and other means.
- Analysis of properties, testing and other processing of fuel debris and radioactive wastes are

required in various phases of mid- and long-term measures, but there is a strong possibility that the work on side will be delayed whenever inspection needs occur and samples are sent to the laboratories outside the plant. To prevent this, the laboratory facilities for analysis and testing shall be provided in the vicinity of the Fukushima Dai-ichi NPP.

- There are many unprecedented challenges including the use of remote equipment in the mid- and long-term measures. Verification in mockup facilities may be effective for checking on-site operation. It is recommended to provide the facilities for verification around the site.
- In conducting the mid- and long-term measures, the cause of accident, technical details of mid- and long-term measures, results of on-site investigations and other details shall be recorded and widely made available to the public to ensure nuclear safety in the future.
- In conducting the mid- and long-term measures and R&D, efforts shall be made with the prospect that the operation contributes to the establishment of new industries which act as the nucleus of the future community development, creation of new jobs, and cultivation of human resources.

7. Conclusion

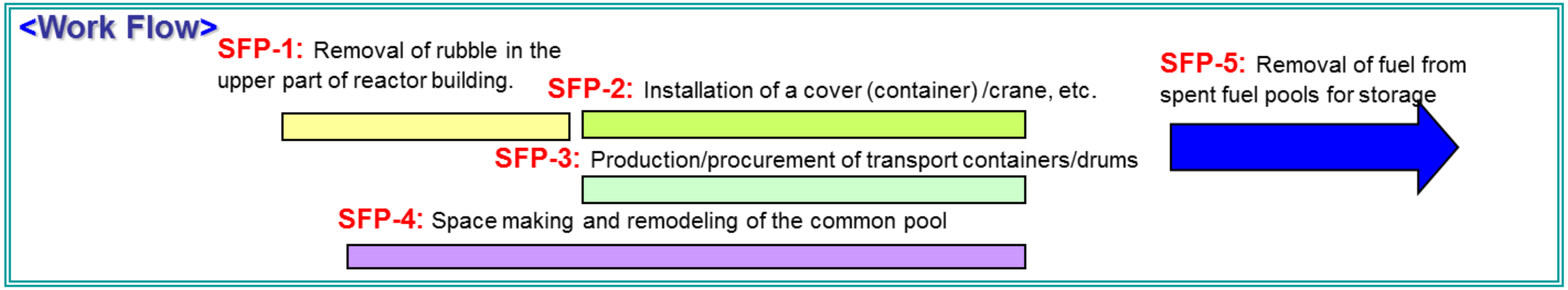
In order to reassure the local residents concerned and the people across Japan at an early date, it is important to achieve the mid- and long-term measures at the Fukushima Dai-ichi NPP as safely and quickly as possible by gathering knowledge and expertise at home and abroad. In this context, the Advisory Committee set a target time within 10 years from the end of Step 2 to the commencement of the removal of fuel debris, and provided a mid- and long-term roadmap (R&D program) required for achieving the target.

As a crucial step toward the accomplishment of the work, the Advisory Committee will define the roadmap in more detail, and requests all related parties to make efforts to carry it forward as early as possible while providing an adequate interface between on-site operation and R&D activities under an "All Japan" disaster response team.

Not only is a smooth execution of R&D but also timely enforcement of regulations concerning safety required. The Government-TEPCO Integrated Response Office issued the "The Concept of Securing the Mid-term Safety for Units 1 to 4 at Fukushima Dai-ichi NPP" in October, which provides the basic targets and requirements of ensuring safety of the public and workers in the period up to the commencement of the decommissioning operation (within around three years).

Following the mid-term operation, safety assuring systems and regulations are also required, and at the same time, the government and related parties need to determine the direction of the remaining issues such as the repositories of radioactive wastes, handling of fuel debris, and transfer of the dry casks temporarily placed in the premises.

Table 1 Conceptual Diagram of Work Flow for Removal of Fuel from Spent Fuel Pools (1/2)



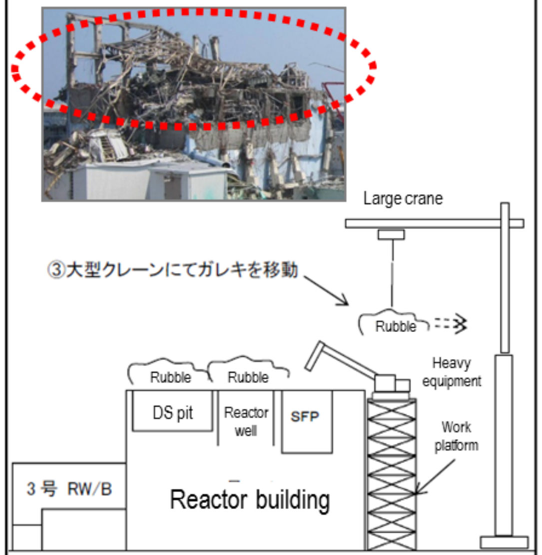
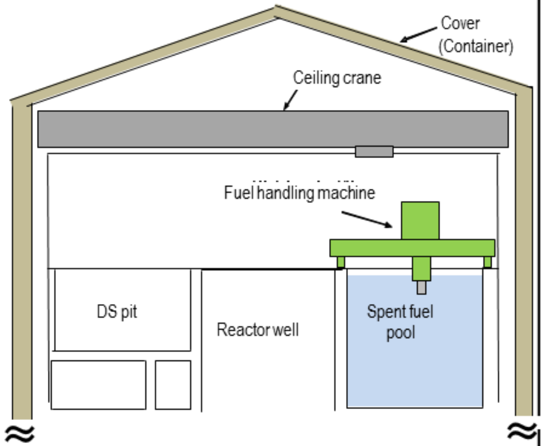
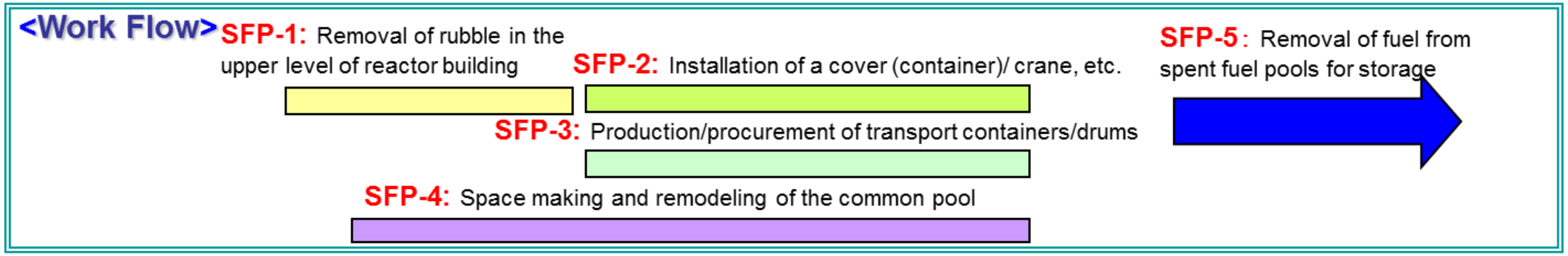
Flow	SFP-1: Removal of rubble in the upper part of reactor building	SFP-2: Installation of a cover (container)/crane, etc.	SFP-3: Production/procurement of transport containers/drums
Conceptual diagram			<Transport container: NH-25> 
Details	Rubble is removed from the upper part of the reactor building using a large crane/heavy equipment.	A cover (container) is installed at the top of the reactor building, and a over head crane and fuel handling machine mounted for removing fuel.	Casks and drums are designed and produced using the existing cask technology for moving fuel assemblies to the common pool.
Notes and issues of R&D	–	–	–

Table 1 Conceptual Diagram of Work Flow for Removal of Fuel from Spent Fuel Pools (2/2)



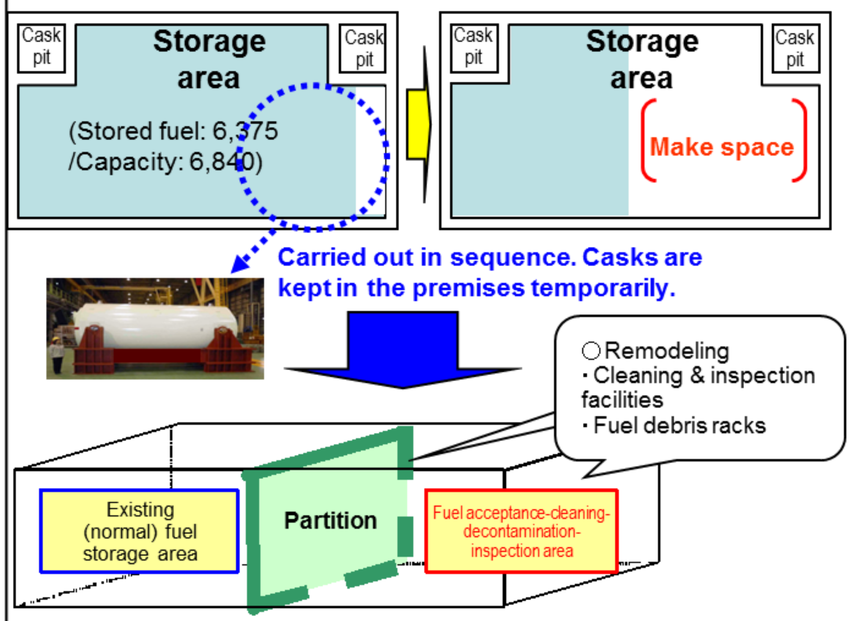
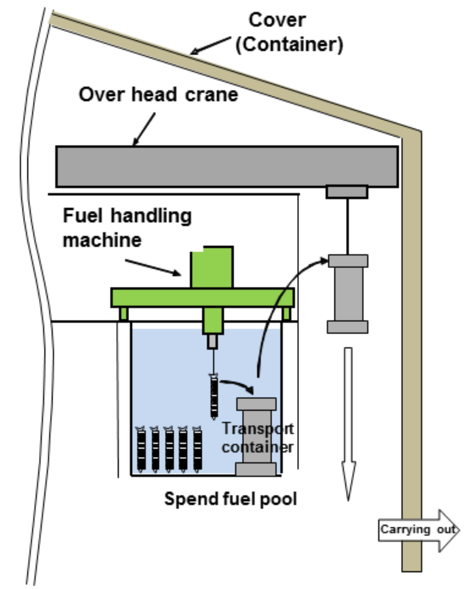
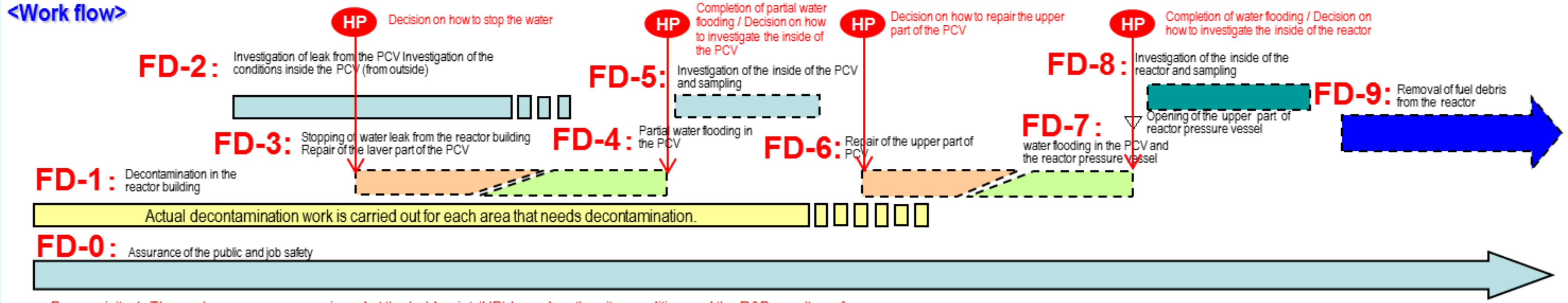
Flow	SFP-4: Space making and remodeling of the common pool	SFP-5: Removal of fuel assemblies from spent fuel pools for storage
Conceptual diagram	<Present>  	
Details	To make space, fuel assemblies now in storage are carried out on casks in sequence, and temporarily kept in the premises. The common pool is then remodeled with a partition, cleaning-inspection facilities, fuel debris racks and other facilities required for storage.	The integrity is inspected (external appearance, and load tests, etc.), and fuel debris is put in drums which are load on the transport containers and carried out. The room is made in the common room in this way.
Notes and issues of R&D	・Cleaning, decontamination and inspection of seawater soaked fuel and leaked fuel.	–

Table 2 Conceptual Diagram of Work Flow for Removal of Fuel from Reactor Core (1/3)

<Work flow>



Prerequisite 1: The work processes are reviewed at the hold point (HP) based on the site condition and the R&D results so far.

Prerequisite 2: Similar to TMI-2, a sequence of work is assumed for removing fuel debris under water. It may be reviewed in accordance with the site conditions and R&D results in the future.

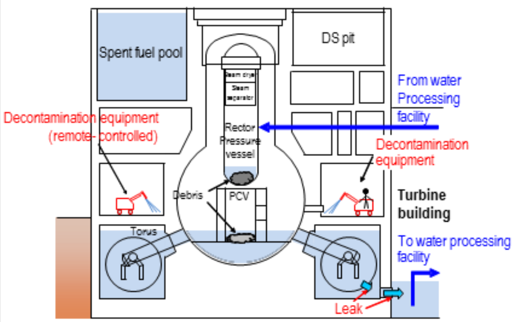
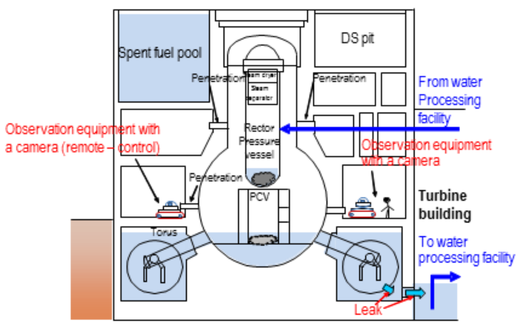
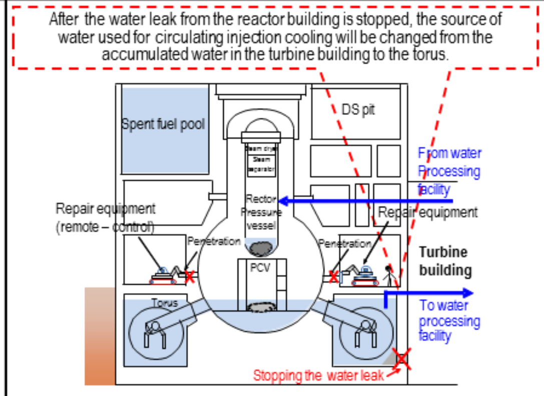
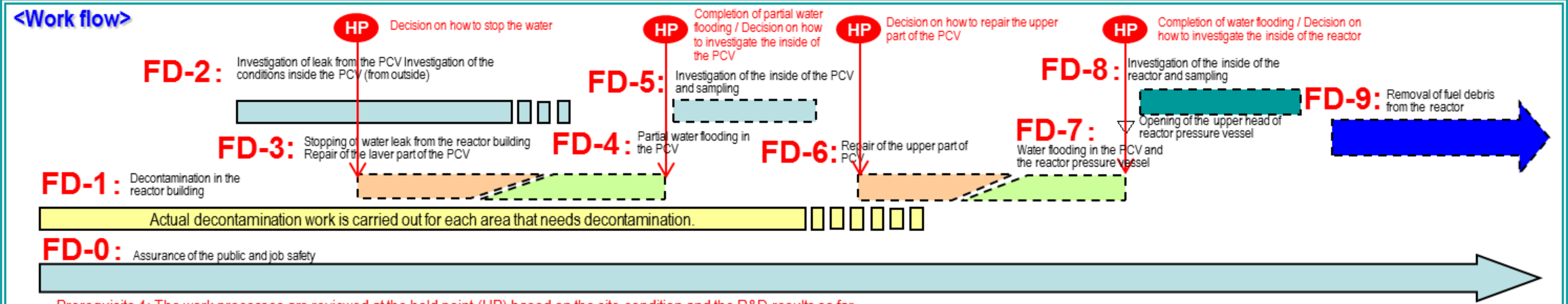
Work	FD-1: Decontamination in the reactor building (Successive decontamination as required for next steps)	FD-2: Investigation of leaks from the PCV Investigation of the conditions inside the PCV (from outside)	FD-3: Stopping of water leak from the reactor building / Repair of the lower part of the containment
Conceptual diagram			
Details	The work area will be decontaminated using high-pressure water, coating, surface chipping, and so forth in order to provide greater access to the PCV.	Investigations will be conducted of leak in the PCV and the reactor building manually or using remote-controlled radiation dose measuring instruments, cameras, and other devices. The condition of the interior of the PCV will be investigated and estimated from outside through Y rays measurements, acoustic investigations, etc.	Since underwater work for removing fuel debris is preferable in terms of radiation shielding, leaking points of PCV will be repaired to stop leakage. For that purpose, priority will be given to repairing the lower parts of PCV to facilitate inspection within PCV.
Notes & issues of R&D	◆ High dose areas (some hundreds to 1000 mSv) ◆ Limited accessibility due to rubble in buildings · It is necessary to consider remote decontamination methods and other measures for locations with high-level radioactivity.	◆ Objects of investigation are in high dose area in contaminated water, or in narrow space · Development of methods and equipment to investigate leak · Development of methods and equipment to investigate the condition of the inside of the PCV from outside	◆ Stop water leak under high dose and water-flowing conditions in parallel with core cooling by circulating water · Development of technology and methods to repair leak in PCV and reactor building and stop water leak · Examination and development of alternative measures
Notes in safety assurance	· Maintenance of stable reactor core cooling · Prevention of radioactive materials from releasing into the air during decontamination work · Decrease of worker's radiation exposures (remote control, shielding)	· Maintenance of stable reactor core cooling · Decrease in worker's radiation exposure (remote control, shielding, etc.)	· Maintenance of stable reactor core cooling · Decrease in worker's radiation exposure (remote control, shielding, etc.)

Table 2 Conceptual Diagram of Work Flow for Removal of Fuel from Reactor Core (2/3)



Prerequisite 1: The work processes are reviewed at the hold point (HP) based on the site condition and the R&D results so far.

Prerequisite 2: Similar to TMI-2, a sequence of work is assumed for removing fuel debris under water. It may be reviewed in accordance with the site conditions and R&D results in the future.

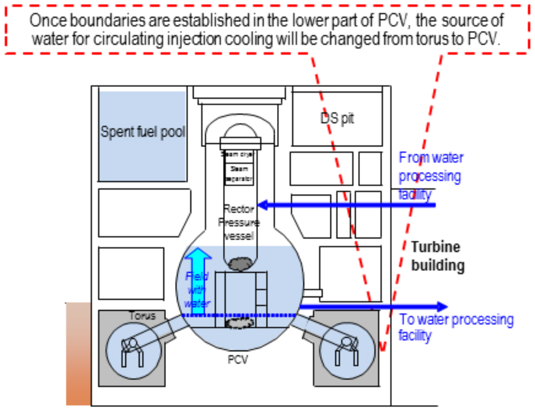
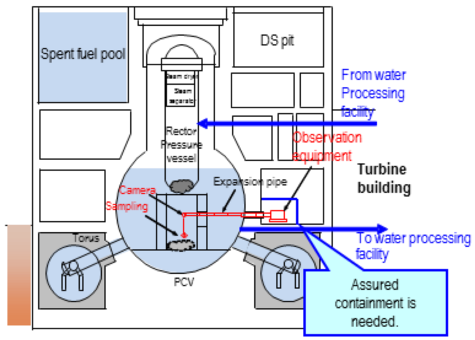
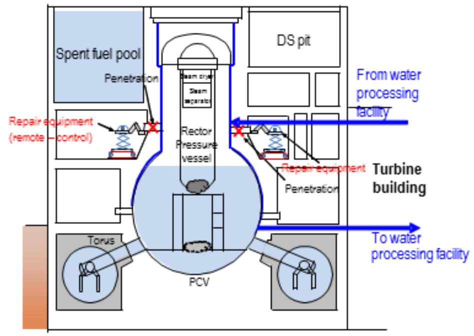
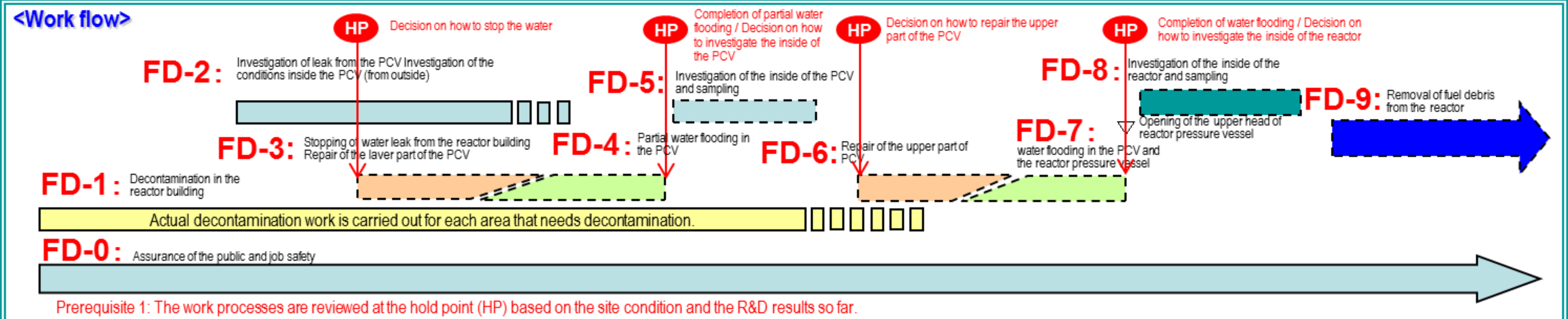
Work	FD-4: Partial flooding of the PCV with water	FD-5: Investigation of the inside of the PCV and sampling	FD-6: Repair of the upper part of the PCV
Conceptual diagram			
Details	The lower part of the PCV will partially be flooded with water before investigations of the inside of the PCV begin.	The inside of the PCV will be investigated to of identify the distribution re fuel debris, which is presumed to have leaked out of the reactor pressure vessel, and to carry out sampling and other types of work.	In order to flood the PCV with water to its top, leak in the upper part of the PCV will be repaired manually or through remote control.
Notes & issues of R&D	◆ Same note as that for FD-3 ・ The major premise is to build boundaries in the lower part of the PCV (including the plan of filling the torus with grout materials).	◆ Limited accessibility due to high dose, difficult environment inside PCV (accumulated water, dropped fuel debris, etc.) ・ Development of methods for remote investigations and sampling in the PCV where there is high-level radioactivity.	◆ Same note as that for FD-2 ・ Development of technology and methods for repairing leak in the PCV and stop the water leak (same as in Process FD-3)
Notes in safety assurance	・ Maintenance of stable reactor core cooling ・ Confirmation of no criticality	・ Maintenance of stable reactor core cooling ・ Confirmation of no criticality ・ Prevention of radioactive materials released from the PCV ・ Decrease in worker's radiation exposure (remote control, shielding, etc.)	・ Maintenance of stable reactor core cooling ・ Decrease in worker's radiation exposure (remote control, shielding, etc.)

Table 2 Conceptual Diagram of Work Flow for Removal of Fuel from Reactor Core (3/3)



Prerequisite 1: The work processes are reviewed at the hold point (HP) based on the site condition and the R&D results so far.
Prerequisite 2: Similar to TMI-2, a sequence of work is assumed for removing fuel debris under water. It may be reviewed in accordance with the site conditions and R&D results in the future.

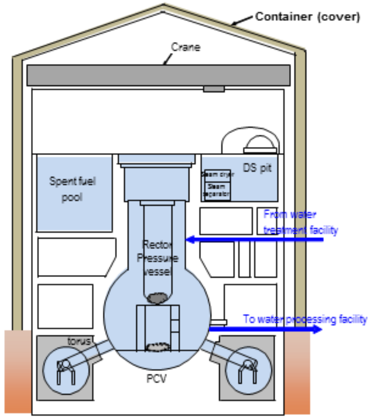
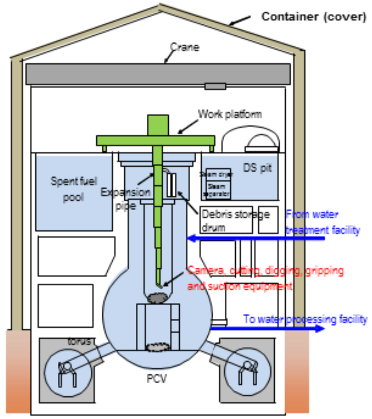
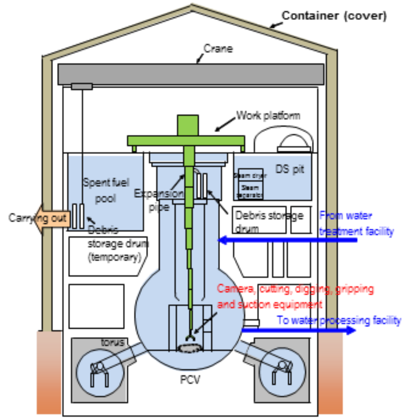
Work	FD-7: Flooding the PCV and the reactor pressure vessel with water ⇒Opening of the upper head of reactor pressure vessel	FD-8: Investigation of the inside of the reactor and sampling	FD-9: Removal of fuel debris from the reactor
Conceptual diagram			
Details	After PCV and reactor pressure vessel are sufficiently filled with water for shielding purpose, the upper head of reactor pressure vessel will be removed.	The inside of the reactor will be investigated to ascertain the condition of the fuel debris, structures in the reactor, etc., and sampling and other sorts of work will be performed.	fuel debris will be removed from the reactor pressure vessel and the PCV.
Notes and issues of R&D	(The major premise is to build PCV boundaries in Process FD-6.)	◆ **Limited accessibility due to high dose difficult environment inside PCV (accumulated water, fuel debris, etc.)** ・Development of methods for remote investigations and sampling in the reactor where there is high-level radioactivity	◆ **Further technological development might be needed depending on the situation (distribution) of fuel debris** ・Development of more advanced techniques and methods than used at TMI for removing fuel.
Notes in safety assurance	・Maintenance of stable reactor core cooling ・Confirmation of no criticality ・Prevention of radioactive materials released from the PCV	・Maintenance of stable reactor core cooling ・Confirmation of no criticality ・Storage of fuel debris (containment, etc.) ・Decrease in worker's radiation exposure (remote control, shielding, etc.)	・Maintenance of stable reactor core cooling ・Confirmation of no criticality ・Storage of fuel debris (containment, etc.) ・Decrease in worker's radiation exposure (remote control, shielding, etc.)

Table 3 Issues and R&D theses in mid- and long-term measures (1/6)

Item	Work element	Issue	Required technique/data	Use of existing technique/data	R&D thesis
I Removal of fuel assemblies from spent fuel pools	SFP-1: Removal of rubble at upper part of the reactor building	・Possible diffusion of large amounts of radioactive materials into the air when rubble is removed from the upper part of the reactor building.	・Diffusion prevention techniques ・Monitoring techniques	・Existing techniques (dust inhibitor agent) may be used. ・Existing techniques may be used for monitoring.	–
	SFP-2: Installation of building cover (container)/crane	–	–	–	–
	SFP-3: Production or procurement of transport containers/canisters	–	–	–	–
	SFP-4: Preparation of space in the common pool /remodeling	・Need for providing partitions to prevent possible negative effects of seawater exposed fuel assemblies on normal fuel.	・Method of installing partitions in the common pool	・Existing techniques may be used for installing the partition in the common pool.	–
	SFP-5: Removal of fuel assemblies from spent fuel pools / storage	・Possible drop of fuel assemblies during removal from pools using remote control equipment. ・Possible effects of seawater on the long-term integrity of fuel assemblies in long-term storage. Required measures (cleaning) are not yet determined for long-term storage and processing. ・Treatment/disposal is not yet determined for damaged fuel assemblies in spent fuel pools. ・Management and approval procedures are not yet determined for measuring damaged fuel (including broken pieces and powder) in spent fuel pools.	・Drop prevention techniques	・Existing techniques may be used for preventing drop.	–
			・Long-term integrity evaluation techniques for fuel assemblies	・Existing techniques may be used for evaluation. There is no data indicating long-term integrity of seawater exposed fuel assemblies.	・Evaluation of long-term integrity of seawater exposed fuel assemblies.
			・Cleaning techniques/criteria for long-term storage/processing of fuel assemblies	・Existing techniques may be used for cleaning. There is no criterion for long-term storage or effects on reprocessing operation.	・Establishment of cleaning criteria for long-term storage and processing.
			・Damaged fuel treatment and disposal methods	・Development of handling techniques according to the degree of damage is required for damaged fuel. ・Evaluation is required for the effects of impurities on chemical processing.	・Development of handling techniques according to the degree of damage. ・Evaluation of effects of impurities on chemical processing.
			・Damaged fuel nuclear measurement techniques	・There is no nuclear measurement techniques available for damaged fuel.	・Development of nuclear measurement techniques for damaged fuel.

Table 3 Issues and R&D theses in mid- and long-term measures (2/6)

Item	Work element	Issue	Required technique/data	Use of existing technique/data	R&D thesis
II Preparations for removal of fuel debris from spent fuel pools	FD-1: Decontamination of reactor buildings	・High dose of reactor buildings. ・The effect of decontamination of the reactor building depends on the degree of contamination and areas (materials), but data is not sufficient for selecting suitable decontamination techniques. ・Rubble in the reactor building hinders access to the inside of building.	・Remote control techniques for inspecting contamination state	・Existing techniques may be used for measuring contamination. ・Development of remote controlled carriers suitable for site conditions such as the presence of scattering rubble is required.	・Development of remote contamination inspection equipment comprised of a measuring instrument and remote controlled carrier used in the reactor building.
			・Remote control techniques for decontaminating the reactor building	・Validity assessment of existing techniques for decontaminating high dose areas, and development of equipment are required (technologies used at TMI may be useful). ・Development of remote controlled carriers suitable for site condition such as the presence of scattering rubble is required.	・Selection or development of decontamination techniques suitable for varied contamination conditions, and development of equipment. ・Development of a remote decontamination system comprised of the above equipment and a remote controlled carrier.
			・Shielding techniques	・Existing shielding techniques may be used.	–
	FD-2: Inspection of leaks from the reactor building and PCV, inspection of inside of PCV from outside	・The areas leaking contaminated water are highly radioactive, narrow and underwater. ・Areas surrounding the PCV are highly radioactive and narrow.	・Remote investigation techniques for use in high dose, narrow and underwater leak areas	・Validity assessment of existing techniques (cameras, dosimeters) for finding leak spots and development of equipment are required. ・Existing remote controlled underwater carriers may be used, but modification is required to suit to the inspection of narrow areas.	・Selection or development of investigation techniques suitable for finding leak spots, and development of equipment. ・Development of a remote investigation system comprised of the above equipment and a remote controlled carrier.
			・Remote internal RPV inspection techniques for checking the PCV from outside	・Validity assessment of existing techniques (γ-ray/acoustic measurement) for inspecting the inside of PCV from outside and development of equipment are required. ・Development of remote controlled carriers suitable for inspecting areas is required.	・Selection or development of internal RPV inspection techniques for inspecting the inside of PCV from outside. ・Development of a remote investigation system comprised of the above equipment and a remote controlled carrier.
	FD-3: Leak sealing in the reactor building, repair of the lower part of PCV	・The areas in the reactor building leaking contaminated water are highly radioactive, narrow and underwater. ・Leaks need to be sealed with water flowing. ・Areas surrounding the PCV are highly radioactive and narrow.	・Remote leak sealing techniques for use in high dose and narrow underwater areas with water flowing	・Validity and long-term integrity assessments of existing leak sealing techniques (grouting, sealing materials) and development of equipment suitable for potential leak spots are required.	・Selection or development of leak seal techniques suitable for leak spots in the reactor building.
			・Remote repairing techniques for use in high dose and narrow areas	・Existing repairing techniques may be used but the development of equipment is required. ・Development of remote controlled carriers suitable for potential leak spots is required.	・Development of repair equipment and remote PCV repair system combined with a remote controlled carrier.
	FD-4: Partial water filling in PCV	・Risks of criticality may increase when the amount of cooling water for fuel debris changes during water filling.	・Fuel debris criticality assessment techniques.	・Development of analytical techniques is required for evaluating temporal changes in the critical state in detail.	・Development of analysis codes for assessing temporal changes in the critical state.
			・Criticality detection techniques	・Existing detection techniques may be used but the development of a detection system, capable of distinguishing target radiation from surrounding high dose radiation even if installed at high dose areas, is required.	・Development of a detection system that can distinguish target radiation from the surrounding high dose radiation.
			・Criticality prevention techniques	・Existing techniques may be used for preventing criticality.	–

Table 3 Issues and R&D theses in mid- and long-term measures (3/6)

Item	Work element	Issue	Required technique/data	Use of existing technique/data	R&D thesis
II Preparations for removal of fuel debris from spent fuel pools	FD-5: Internal RPV inspection and sampling	・The inside of PCV is narrow , partially filled with water and in high dose, high-temperature and high-humidity conditions. ・The internal conditions of PCV, such as the turbidity of water and location of fuel debris, are not known. Fuel debris may have been fallen into the pedestals, where access is especially difficult. ・The basic properties of fuel debris to be sampled are not known. ・Risks of criticality may increase with changes in the relative amount of water moderator to fuel debris during sampling. ・Methods of fuel debris measurement management and approval (including samples) are not determined.	・Remote in-vessel inspection techniques for used in high dose, narrow, high-temperature, high-humidity underwater areas	・Validity assessment of existing techniques (underwater camera, etc.) used in high temperatures and high dose conditions, and development of equipment.	・Selection or development of observing techniques in high-temperatures and high-dose conditions, and development of equipment are required. ・Development of a remote investigation system comprised of the above equipment and a remote controlled carrier.
			・Remote fuel debris sampling techniques for use in high dose, narrow underwater areas	・Technologies used at TMI may be useful, but the development of new sampling techniques is required for the inside of PCV. ・Development of remote controlled carriers suitable for sampling locations and conditions is required.	・Development of sampling techniques for fuel debris inside the PCV, and equipment. ・Development of a remote sampling system comprised of the above equipment and a remote controlled carrier.
			・In-core fuel debris distribution prediction techniques	・Existing analysis codes (MAAP, , MELCOR, THALES, SAMPSON) may be applied to general assessment but improvements are required for increased accuracy.	Upgrade of severe accident analysis codes.
			・Data on basic properties of fuel debris	・Data on fuel debris at TMI may be useful, but data on fuel debris including conditions of generation at Fukushima is also required.	・Acquisition of data on basic properties of fuel debris from simulated production conditions
			・Fuel debris nuclear measurement technique	・There is no nuclear measuring techniques available for fuel debris.	・Development of fuel debris nuclear measurement techniques.
	FD-6: Repair of the upper part of PCV	・The locations of repair are highly radioactive and narrow.	・Remote repairing techniques for use in high dose and narrow areas	・Existing techniques may be used, but development of equipment is required. ・Development of remote controlled carriers suitable for potential leak spots is required.	・Remote PCV repairing system comprised of a repairing technique and remote controlled carrier.
	FD-7: Water filling in RPV and PCV	・Risks of criticality may increase with changes in the relative amount of water moderator to fuel debris during water filling.	・Criticality assessment, detection and prevention techniques	・Same as FD-4.	・Same as FD-4.
	FD-8: Internal RPV inspection and sampling	・The inside of RPV is highly radioactive, narrow and hot, and the RPV is submerged. ・The internal conditions of RPV, such as the turbidity of water and location of fuel debris are not known. ・The basic properties of fuel debris required for designing the removing tools and storage canisters are not known. ・Risks of criticality may increase with changes in the relative amount of water moderator to fuel debris during sampling. ・Methods of fuel debris measurement management and approval (including samples) are not determined.	・Remote internal RPV inspection techniques for use in high dose, narrow and high temperature underwater areas	・Validity assessment of existing techniques (e.g., underwater cameras) for use in high-temperature, high dose conditions, and development of equipment is required. ・Improvements of existing techniques are required for access to the reactor.	・Development of a monitoring system available in high-temperature, high-dose conditions. ・Development of a platform structure for access to the reactor.
			・Remote fuel debris sampling techniques for use in high dose and narrow underwater areas	・The technologies used at TMI may be useful, but the distance between the refueling floor and location of fuel debris is longer at Fukushima than TMI. Development of new technologies is required.	・Development of sampling technique and equipment for fuel debris inside the RPV. ・Development of remote in-core sampling system comprised of the above equipment and a remote controlled carrier.
			・Fuel debris in-core distribution prediction techniques	・Existing analysis codes (MAAP, MELCOR, THALES, SAMPSON) may be used for general assessment, but improvements are required for more accurate analysis.	Upgrade of severe accident analysis codes.
			・Data on the basic properties of fuel debris	・Same as FD-5.	・Same as FD-5.
			・Criticality assessment, detection and prevention techniques	・Same as FD-4.	・Same as FD-4.
			・Fuel debris nuclear measurement techniques	・There is no available fuel debris nuclear measurement technique.	・Development of fuel debris nuclear measurement techniques.

Table 3 Issues and R&D theses in mid- and long-term measures (4/6)

Item	Work element	Issue	Required technique/data	Use of existing technique/data	R&D thesis
III Development of fuel debris removal techniques and removal of fuel debris	FD-9: Development of fuel debris removal technique and removal of fuel debris	・Fuel debris may spread outside the RPV and other areas extensively. ・Risks of criticality may increase with changes in the relative amount of water moderator to fuel debris during the removal of fuel debris. ・Accurate basic properties of fuel debris, not the ones obtained from the simulation are required for removing fuel debris. ・Methods of storing fuel debris are not determined. ・Methods of measurement management and approval of fuel debris (including samples) are not determined. ・Future handling of fuel debris is uncertain. The fuel debris at TMI has been put in long-term storage state. The treatment and disposal of fuel debris have yet to be definitively determined in the world. ・There is no definite idea for fuel removal if water filling is unsuccessful.	・Remote fuel debris removal techniques for a wide range of narrow and underwater areas	・The technologies used at TMI may be useful for fuel debris inside the RPV, but the distance between the refueling floor and location of fuel debris is longer at Fukushima than in TMI. Development of new technologies is required. None of existing technologies are available for removing fuel debris outside the RPV both at home and abroad. ・Development of remote retrieval techniques and equipment suitable for site conditions is required for removing fuel debris.	・Development of removal techniques and equipment for retrieving fuel debris inside and outside the RPV. ・Development of a remote fuel debris removal system for performing the above techniques in remote mode.
			・Criticality assessment, detection and prevention techniques	・Same as FD-4.	・Same as FD-4.
			・The basic properties of actual fuel debris	・Existing techniques may be used for analyzing actual fuel debris. Data on fuel debris at TMI may be useful, but more accurate data is required to match the difference in the process of generation.	・Acquisition of data on the basic properties of actual fuel debris.
			・Fuel debris nuclear measurement techniques	・There is no available fuel debris nuclear measurement technique.	・Development of fuel debris nuclear measurement techniques.
			・Fuel debris storage techniques	・There is no available fuel debris storage technique in Japan. Technologies used at TMI may be useful, but effects of exposure to seawater need to be considered.	・Development of fuel debris storage techniques with effects of seawater taken into account.
			・Fuel debris treatment and disposal techniques	・Application of existing treatment and disposal techniques has yet to be evaluated.	・Examination of existing fuel debris treatment and disposal techniques.
			・Fuel debris removal techniques in case of failure in water filling	・None of existing technologies are available for removing fuel debris without water filling.	・Development of fuel removal without water filling.
IV Assurance of public and job safety	Maintenance of subcriticality	・Risks of criticality may increase with changes in the relative amount of water moderator to fuel debris.	・Diffusion suppression techniques ・Monitoring techniques	・Same as FD-4.	・Same as FD-4.
	Continuation of stable cooling of fuel debris	・Assessment of effects of work on reactor circulating cooling water injection.	・Risk assessment for each work	・Assessment using an existing technique (PSA) is possible.	–
	Prevention of radioactive materials from diffusing into the air	・Possibilities of large amounts of radioactive materials released into the air during removal of rubble in upper part of the reactor building.	Same as SFP-1	Same as SFP-1.	Same as SFP-1.
		・Corrosion may affect the long-term integrity of RPV and PCV which have been exposed to seawater for a prolonged period of time.	・Data on the long-term integrity of RPV/PCV which have been exposed to seawater	・There is no data on the assessment of long-term integrity of RPV/PCB which have been exposed to seawater for a prolonged period of time.	・Acquisition of data on the assessment of long-term corrosion resistance of RPV/PCV exposed to seawater for a prolonged period of time.
		・Antirust agent may be ineffective for the RPV and PCV which have been exposed to high-temperature seawater for a prolonged period of time.	・Corrosion suppression techniques used for the equipment exposed to high-temperature seawater	・The validity of existing corrosion suppression agents is not evaluated in case of exposure to high-temperature seawater.	・Selection or development of corrosion suppression agents for the RPV/PCB exposed to high-temperature seawater.

Table 3 Issues and R&D theses in mid- and long-term measures (5/6)

Item	Work element	Issue	Required technique/data	Use of existing technique/data	R&D thesis
IV Assurance of public and job safety		・Methods of the treatment and disposal or stable, long-term storage of secondary wastes (waste zeolite, waste sludge, concentrated liquid waste, etc.) produced from the treatment of contaminated water mixed with seawater are yet to be determined.	・Stable storage, treatment and disposal of secondary wastes	・Secondary waste property analysis, safety assessment for hydrogen gas and heat generation, and corrosion resistance assessment are yet to be conducted for stable, long-term storage. ・Waste body assessment for the waste from reactors and during reprocessing, etc. may be useful for waste encapsulation operation, but another assessment is required for different properties.	・Secondary waste property analysis, safety assessment, and corrosion resistance assessment. ・Examination of waste body and disposal.
			・Monitoring techniques	・Existing techniques may be used for monitoring.	–
		・Handling of radioactive wastes produced from the work is yet to be determined.	・Property analysis techniques for classifying radioactive wastes	・Existing categories may be used for classification. ・Property analysis suitable for the property of wastes is required.	・Analysis techniques suitable for the properties of radioactive materials.
			・Treatment and disposal techniques for radioactive wastes	・New processes of waste handling may be required depending on the form of waste.	・Investigation of waste treatment and disposal.
		・When the top of RPV is opened, radioactive materials may be diffused from the damaged secondary storage facility (reactor building).	・Techniques to prevent diffusion of radioactive materials from the reactor building ・Monitoring techniques	・Reactor building cover (or container) may be used. ・Existing techniques may be used for monitoring.	–
		・Long-term prevention of radioactive materials from diffusing to seawater.	・Techniques to prevent radioactive materials from diffusing into seawater ・Monitoring techniques	・Leak sealing from a vertical shaft, silt fences, seawater circulating purification systems, or water shielding walls may be used for minimizing the diffusion of radioactive waste. ・Existing techniques may be used for monitoring.	–
	Reduction of radiation exposure of workers	・Serious exposure of workers to radiation in high dose, highly contaminated and humid conditions.	・Decontamination techniques	・Same as FD-1.	・Same as FD-1.
			・Shielding techniques	・Same as FD-1.	・Same as FD-1.
			・High dose radiation protection techniques ・Techniques to protect from exposure in highly contaminated, highly humid areas	・No protective gears are available for the efficient work in high dose conditions. ・No protective gears are available for highly contaminated, highly humid environment.	・Development of flexible protective gears for external exposures. ・Development of protective gears for internal exposures in highly contaminated, highly humid environment.

Table 3 Issues and R&D theses in mid- and long-term measures (6/6)

Item	Work	Issue	Required technique/data	Use of existing technique/data	R&D thesis
V. Determination of the cause of accident	FD-10: Determination of the cause of accident, assessment of core damage behavior, etc.	・Detailed core meltdown and progression behavior or behavior inside the PCV, required for determining the cause of accident at Fukushima Daiichi NPP have yet to be known due to insufficient plant data resulting from the loss of power.	・Severe accident analysis codes including seawater injection ・Data required for upgrading analysis codes	・Existing analysis codes (MAAP, MELCOR, THALES, SAMPSON) may be used to general assessment but upgrading of codes and acquisition of related data are required for detailed analysis.	・Enhancement of severe accident analysis codes.

Table 4 Issues of R&D Theses concerning Remote Control Equipment

	Work element	R&D thesis	Range	Issues concerning development of remote control equipment									
				Type of work（examples are indicated in parentheses）							Structure	Control	
			Location	Measurement (Image, morphology, temperature, humidity, radiation, etc.)	Decontamination	Sampling	Shielding installation	Drilling holes /cutting	Leak sealing (including repair)	Transfer	Positioning in narrow /complicated space	Man-machine interface	Communication
				Measurement performance and durability under certain conditions (radiation, temperature, humidity)	Selection of optimum decontamination methods for various sections /radiation sources and accessibility	Handling of high dose materials after retrieval	Range of installation at narrow area or high place	Optimization of drilling holes, secondary product assessment, and retrieval	Optimization of leak sealing methods	Range of transfer and installation at narrow area			
Use of remote control technique	Decontamination of reactor building	Development of a remote contamination inspection system	Floors, walls and ceilings of reactor building, surface of equipment and ducts, and external surface of PCV	O (Image, radiation)		O (Suction, boring)	O (Transfer of heavy load)			O (Steps, high places)	O Consolidation of conceptual design for combining common remote controlled robots and tools for various measurements and types of work (end effectors) according to the place of installation and the range of required access	O Standardization to some extent according to the types of equipment configuration	O Introduction of common infrastructures for remote communication from the operation center; radio control inside and outside the building
		Development of a remote decontamination system			O (High-pressure spraying, chipping)					O (Steps, high places)			
	Investigation of leaks from reactor building and PCV / investigation of inside of PCV from outside	Development of a remote leak inspection system	Reactor building (including underwater portions), external surface of PCV and suppression chamber	O (Image, morphology measurement, temperature, radiation, infrared light, sound)		O (Suction)	O (Transfer of heavy load)	O (Drilling holes on concrete floors and walls)		O (Underwater, narrow areas)			
		Development of a remote in-vessel inspection system for inside of PCV from outside		O (Radiation, sound)						O (Steps, high places)			
	Leak sealing of reactor building and repair of lower part of PCV	Development of a remote repair system for PCV	Reactor building (including underwater portions), and external surface of PCV	O (Image, morphology measurement)			O (Transfer of heavy load)	O (Drilling holes on concrete floors and walls)	O (Grouting, welding)	O (Steps, high places)			
	Investigation of inside of PCV and sampling	Development of a remote in-vessel inspection system for the inside of PCV	Reactor building (including underwater portions), inside of PCV and external surface of PCV	O (Image, morphology measurement, temperature, humidity, radiation)			O (Transfer of heavy load)	O (Drilling holes and cutting of metals)	O (Boundary formation)	O (Underwater, narrow areas)			
		Development of a remote sampling system	Reactor building (including underwater portions), inside of PCV and external surface of PCV	O (Image, radiation)		O (Suction, boat sampling, handling of metallic fragments)				O (Underwater, narrow areas)			
	Repair of upper part of PCV	Development of a remote repairing system for PCV	External surface of PCV	O (Image, morphology measurement)			O (Transfer of heavy load)	O (Drilling)	O (Grouting, welding)	O (Steps, high places)			
	Internal RPV inspection and sampling	Development of a remote in-vessel sampling system	Reactor building (refueling floor) and inside of RPV	O (Image, morphology measurement, radiation)		O (Suction, boat sampling, handling of metal fragments)	O (Transfer of heavy load)			O (Underwater, narrow areas)			
	Removal of fuel debris	Development of a remote fuel debris removing system	Reactor building (refueling floor) and inside of RPV	O (Image, morphology measurement)		O (Suction, boat sampling, handling of metal fragments)	O (Transfer of heavy load)	O (Drilling holes and cutting of metals)		O (Underwater, narrow areas)			

Table 5 Technology Roadmap for Mid- and Long-term Measures (1/2)

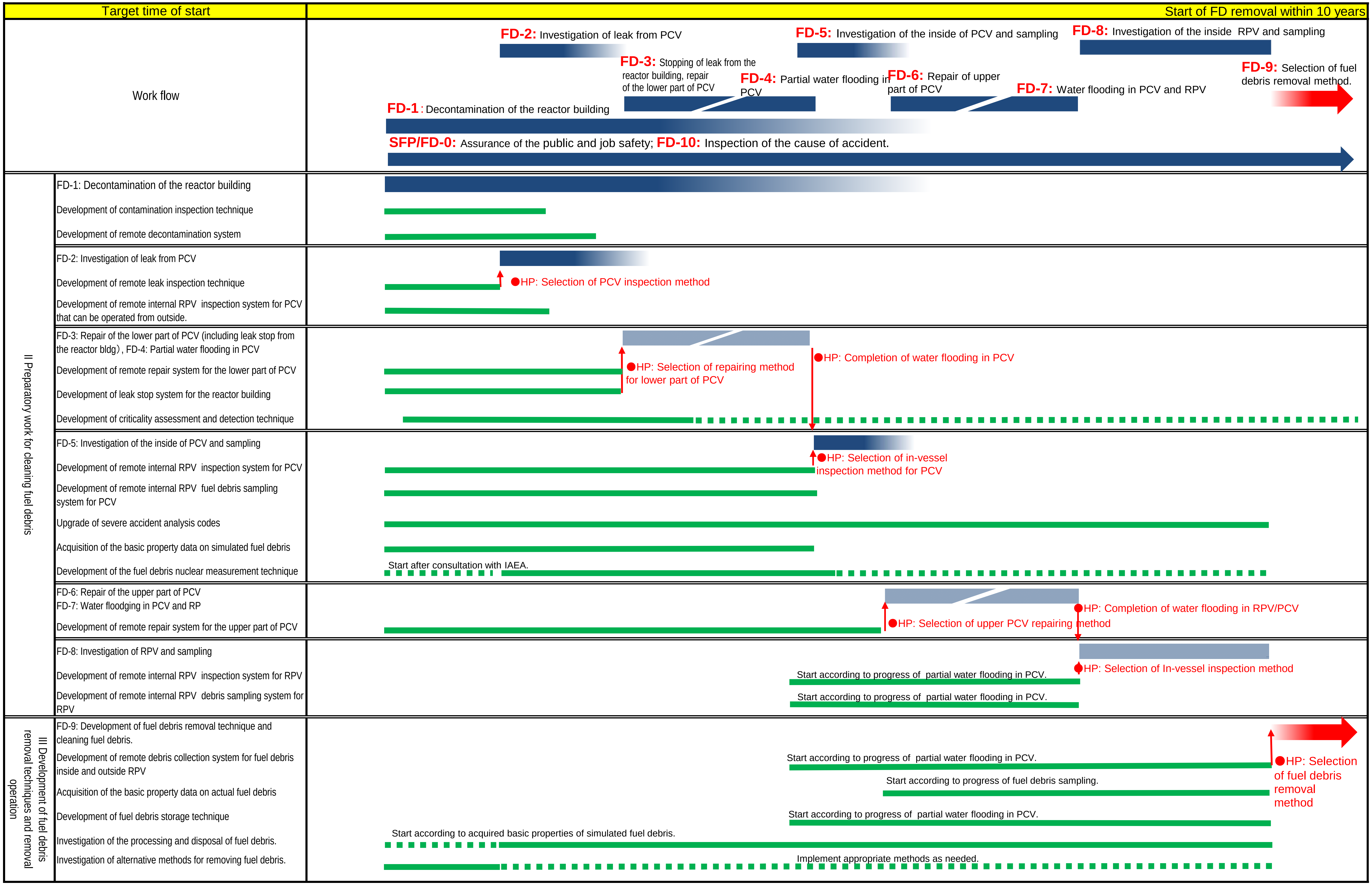
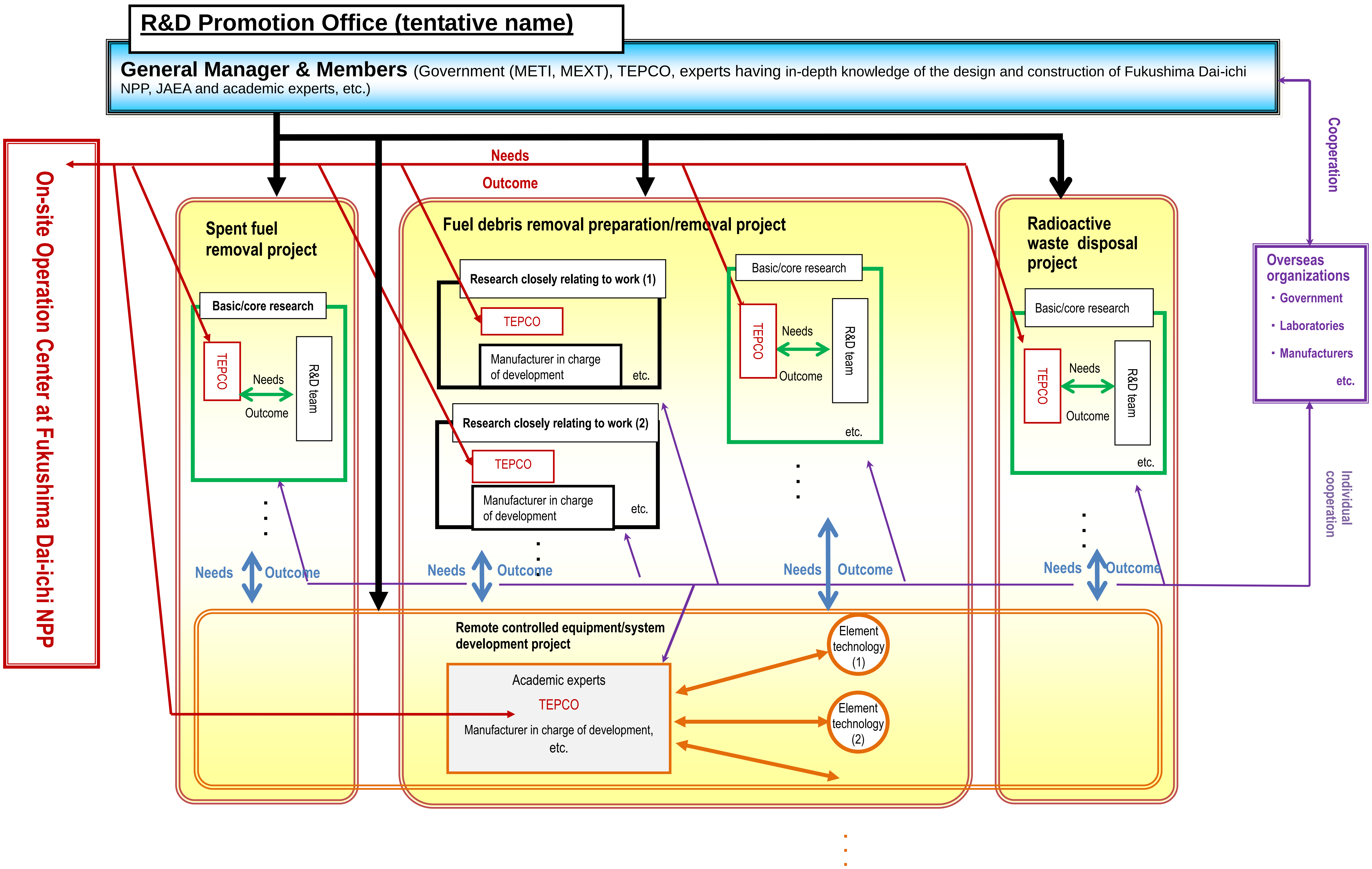


Table 5 Technology Roadmap for Mid- and Long-term Measures (2/2)

Target time of start		Start of SF removal within 3 years / Start of FD removal within 10 years
Work flow		SFP-1: Removal of rubble in the upper part of reactor building SFP-2: Installation of a cover (or container) and crane, etc. SFP-3: Production/procurement of transport containers/drums SFP-5: Removal of fuel assemblies from spent fuel pools for storage SFP-4: Space making and remodeling of the common pool SFP/FD-0: Assurance of the public and job safety; FD-10: Inspection of the cause of accident.
I Removal of fuel assemblies from spent fuel pools	SFP-5: Removal and storage of fuel assemblies from spent fuel pools	
	Evaluation of long-term integrity of seawater soaked fuel and selection of cleaning criteria.	●HP: Determine cleaning criteria.
	Determination of processing and disposal of damaged fuel	Start according to degree of damage of fuel stored in pools.
	Development of damaged fuel nuclear measurement technique.	Start according to degree of damage of fuel stored in pools.
IV Ensuring of public and job safety	SFP/FD-0: Assurance of public and job safety	
	Development of technique for evaluating long-term integrity of RPV/PCV and minimizing corrosion	
	Property analysis, safety assessment, and investigation of long-term stable storage technique of secondary wastes generated by treatment of contaminated water	
	Investigation of the processing and disposal of secondary wastes generated by treatment of contaminated water	
	Investigation of the processing and disposal of radioactive wastes	
	Development of high dose radiation protection technique	
V Inspection of cause of accident	FD-10: Investigation of the cause of accident	
	Upgrade of severe accident analysis codes	

Figure 1. Conceptual Diagram of R&D System



(Annex 1)

Establishment of the Advisory Committee for Formulating Mid- and Long-term Strategies
to Clean up the Fukushima Dai-ichi NPP of TEPCO

July 21, 2011

Atomic Energy Commission

1. Purpose

To restore the Fukushima Dai-ichi Nuclear Power Plant of Tokyo Electric Power Co., Inc. (TEPCO) from the accident caused by the Tohoku District-Off the Pacific Ocean Earthquake on March 11, 2011, efforts have been made to build a stable reactor cooling system for maintaining a sustainable safe shutdown condition of the reactors.

When this restoration work is accomplished, the removal of spent fuel will begin. The operation ends with the ultimate decommissioning of reactors while controlling radioactive wastes generated in the work, but considering the accident at the TMI in the past, it is expected to take a significantly long period of time to complete the work. The government need to identify the requirement of technological development useful for creating a roadmap and encouraging TEPCO to promote its efforts to accomplish its obligation. This allows the government, industry and laboratories to work together for gathering in-depth knowledge and expertise at home and abroad to conduct research and development on time which may lead to strengthen the safety infrastructure of nuclear power generation, as well as making preparations to begin collaborative studies with various nations.

In this context, the Advisory Committee for Formulating Mid- and Long-term Strategies to Clean up the Fukushima Dai-ichi NPP of TEPCO (Advisory Committee) was established to create a roadmap of the operation and make proposals to related parties about the allocation of research and development efforts and the establishment of necessary systems towards the accomplishment of the roadmap.

2. Items on Studies

(1) Mid- and long-term efforts at the Fukushima Dai-ichi Nuclear Power Plant.

(2) Technological development effective for the mid- and long-term efforts at the Fukushima Dai-ichi Nuclear Power Plant.

(3) International cooperation in the mid- and long-term efforts at the Fukushima Dai-ichi Nuclear Power Plant.

3. Members

Shown in the attached sheet.

4. Miscellaneous

The Regulations concerning the Operation of Advisory Committees, etc. of Atomic Energy Commission apply to the operation of the Advisory Committee at the Fukushima Dai-ichi Nuclear Power Plant, TEPCO.

Attached Sheet

Members of the Advisory Committee for Formulating Mid- and Long-term Strategies to Clean up the Fukushima Dai-ichi NPP of TEPCO

	Etsuko Akiba	Member of the Atomic Energy Commission
	Hajime Asama	Professor of the Graduate School of Engineering, Tokyo University
	Tadashi Inoue	Research consultant, Central Research Institute of Electric Power Industry
	Katsumasa Ota	Professor of the Medical Faculty, Nagoya University
	Mie Oba	Member of the Atomic Energy Commission
	Akira Omoto	Member of the Atomic Energy Commission
	Shunsuke Kondo	Chair of the Atomic Energy Commission
	Tatsujiro Suzuki	Acting chairperson of the Atomic Energy Commission
	Tsuyoshi Takada	Professor of the Graduate School of Engineering, Tokyo University
	Satoru Tanaka	Professor of the Graduate School of Engineering, Tokyo University
	Shigeaki Tsunoyama	President of Aizu University
	Wako Tojima	Science journalist
	Hideki Toyomatsu	Chair of the Nuclear Power Development Committee, Federation of Electric Power Companies (Executive vice-president of Kansai Electric Power Co., Inc.)
	Kaoru Naito	Executive director of the Nuclear Material Control Center
	Shigeo Nomura	Executive board member of the Japan Atomic Energy Agency
	Masaharu Hanyu	Chair of the Committee on Policy Matters, Japan Electrical Manufacturer's Association (Executive director of Hitachi, Ltd.)
	Yuichi Hayase	Consultant of TEPCO
	Kazuhiro Matsumura	Executive vice-president of Japan Nuclear Fuel Ltd.
*	Hajimu Yamana	Professor of the Research Reactor Institute, Kyoto University
	Yoko Wake	Professor of the Faculty of Commerce, Keio University

* Committee chairman, selected at the 1st meeting.

(Annex 2)

Meetings of the Advisory Committee for Formulating Mid- and Long-term Strategies to Clean up the Fukushima Dai-ichi NPP of TEPCO.

1st Meeting - Wednesday, August 3, 2011

Subject: (1) Operation of the Advisory Committee

(2) Situations of the Fukushima Dai-ichi Nuclear Power Plant of TEPCO

(3) The case of accident at the Three Mile Island NPP

(4) Issues in the mid- and long-term measures

2nd Meeting - Wednesday, August 31, 2011

Subject: (1) How to deal with the issues in the mid- and long-term measures

3rd Meeting- Wednesday, September 14, 2011

Subject: (1) Safety assurance in operation of the mid- and long-term measures

(2) Research and development and the related international cooperation

4th Meeting - Tuesday October 4, 2011

Subject: (1) Research and development theses concerning the mid- and long-term measures

(2) Research and development organization for the mid- and long-term measures

5th Meeting - Friday October 28, 2011

Subject: (1) Concept of safety assurance in the mid-term operation

(2) Research and development organization for the mid- and long-term measures

(3) Research and development roadmap for the mid- and long-term measures

(4) Report of the Advisory Committee (draft)

6th Meeting - Wednesday November 9, 2011

Subject: (1) Report of the Advisory Committee (draft)

7th Meeting - Tuesday December 7, 2011

Subject: (1) Report of the Advisory Committee (draft)