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MISSION REPORT

IAEA INTERNATIONAL PEER REVIEW MISSION ON MID-AND-LONG-TERM ROADMAP TOWARDS THE DECOMMISSIONING OF TEPCO'S FUKUSHIMA DAIICHI NUCLEAR POWER STATION UNITS 1-4

(Second Mission)

Tokyo and Fukushima Prefecture, Japan
25 November – 4 December 2013

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MISSION REPORT TO
THE GOVERNMENT OF JAPAN

Tokyo and Fukushima Prefecture, Japan

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Mission date: 25 November – 4 December 2013

Location: Tokyo and Fukushima Prefecture, Japan

Organized by: International Atomic Energy Agency

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MISSION REPORT

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EXECUTIVE SUMMARY

Following the accident at TEPCO's Fukushima Daiichi Nuclear Power Station (NPS) on 11 March 2011, the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4" (hereinafter referred to the "Roadmap") was adopted by the Government of Japan and the TEPCO Council on Mid-to-Long-Term Response for Decommissioning in December 2011. The Roadmap was revised in July 2012 and June 2013. The Roadmap includes a description of the main steps and activities to be implemented for decommissioning the Fukushima Daiichi NPS through the combined efforts of the Government of Japan and TEPCO.

Within the framework of the IAEA Action Plan on Nuclear Safety, the Government of Japan (Ministry of Economy, Trade and Industry – METI) invited the IAEA to conduct an independent peer review of the Roadmap with two main objectives:

- To improve the decommissioning planning and the implementation of pre-decommissioning activities at TEPCO's Fukushima Daiichi NPS; and
- To share the good practices and lessons learned by the review with the international community.

The review was organized in two steps. The first IAEA mission was conducted from 15 to 22 April 2013 with the main purpose of undertaking an initial review of the Roadmap including assessments of decommissioning strategy, planning and timing of decommissioning phases and a review of several specific short-term issues and recent challenges. This mission report is available on the IAEA webpage (http://www.iaea.org/newscenter/focus/fukushima/missionreport230513.pdf).

After the first IAEA mission, the Government of Japan and TEPCO considered the advice given by this mission report in the course of revising the Roadmap. The revised Roadmap, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4 revised 27 June 2013" is available on METI website (http://www.meti.go.jp/english/press/2013/pdf/0627_01.pdf).

The objective of the second IAEA mission was to provide more detailed and holistic review of the revised Roadmap and mid-term challenges, including the review of specific topics agreed and defined in the first IAEA mission, such as removal of spent fuel from storage pools, removal of fuel debris from the reactors, management of contaminated water, monitoring of marine water, management of radioactive waste, maintenance and enhancement of stability and reliability of structures, systems and components (SSCs), and research and development relevant to pre-decommissioning and decommissioning activities.

The IAEA team involved 16 international experts. Additionally, three experts of the Working Group 5 (Subgroup 5.3, Decommissioning) in charge of preparing the IAEA Fukushima Report accompanied the mission as observers, to obtain first-hand information for the report in preparation.

The Government of Japan and TEPCO have provided comprehensive information on the decommissioning plan. The IAEA team assessed these information, and had extensive discussions with the relevant institutions in Japan, followed by a visit to TEPCO's Fukushima

Daiichi NPS. The IAEA team also met with Japan's Nuclear Regulation Authority (NRA) to discuss the issues concerning marine monitoring.

Main Findings and Conclusions

The decommissioning of TEPCO's Fukushima Daiichi NPS is a challenging task that requires the allocation of significant resources, as well as the development and use of innovative technologies. The IAEA team considers that Japan developed its efforts towards decommissioning the plant promptly after the accident, and since then, Japan has achieved good progress in improving its strategy and the associated plans, as well as in allocating the necessary resources towards the safe decommissioning of TEPCO's Fukushima Daiichi NPS.

Since the first IAEA mission in April 2013, the Government of Japan and TEPCO have adopted a more proactive attitude and approach towards addressing the many difficulties at the site.

The IAEA team also notes that the current situation is very complex, and that there are still some challenging issues (e.g., contaminated water management, nuclear fuel removal, and fuel debris removal) that must be resolved to achieve the long-term stable condition of the plant. In light of these challenges, Japan appears to have adopted a well-oriented set of countermeasures.

Acknowledgements and Advisory Points

This report provides highlights of important progress (acknowledgments) in 19 areas such as spent fuel management, waste and contaminated water management, activities towards decommissioning and marine monitoring. The report also offers 19 advisory points where the IAEA team feels that current practices could be improved taking into account both international standards and the experience from planning and implementation of decommissioning programmes in other countries.

Holistic review of the revised and updated Roadmap

(1) Revised and updated Roadmap

Acknowledgement 1:

The IAEA team acknowledges that the revised Roadmap was developed based on more-realistic assumptions, a reflection of the current knowledge of the condition of each specific unit, and the feedback and opinions from stakeholders. The advice provided by the first IAEA mission in April 2013 was also taken into account. Within the framework of this revised Roadmap, a graded approach has been adopted to deal with more challenging issues, such as contaminated water management and fuel removal. The revised Roadmap describes a comprehensive structure of work needed for safe implementation and possible acceleration of the activities towards decommissioning of TEPCO's Fukushima Daiichi NPS, which includes national and international expertise and their technical capabilities, as well as establishing the International Research Institute for Nuclear Decommissioning (IRID).

Advisory point 1:

The IAEA team encourages the Government of Japan to continue leading and promoting efforts towards the safe implementation of the decommissioning of TEPCO's Fukushima Daiichi NPS. In relation to this, the IAEA team recognizes the important role of the NRA in ensuring nuclear and radiation safety. In addition, the IAEA team encourages the regulator to continue its involvement in overseeing the Implementation Plan activities.

(2) Public relations and communication

Acknowledgement 2:

TEPCO has become more proactive in implementing public information and communication activities. In particular, TEPCO has:

- established the Social Communication Office with communication and risk management experts under the TEPCO President's direct supervision, which is a good basis to enhance the needed competence and capability for timely dissemination of accurate information, and
- created comprehensive criteria to define methods and timing of public releases describing the operation, incidents and problems at TEPCO's Fukushima Daiichi NPS, through consultations with the NRA, the Fukushima Prefecture, municipalities and local communities.

Advisory point 2:

Recognizing the efforts by the Government of Japan to communicate with a variety of local stakeholders, the IAEA team urges METI to move forward for establishing the Fukushima Advisory Board without delay so that it can begin engaging stakeholders in a more structured manner. A clear definition about the role and competencies of the Board should be developed and agreed before starting the work.

Advisory point 3:

TEPCO should consider revising its communication strategy by expanding its targeted stakeholders to include on-site staff and contractors. Interactive outreach efforts that are now used for public stakeholders could also be effective for engaging the worker community. As these workers are responsible for safely conducting all activities at the power plant, it is critical that they have a clear understanding of plant conditions and how their work contributes to the plant's recovery.

Review of mid-term challenges and specific issues

(1) Spent fuel removal and fuel debris removal

(a) Removal of spent fuel from storage pools and further management

Acknowledgement 3:

The IAEA team recognizes the substantial efforts made by TEPCO in transitioning the Unit 4 refuelling floor to a state in which the first fuel assemblies could be removed in November 2013, thus completing a major milestone one month ahead of the original plan. A number of good practices have been identified, including: the use of mock-ups in operator training; the introduction of licensed operators with annual renewal; the use of detailed process flow charts; the invitation of international peer review; and the adoption of a post-operations review and continuous improvement process.

Acknowledgement 4:

The IAEA team recognizes that individual plans for the recovery of fuel from Units 1-3 have been developed and that the plans include hold points and contingency options. Additionally, the IAEA team recognizes TEPCO's efforts to meet the milestones identified in these plans, in particular the completion of debris removal from the Unit 3 refuelling floor to enable remote decontamination work to start.

Advisory point 4:

The IAEA team advises TEPCO to consider alternative options and additional measures to support the on-going fuel storage operations in the Common Spent Fuel Pool and future fuel disposition. These include: management of non-irradiated fuel; collection of data to assess fuel integrity; efforts to prevent cross contamination; techniques for removing rubble from fuel assembly internals; and management of the different categories of spent fuel.

(b) Removal of fuel debris from the reactors and further management

Acknowledgement 5:

The IAEA team recognizes TEPCO's and IRID's efforts to develop remote technology to identify water leakage locations in primary containment vessels (PCVs) and the supporting development work on techniques for fixing these leaks. Applying these devices to identify leak locations can be a significant step towards isolating the PCVs.

(2) Management of Contaminated Water

(a) Treatment and storage of contaminated water

Acknowledgement 6:

The IAEA team acknowledges the proactive steps taken by the Government of Japan to address the contaminated water issue, including the formulation of policies and the establishment of the Committee on Countermeasures for Contaminated Water Treatment. The IAEA team had an opportunity to meet with this Committee and exchange information and views on this topic.

Acknowledgement 7:

The IAEA team acknowledges the continued successful use of the caesium removal system to treat contaminated water accumulated in the reactor and turbine buildings, with consistently high system availability and performance. This has made it possible to very efficiently remove caesium isotopes, the major gamma emitters in the contaminated water, thereby enabling the recycling of part of the treated water for cooling of the damaged reactor cores, and the storing of the remaining part in above-ground tanks.

Advisory point 5:

The IAEA team believes it is necessary to find a sustainable solution to the problem of managing contaminated water at TEPCO’s Fukushima Daiichi NPS. This would require considering all options, including the possible resumption of controlled discharges to the sea. TEPCO is advised to perform an assessment of the potential radiological impact to the population and the environment arising from the release of water containing tritium and any other residual radionuclides to the sea in order to evaluate the radiological significance and to have a good scientific basis for taking decisions. It is clear that final decision making will require engaging all stakeholders, including TEPCO, the NRA, the National Government, Fukushima Prefecture Government, local communities and others.

Advisory point 6:

TEPCO’s strategy for managing contaminated water stored on-site depends heavily on the consistent and high performance of the Advanced Liquid Processing System (ALPS). The IAEA team encourages TEPCO to continue, and even intensify, its efforts to improve the performance and enhance the capacity of ALPS to be able to meet these goals as planned.

(b) Leakage issues including review of root cause analysis and countermeasures

Acknowledgement 8:

TEPCO has taken a more proactive role in identifying and permanently controlling leakage issues instead of a reactive role that focused on the mitigation of consequences and the treatment of symptoms by provisional countermeasures.

Advisory point 7:

The IAEA team emphasizes the importance of establishing a thorough and structured impact review process. Such a process should identify the effects of the individual countermeasures, which have been taken to address on-site issues, on the overall Roadmap activities and schedule (or vice versa). This would help to ensure compliance with the Implementation Plan.

(3) Management of Radioactive Waste

(a) Management of secondary waste from treatment of contaminated water

Acknowledgement 9:

The on-going treatment of contaminated water is resulting in the generation of large volumes of secondary waste streams that have high levels of radioactivity. The IAEA team was informed that adequate facilities and arrangements are in place for safely storing these wastes on a temporary basis. Efforts are also being made by TEPCO and other Japanese organizations to characterize these wastes and develop options for their processing in preparation for future disposal.

(b) Management of solid waste

Acknowledgement 10:

The IAEA team acknowledges that TEPCO is on the way to optimising the classification and handling of the solid waste to minimise volumes by reducing generation and recycling non- or low-contaminated waste.

Advisory point 8:

As radiological characterisation and waste classification are important for developing a long-term waste management strategy, establishing an on-site or near-site facility for radiological characterisation of the waste should be accelerated. Based on a sound radiological characterisation of the waste, it will be possible to establish a useful waste classification scheme, which will enable TEPCO to further develop its strategy for the processing, storage and final disposal of the waste.

Advisory point 9:

As decommissioning activities progress, large amounts of waste will continue to be generated and may require on-site storage for a long period of time. Therefore, careful planning of storage facilities for the whole decommissioning period should be in place. Design life of waste storage facilities should take into consideration the expected long decommissioning period. Due to limited space at the site, appropriate measures for waste minimisation and volume reduction should also be implemented.

(c) R&D to support waste management activities

Acknowledgement 11:

The IAEA team acknowledges further progress in developing and implementing a comprehensive research and development (R&D) programme to support the management of waste generated during the emergency phase and during pre-decommissioning and decommissioning activities at TEPCO’s Fukushima Daiichi NPS. A clearly demonstrated intention to take into account international experience and to benefit from international cooperation by involving the IRID has been recognized.

(4) Measures to stop or reduce ingress of groundwater into reactor and turbine buildings

Acknowledgement 12:

TEPCO has provided a comprehensive and multi-barrier approach to control the flow into and out of the reactor and turbine buildings. This multi-barrier approach to control groundwater flow appears to be underpinned by project planning, information and data gathering, testing of the proposed methods, and peer review by the Committee on Countermeasures for Contaminated Water Treatment. TEPCO has made a good beginning to address these issues in preparation for decommissioning. For example, there is a comprehensive plan for the feasibility, design and implementation of a frozen wall around the reactor buildings of Units 1-4. The lead technical role is handled by an expert task group with good planning of test activities that are to establish the feasibility and design parameters of the wall.

Advisory point 10:

The IAEA team encourages TEPCO to advance the implementation and careful monitoring of its measures to reduce the ingress of groundwater into reactor and turbine buildings and to prevent radioactive releases. In preparation for this, TEPCO should continue to evaluate and optimise the selected strategy for reducing water inflow into Units 1-4. The approach using the simultaneous operation of the proposed freeze wall, active sub-drain and water recharge -- in light of the limited space on site and the complex radiological environment -- should be carefully re-evaluated at each stage of the project as more data is collected.

Advisory point 11:

The IAEA team encourages TEPCO to continue to ensure that during the detailed planning stage an evaluation is performed (as a series of 'what if' scenarios) of the resilience of the overall approach to controlling the flow of groundwater into and out of the reactor and turbine buildings (and trenches). The IAEA team encourages TEPCO to consider the potential implications and possible mitigation measures arising from these scenarios. For example, such scenarios may include: the presence of higher-than-expected contamination levels observed in the groundwater removed from one or more of the sub-drains; the possibility of continued hydraulic connection between buildings at different elevations; and the incomplete effectiveness of an individual barrier.

(5) Reviewing of the public radiation exposure in the surrounding areas from on-going activities at the site

Advisory point 12:

As advised by the April 2013 mission, the IAEA team reiterates that the Government of Japan and TEPCO should establish constructive discussions with relevant authorities and stakeholders, including the NRA and local authorities, to assess and balance the risks and benefits of the dose limit at the boundaries and its practical implementation, particularly from direct exposures at the site-boundary arising from contaminated solids and accumulated liquids on the site and for the possibility of controlled liquids discharges from the site. The discussions should include an assessment of the balance of off-site and on-site exposure risks, as well as the consideration of the parallel progress of the off-site remediation programme and the roadmap for on-site decommissioning and their mutual interaction. The discussion should also include the definition of representative members of the public to be considered in the assessments of individual doses in different areas, taking into consideration the real and evolving off-site situation.

Advisory point 13:

Considering that controlled water discharges to the sea could be necessary in the future to achieve the long-term stable situation on-site and to reduce risks of accidental leakages as well as exposure to workers, the IAEA team encourages TEPCO to prepare safety and environmental impact assessments of this possible practice based on the limit of 1 mSv/year established by the NRA for the population, and to submit it to the NRA for the necessary regulatory review. In addition, the IAEA team encourages the Government of Japan, TEPCO and the NRA to hold constructive discussions with the relevant stakeholders on the implications of such authorized discharges, taking into account that they could involve tritiated water. Because tritium in tritiated water (HTO) is practically not accumulated by marine biota and shows a very low dose conversion factor, it therefore has an almost negligible contribution to radiation exposure to individuals.

For this purpose, the IAEA is ready to offer further advice to Japan on the suitable methodology to conduct the safety and environmental impact assessments associated with controlled discharges, as well as assistance for training experts in the involved parties (namely TEPCO and the NRA).

(6) Specific decommissioning programmes and decommissioning planning

Acknowledgement 13:

The IAEA team acknowledges all the Japanese stakeholders for the commendable work they are performing on Fukushima’s activities towards decommissioning and particularly for beginning discussion about the end state of decommissioning process, even if it involves a several decades schedule.

(7) Preparation for licensing and regulatory requirements

Acknowledgement 14:

Authorization process for the fuel removal from the spent fuel storage pool of Unit 4 to the Common Spent Fuel Pool was conducted in an efficient way between TEPCO and the NRA. Modifications to the initially submitted “Implementation Plan on Fuel Removal” were discussed and agreed in a timely manner, which enabled TEPCO to get the authorization to commence the activities with no delay. This is a good example to be followed in the future.

A thorough assessment of risks during the fuel removal operations at Unit 4 and identification of preventive and mitigation measures was performed and was included in the related “Implementation Plan on Fuel Removal”. Such an evaluation of safety, and demonstration of the adequacy of the proposed safety measures, contributed to the efficiency of the interaction with the regulator and to the timely completion of the authorization process.

Advisory point 14:

The Roadmap introduces hold points prior to the commencement of some activities. These hold points were introduced mainly due to the need to make technical decisions and to select and develop technical options for implementing activities. The IAEA team suggests that the licensing hold points should be integrated into the Roadmap or its implementing documents in order to include points of important regulatory decisions and to account for the time needed for regulatory reviews and approvals prior to commencing certain activities or implementation phases.

In addition to its involvement in the review of the official submissions by TEPCO and in the inspections of activities, the NRA should be more actively involved during the planning and preparatory process and should be kept informed about the options considered for the future activities. This will help the NRA to plan its activities and resources more efficiently, and to better respond to public expectations.

(8) Technologies for remote decontamination, technologies for investigation of PCV/RPV interiors, etc.

Acknowledgement 15:

The IAEA team visited the remote-control room for operating robotic equipment that is being used for clearing rubble from the top floor of Unit 3. This is an excellent beginning for what will be ever-increasing needs for remotely operated equipment for many diverse future tasks. This real-time experience will provide valuable lessons for the expansion of capacity.

Acknowledgement 16:

Establishing a working group for developing remotely operated equipment has resulted in shortening the time between identification of a specific need and delivery of individual remote technology equipment. For example, after the working group was established, the subsequent devices for leak location within the drywell have taken only seven to eight months. The participation of the plant representatives in the working group is a good practice that will contribute to success of development.

(9) Programme and processes to maintain and to enhance stability and reliability of structures, systems and components until decommissioning

Acknowledgement 17:

The IAEA team acknowledges the efforts that have been implemented by the focused reliability improvements, quality assurance, countermeasure project, contaminated water treatment organizations and the site personnel as a sign of the utility’s progress toward taking a more anticipatory role in identifying and controlling equipment issues instead of a reactive role. TEPCO has made proactive and diligent attempts and has demonstrated visible processes and efforts trying to identify areas of concern and measures to maintain and improve performance and reliability of SSCs, and minimising risk.

Advisory point 15:

The IAEA team suggests that TEPCO revisit the assumptions, especially on service lifetimes and other technical specifications, of the SSCs placed as a prompt action immediately following the accident as well as to consider conservative lifetime assumptions in design of new SSCs.

Advisory point 16:

The IAEA team suggests that specific measures to control and to sample run-off storm water from each storage facility are taken to minimise the potential dispersing contamination through ground/storm water. This suggestion is in line with good industry practices and with TEPCO's commitment for implementation of preventive measures.

Marine monitoring and assessment of potential radiological impact

Acknowledgement 18:

A comprehensive "Sea Area Monitoring Plan" was established with a detailed description of sampling positions, including depth distribution, frequency of sampling, detection limit of the analysis to be performed, and indication of the responsible entity. The plan is kept flexible in space and time for reaction on special events when additional inputs to the marine environment can occur or would be expected. The Plan will ensure a comprehensive overview of the environmental situation in the marine environment and the data will provide sufficient background for dose assessments for radiation exposure from marine pathways.

The analytical centres visited by the IAEA team are accredited according to ISO 17025 and should therefore produce reliable, and thus comparable, data. The marine monitoring results are made public nationwide and internationally by means of information dissemination to international organizations and nuclear regulatory bodies, as well as by websites of the monitoring organizations in a prompt way.

Acknowledgement 19:

Wherever possible, a number of countermeasures were implemented to protect further contamination of the marine environment, such as isolating and removing the contamination sources and preventing leakages. Thus, the initial levels of concentrations in the sea area have dropped significantly since 2011 and are found near the plant outside the port to be around 1 Bq/L for Cs-137. The levels further off-shore between 2 and 20 kilometres away are now mostly below 0.1 Bq/L, and beyond this region, the levels are almost near those prior to the accident of 0.001–0.003 Bq/L for Cs-137. The decrease of activity concentration in seawater is also reflected in the levels in biota and seafood.

Advisory point 17:

Because about 10 Japanese institutions are involved in marine monitoring, it is advised to perform interlaboratory comparisons to ensure the high quality of data and to prove the comparability of the results. This can be done by splitting and sharing samples or by a proficiency test (PT). The IAEA Environment laboratories would be pleased to organise such tests in collaboration with responsible authorities in Japan.

International partners could be included in the analyses of samples collected by Japanese institutions to enhance the credibility of the data. The IAEA would be ready to recommend good laboratories to take part in this exercise based on the recently performed PT in relation to the determination of Cs-134, Cs-137 and Sr-90 in seawater. Other radionuclides, such as tritium, could also be included in these exercises.

Such activities could contribute to more confidence in the results produced and improve the credibility of the results produced by the involved institutions. It will also help to show higher transparency of the monitoring activities.

Advisory point 18:

Interpreting the data and presenting it to the public in an understandable, but scientifically correct, way is extremely important but not always simple. Just to show the concentration of radionuclides in the environment without interpretation is not sufficient to gain trust from the public. One possibility could be to refer these data to doses arising from natural radionuclides or to show the temporal trend since the accident. By this, the improvement of the general situation can be demonstrated.

The IAEA team encourages Japan to continue with public seminars or workshops as done in the past and to involve relevant stakeholders (in particular fishermen, consumers and market traders) in data interpretation.

Advisory point 19:

The IAEA team encourages relevant counterparts to consider installing underwater in-situ measurement detectors close to the TEPCO's Fukushima Daiichi NPS site to measure continuously the concentration of gamma-emitting radionuclides in seawater. This would complement the monitoring strategy with separate sampling from ships and only in a limited time scale due to discontinuous sampling. Based on present concentration in the port and near to the port, the detectors will allow detecting Cs-137 in seawater continuously by gamma-spectrometry. This data could also be made available to the public by Internet. These systems would allow detecting any sudden increase of inflow from unknown sources, such as from contaminated groundwater. However, it needs to be mentioned that structures must be found to install these systems properly and transmit the data and spectra. The systems also need to be cleaned from biological fouling growing on the containment. Underwater systems are commercially available in the meantime.

1. BACKGROUND, OBJECTIVES AND SCOPE OF THE MISSION

1.1. BACKGROUND

Following the accident at TEPCO's Fukushima Daiichi NPS on 11 March 2011, the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4" (hereinafter referred to the "Roadmap") was adopted by the Government of Japan and the TEPCO Council on Mid-to-Long-Term Response for Decommissioning in December 2011. The Roadmap was revised in July 2012 and June 2013. The Roadmap includes a description of the main steps and activities to be implemented for the decommissioning of the TEPCO's Fukushima Daiichi NPS through the combined effort of the Government of Japan and TEPCO.

The Government of Japan (Ministry of Economy, Trade and Industry – METI) asked the IAEA to organize an International Peer Review of Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4, with the aims of enhancing international cooperation and sharing of information and knowledge with the international community. The intention to host the review was expressed during the Fukushima Ministerial Conference on Nuclear Safety in December 2012.

The International Peer Review was planned to be implemented in two steps (two missions) in the framework of the IAEA Action Plan on Nuclear Safety. The first IAEA mission was conducted from 15 to 22 April 2013 with the main purpose of undertaking an initial review of the Roadmap including assessments of decommissioning strategy, planning and timing of decommissioning phases and a review of several specific short-term issues and recent challenges. This mission report is available on the IAEA webpage (http://www.iaea.org/newscenter/focus/fukushima/ missionreport230513.pdf).

After the first IAEA mission, the Government of Japan and TEPCO considered the advice given through the mission report in the course of revising the Roadmap. The revision of the Roadmap, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4 revised 27 June 2013" is available on METI's website (http://www.meti.go.jp/english/press/2013/pdf/0627_01.pdf).

1.2. OBJECTIVE

The objective of the International Peer Review was to provide an independent review of the activities associated with planning and implementation of TEPCO's Fukushima Daiichi NPS decommissioning. It was based on the IAEA Safety Standards and other relevant safety and technical advice and aimed at assisting the Government of Japan in the implementation of the "Mid-and-Long-Term Roadmap towards the Decommissioning of the TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4". In particular, it was intended to:

- Improve the planning of decommissioning and the implementation of pre-decommissioning activities at TEPCO's Fukushima Daiichi NPS; and

- Facilitate the sharing of good practices and lessons learned with international community for decommissioning operations after the accident.

The objective of the second IAEA mission was to provide more detailed and holistic review of the revised Roadmap and mid-term challenges including the review of specific topics agreed and defined in the first IAEA mission.

1.3. SCOPE OF THE MISSION

The scope of the second IAEA mission covered following items:

Item 1: Holistic review of the revised and updated Roadmap including public relation and communication issues.

Item 2: Review of mid-term challenges including following specific topics:

- Item 2-1:
  - Removal of spent fuel from storage pools and further management;
  - Removal of fuel debris from the reactors and further management.
- Item 2-2:
  - Management of contaminated water:
    - treatment of contaminated water;
    - storage of accumulated water;
    - leakage issues including review of root cause analysis and countermeasures.
  - Waste management:
    - management of secondary waste from treatment of contaminated water;
    - management of solid waste;
    - R&D to support waste management activities.
  - Measures to stop or reduce ingress of groundwater into reactor and turbine buildings;
  - Reviewing of the public radiation exposure in the surrounding areas from on-going activities at the site;
  - Marine monitoring and assessment of potential radiological impact.
- Item 2-3:
  - Specific decommissioning programmes and decommissioning planning;
  - Preparation for licensing and regulatory requirements;
  - Technologies for remote decontamination, technologies for investigation of PCV/RPV interiors, etc.

- Item 2-4:
  - Programme and processes to maintain and to enhance stability and reliability of structures, systems and components until decommissioning.

Management of radioactive waste from off-site remediation activities was not within the scope of this review, however it was considered during the review in so far as it would have an impact on the decommissioning process.

2. CONDUCT OF THE MISSION

The mission involved 16 international experts. Additionally, three experts of the Working Group 5 (Subgroup 5.3, Decommissioning) in charge of preparing the IAEA Fukushima Report accompanied the mission as observers, to obtain first-hand information for the report in preparation.

The mission was conducted from 25 November through 4 December 2013. The mission consisted of meetings with METI, TEPCO, IRID and NRA in Tokyo, a visit to the TEPCO's Fukushima Daiichi NPS, and further meetings at the Fukushima Daini NPS (see Mission Programme in Appendix I). The Japan Chemical Analysis Centre in Chiba and the Analytical Radioactivity Monitoring Centre of Fukushima in Fukushima City were also visited.

The visit to TEPCO's Fukushima Daiichi NPS provided an opportunity to observe how the Roadmap activities were progressing and the discussion of generic and specific site issues by the plant operator.

Sufficient time was allocated for drafting of the report and for further discussions with METI/TEPCO. The meeting with the NRA and other relevant ministries on sea water monitoring issue and the meeting with the Committee on Countermeasures for Contaminated Water Treatment were also organized as planned.

The IAEA team delivered a Preliminary Summary Report with acknowledgements and advisory points for Japan's consideration on the final day of the mission. This report was published on the METI website http://www.meti.go.jp/english/press/2013/1204_01.html and on the IAEA website http://www.iaea.org/newscenter/focus/fukushima/missionreport041213.pdf.

In addition, an IAEA press conference was held in Tokyo to inform journalists about the mission and its main findings.

3. MAIN FINDINGS, ACKNOWLEDGEMENTS AND ADVISORY POINTS

3.1. HOLISTIC REVIEW OF THE REVISED AND UPDATED ROADMAP INCLUDING PUBLIC RELATION AND COMMUNICATION ISSUES

3.1.1. REVISED AND UPDATED ROADMAP

Main Findings

The “Mid-and-Long-Term Roadmap towards Decommissioning of TEPCO’s Fukushima Daiichi NPS Units 1-4” is the basic document that describes the strategy and planning for decommissioning TEPCO’s Fukushima Daiichi NPS units 1-4. The first version of this document was adopted by the Government of Japan and the TEPCO Council in December 2011, and it was updated in July 2012.

The revised Mid- and Long-Term Roadmap was compiled and adopted by the Council for the Decommissioning of TEPCO’s Fukushima Daiichi NPS in June 2013. The key points of the revised Roadmap are as follows:

- Re-examining the schedule towards decommissioning based on the condition of each unit, which also includes the provision of several options for the most relevant decommissioning activities (contingency plans), to take into consideration the results of the evaluations of each specific situation;
- Strengthening of communication with the local stakeholders and across all levels of society; and
- Developing a comprehensive structure to work with international expertise.

The revised Roadmap prioritizes the safety of local residents and workers during the implementation of decommissioning activities, the importance of transparent communication with the public, the necessity of further updating the Roadmap based on the on-site situation and the latest R&D developments, and the importance of harmonizing TEPCO and Government efforts to achieve the Roadmap’s goals. The Roadmap also establishes an organizational structure and indicates relations between organizations directly involved in TEPCO’s Fukushima Daiichi NPS decommissioning. The Government of Japan is determined to play a proactive role in decommissioning. TEPCO is responsible, inter alia, for developing implementation plans with regard to all activities towards the decommissioning of specified reactor facilities. The Council for the Decommissioning of TEPCO’s Fukushima Daiichi NPS is the highest organizational executive body leading the project. Other subordinated bodies have been created to deal with specific issues in a proactive way, such as the Committee on Countermeasures for Contaminated Water Treatment.

The revised Roadmap provides the basis for defining a scenario for the decommissioning of TEPCO’s Fukushima Daiichi NPS Units 1 to 4, so that decommissioning activities will be conducted towards a rational end. Possible decommissioning scenarios will be considered and established through gathering information both from Japan and abroad on how to ensure safe decommissioning in consideration of the end state of facilities. It is planned to involve experts in Japan and academic societies in the review of the decommissioning scenario.

An important milestone was achieved on 18 November, 2013, when TEPCO began to remove the first fuel assemblies from Unit 4's Spent Fuel Pool. Phase 1 of the Roadmap, which included all activities up to the start of fuel removal from the spent fuel pool, is thus over. Phase 2, covering the period up to the commencement of fuel debris removal, may last for about 10 years. Phase 3, the period up to the completion of all decommissioning measures, is expected to take from 30 to 40 years.

Acknowledgements

Acknowledgement 1:

The IAEA team acknowledges that the revised Roadmap was developed based on more-realistic assumptions, a reflection of the current knowledge of the condition of each specific unit, and the feedback and opinions from stakeholders. The advice provided by the first IAEA mission in April 2013 was also taken into account. Within the framework of this revised Roadmap, a graded approach has been adopted to deal with more challenging issues, such as contaminated water management and fuel removal. The revised Roadmap describes a comprehensive structure of work needed for a safe implementation and possible acceleration of the activities towards decommissioning of TEPCO's Fukushima Daiichi NPS, which includes the national and international expertise and their technical capabilities, as well as establishing the International Research Institute for Nuclear Decommissioning (IRID).

Advice

Advisory point 1:

The IAEA team encourages the Government of Japan to continue leading and promoting of efforts towards the safe implementation of the decommissioning of TEPCO's Fukushima Daiichi NPS. In relation to this, the IAEA team recognizes the important role of the NRA in ensuring nuclear and radiation safety. In addition, the IAEA team encourages the regulator to continue its involvement in overseeing the Implementation Plan activities.

3.1.2. PUBLIC RELATIONS AND COMMUNICATION

Main Findings

To help people understand the plans and efforts underway to decommission TEPCO's Fukushima Daiichi NPS, the Government of Japan and TEPCO must undertake public relations and communication activities in an open and transparent manner. Such public information efforts are most effective if they include two-way communication opportunities instead of only one-directional releases of messages. Engaging stakeholders can build trust and credibility while reducing public anxiety. One of the revised Roadmap's basic principles is the importance of maintaining transparent communication with the public both at the local and national levels to gain their understanding and respect.

TEPCO has recognized that there has been a perception gap between TEPCO and the public in terms of how to communicate about on-site incidents, potential risks, and possible countermeasures to mitigate such risks. TEPCO has created a new position of Risk Communicator and established the Social Communication Office to fill this gap and to promote appropriate public relations and risk communication.

In line with the advice given by the previous IAEA Decommissioning Mission in April 2013, the Government of Japan has been working to set up the provisionally named Fukushima Advisory Board (FAB), with the participation of the Fukushima Prefectural government, municipalities, relevant local organizations such as the associations of commerce and industry, fishermen's associations, local media, universities, non-profit organizations, etc., to strengthen public relations and promote public communication by providing information and listening to opinions and suggestions. As of this report, however, work to establish the FAB is behind schedule. METI expects to resume efforts to organize the FAB by the end of FY2013.

Further, following the significant delay in announcing a water-leakage event in August 2013, TEPCO has updated its communication strategy to place more emphasis on "rapid and honest announcements concerning the risks and negative situations, without fear of repercussions, even when the results of evaluation do not adequately establish clear grounds."

The IAEA team supports this move toward releasing information on a more timely basis. At the same time, the IAEA team stresses the importance of not sacrificing accuracy, clarity and appropriate context in a rush to communicate. In short, simple and clear communications can be provided quickly, but they must still be produced after careful consideration. In this connection, the IAEA team encourages TEPCO to utilize the expertise of the Nuclear Reform Monitoring Committee, which has been asked to monitor the effectiveness of communication strategies and plans and to recommend improvements as needed.

The Government of Japan has begun efforts to revive economic activity in communities near TEPCO's Fukushima Daiichi NPS. By engaging local industries and workers, these revitalization activities have contributed to a better understanding of plant conditions and of plans and efforts to decommission the accident site. These efforts may also contribute to the overall public understanding of the situation.

Acknowledgements

Acknowledgement 2:

TEPCO has become more proactive in implementing public information and communication activities. In particular, TEPCO has:

- *established the Social Communication Office with communication and risk management experts under the TEPCO President's direct supervision, which is a good basis to enhance the needed competence and capability for timely dissemination of accurate information, and*
- *created comprehensive criteria to define methods and timing of public releases describing the operation, incidents and problems at TEPCO's Fukushima Daiichi NPS, through consultations with the NRA, the Fukushima Prefecture, municipalities and local communities.*

Advice

Advisory point 2:

Recognizing the efforts by the Government of Japan to communicate with a variety of local stakeholders, the IAEA team urges METI to move forward for establishing the Fukushima Advisory Board without delay so that it can begin engaging stakeholders in a more structured manner. A clear definition about the role and competencies of the Board should be developed and agreed before starting the work.

Advisory point 3:

TEPCO should consider revising its communication strategy by expanding its targeted stakeholders to include on-site staff and contractors. Interactive outreach efforts that are now used for public stakeholders could also be effective for engaging the worker community. As these workers are responsible for safely conducting all activities at the power plant, it is critical that they have a clear understanding of plant conditions and how their work contributes to the plant's recovery.

3.2. REVIEW OF MID-TERM CHALLENGES AND SPECIFIC ISSUES

3.2.1. SPENT FUEL REMOVAL AND FUEL DEBRIS REMOVAL

Fuel stored in Units 1-4 and fuel debris present in the cores of Units 1-3 represent the greatest hazard on the Fukushima site. While there is an incentive to reduce this hazard as soon as possible it needs to be recognized that this is a complex task, which needs to be tackled in a sequential manner, and which will take many years to complete.

3.2.1.1 Removal of spent fuel from the storage pools and further management

Main Findings

The nine casks, which originally were housed in the Cask Custody Area located beside the sea and affected by the tsunami, were removed from the Cask Custody Area. After integrity checks and replacement of the outer lid seals, they were transferred to the new Temporary Cask Custody Area. Operations were completed in May 2013.

The new Cask Custody Area is identified as temporary. Temporary implies a short-term position while the longer-term solution is put in place. Similarly, fuel stored in the Common Spent Fuel Pool is an interim position. The longer-term position and its options are to be identified.

<u>Unit 4</u>

Spent fuel removal operations at Unit 4 Spent Fuel Pool were initiated on 18 November 2013, marking the achievement of a major Roadmap milestone Since the peer review mission in April 2013, the refuelling floor in Unit 4 has undergone a transition from a state of damage to one representing normal operations. The scale of this achievement within the target timeframe is commended.

Over the last five months, 659 fuel assemblies have been removed from the Common Spent Fuel Pool (now accommodated in 14 new dry storage casks in the Temporary Cask Custody Area), the fuel removal cover on Unit 4 has been completed, the fuel handling machine and building crane have been installed and commissioned, large debris from the spent fuel storage pool has been removed, small debris has been removed from ~73% of the spent fuel storage racks, vacuuming the top of fuel assemblies in ~19% of storage racks has been completed, and provisions have been made to secure the spent fuel pool cooling systems in both Unit 4 and the Common Spent Fuel Pool.

To support the initiation of spent fuel operations, a full safety analysis and process flow diagram have been completed and subjected to international peer review. The faults identified have been analysed and safety measures introduced to mitigate these fault scenarios. A range of measures have been introduced to confirm fuel mechanical integrity and to mitigate the potential for fuel drops. These include: operating procedures developed for routine operations and all fault scenarios; independent review of operating procedures by the International Expert Group that was established by IRID; checks on fuel that had been impacted by large debris; visual integrity checks before moving fuel; a reduction in fuel hoist speeds; a two-point check to ensure fuel handling grabs are engaged[1]; oversight by the NRA of fuel handling operations; and recovery techniques in the event that a fault scenario is realized.

Through discussion, the IAEA team has identified a number of areas where additional support to on-going fuel storage operations in the Common Spent Fuel Pool and future fuel disposition should be considered; these include:

- The current strategy for non-irradiated fuel is to transfer it to the Common Spent Fuel Pool while a longer–term strategy is being studied. While non-irradiated fuel is useful for commissioning purposes, apart from surface contamination the fuel does not represent a radiological risk. The current strategy utilises valuable storage space, and storing non-irradiated fuel in the presence of a moderator is a criticality risk (although assessed to be very low) which could be avoided altogether. TEPCO should consider alternative options for managing this fuel;
- The Roadmap identifies that the evaluation of the long-term soundness of fuel assemblies removed from spent fuel pools will be completed by 2017. Experience has shown that the data to inform on-going spent fuel integrity needs to be established up-front. Examples include: visual inspections on a number of fuel assemblies to make reference points; and trend monitoring of pool and cask liquor samples. TEPCO should consider establishing and collecting the data that will be required to confirm on-going spent fuel integrity;
- The potential remains for debris to be trapped within the fuel assemblies. Debris will affect the ability to dry fuel and the acceptance criteria for downstream plants. Technology will need to be developed to remove debris from fuel assembly internals. TEPCO needs to consider how to address this issue;
- While it is recognised that TEPCO has analysed the impact of cross contamination of the common pool with liquid and particulates from Unit 4, consideration, however, should be given to minimising this possibility by introducing transport cask flushing operations prior to discharge in the common pool;
- Currently, the Common Spent Fuel Pool will end up with five categories of fuel: intact fully irradiated fuel; intact partially irradiated fuel; non-irradiated fuel; failed fuel[2]; and damaged fuel.[3] Consideration needs to be given to each of the fuel categories in terms of the long-term management, For example, the reprocessing of large quantities of partially irradiated fuel can present a process challenge.

Units 1-3

The IAEA team recognises that the recovery of spent fuel from Units 1-3 is more challenging than Unit 4; although learning from Unit 4 should inform spent fuel recovery from Units 1-3. There are differences in terms of activity levels inside in the pool, contamination of the refuelling floor, and impact on storage racks and fuel within the storage pool. In this respect,

[1] A two-point check involves checking that the fuel handling grab is engaged onto the fuel assembly visually from above the water surface and underwater with a camera.

[2] Failed fuel describes assemblies where the barrier containing the fission products has been breached.

[3] Damaged fuel describes assemblies where mechanical damage has occurred that has resulted in a geometrical change from the ‘as manufactured’ condition.

multi-option plans have now been developed for each of the reactor units. Removal of fuel from individual unit storage pools is being addressed in a sequential manner; based upon radiation surveys.

Enablers to facilitate man access and the construction of the fuel removal cover on Unit 3 have included the completion of the removal of debris from the top of Unit 3 to reveal the refuelling floor. Recovery of the fuel handling machine from within the storage pool remains a task to be completed and will require detailed underwater surveys. Decontamination of the refuelling floor will be initiated shortly using one of the three robotic decontamination techniques which have been developed.

Acknowledgements

Acknowledgement 3:

The IAEA team recognizes the substantial efforts made by TEPCO in transitioning the Unit 4 refuelling floor to a state in which the first fuel assemblies could be removed in November 2013, thus completing a major milestone one month ahead of the original plan. A number of good practices have been identified, including: the use of mock-ups in operator training; the introduction of licensed operators with annual renewal; the use of detailed process flow charts; the invitation of international peer review; and the adoption of a post-operations review and continuous improvement process.

Acknowledgement 4:

The IAEA team recognizes that individual plans for the recovery of fuel from Units 1-3 have been developed and that the plans include hold points and contingency options. Additionally the IAEA team recognizes TEPCO's efforts to meet the milestones identified in these plans in particular the completion of debris removal from the Unit 3 refuelling floor to enable remote decontamination work to start.

Advice

Advisory Point 4:

The IAEA team advises TEPCO to consider alternative options and additional measures to support the on-going fuel storage operations in the Common Spent Fuel Pool and future fuel disposition. These include: management of non-irradiated fuel; collection of data to assess fuel integrity; efforts to prevent cross contamination; techniques for removing rubble from fuel assembly internals; and management of the different categories of spent fuel.

3.2.1.2 Removal of fuel debris from the reactors and further management

Fuel "debris" refers to nuclear fuel that has melted, melted fuel that might have got mixed with other surrounding materials and components that served to make up the reactor core and other reactor internal components. An important ultimate objective of the clean-up is the removal of the fuel debris remaining within the reactor vessels and that which has escaped into the primary containment vessels or elsewhere within connected systems.

Debris removal will require special methods and equipment that are based on the debris characteristics, its configuration, and the paths by which access to its locations can be achieved. Before such designs can be fully developed, it is essential to obtain characterization information and data that includes visual inspection, material characteristics (such as size, hardness), its radioactivity, and other properties, not only of the material itself but also of its surroundings. All of these factors can vary widely by location within the RPV and the PCV where vessel overheating has occurred.

The ability to conduct such characterization and eventual debris removal are significantly hindered because of the damage and radioactive conditions created by the accidents. Specifically, the PCV water leakage to the reactor building and from the reactor buildings to the turbine buildings must be resolved to allow gaining access and establishing conditions that will make possible the subsequent phases of work towards debris removal.

Main Findings

Progress is being made in locating water leaks from the Unit 1 PCV, such as those at the drain line pipe headed to the PCV. In addition, limited success has been made towards gaining a visual record of the area beneath the Unit 2 reactor vessel pedestal . Four approaches are being considered for blocking the leakage; which one will prove useful depends on further identification of the leak locations.

Recognizing that it will be several years before the fuel debris can be removed, a preliminary, high-level concept has been put forward. The approach uses a remote handling machine mounted atop the reactor vessel flange while the debris remains submerged in water. However, alternate methods that include dry removal have not been ruled out. R&D is being conducted related to fuel debris and further R&D activities are also planned.

Acknowledgements

<u>Acknowledgement 5:</u>

The IAEA team recognizes TEPCO's and IRID's efforts to develop remote technology to identify water leakage locations in primary containment vessels (PCVs) and the supporting development work on techniques for fixing these leaks. Applying these devices to identify leak locations can be a significant step towards isolating the PCVs.

3.2.2. MANAGEMENT OF CONTAMINATED WATER

3.2.2.1 Treatment and storage of contaminated water

Management of contaminated water at TEPCO's Fukushima Daiichi NPS continues to be one of the major challenges for TEPCO and the Government of Japan. This was indeed one of the key areas addressed during the IAEA international peer review mission to Japan in April 2013. Given the risk of leakage and the potential for spreading contamination to the surrounding environment, together with possible risks to the long-term integrity of the plant structures, special emphasis was placed on the need for adequate measures for early detection of leaks and prompt mitigation of their consequences.

The risk of leakage from storage tanks has been brought into focus by several recent events. In July 2013, TEPCO discovered contaminated groundwater entering the sea port, with the source of the contamination suspected to be water from one of the trenches connected to the Unit 2 turbine building. In August 2013, TEPCO found that highly contaminated water (approximately 300 m^3) had leaked from one of the storage tanks into the surrounding soil. These discoveries led to significant international attention and to concerns about safety arrangements at the TEPCO's Fukushima Daiichi NPS site.

Responding these incidents, the Government of Japan announced on 3 September 2013 its decision to play a more proactive role in implementing preventive and multi-layered countermeasures to address the contaminated water problem, and the Government published its "Basic Policy for the Contaminated Water Issues at the TEPCO's Fukushima Daiichi Nuclear Power Station". In line with this policy, the Government established the "Inter-Ministerial Council for Contaminated Water and Decommissioning Issues", the "Inter-Governmental Liaison Office near TEPCO's Fukushima Daiichi NPS" and the "Inter-Governmental Council for Fostering Mutual Understanding on the Contaminated Water Issue".

The policy laid out three basic principles for the countermeasures: (i) Removing the source of the contamination; (ii) Isolating groundwater from the contamination source; and (iii) Preventing leakage of the contaminated water. Based on these principles, TEPCO took a number of immediate countermeasures and planned fundamental countermeasures to be implemented within one to two years as enumerated below.

Immediate countermeasures: (i) Enclosing contaminated soil with sodium silicate walls; (ii) Pumping out contaminated water from the trenches and isolating them; and (iii) Bypassing groundwater.

Fundamental countermeasures: (i) Pumping out the groundwater from the sub-drain before it can reach the reactor buildings; (ii) Installation of sea-side impermeable walls; (iii) Installation of land-side impermeable walls; and (iv) Installation of contaminated water treatment equipment with superior performance.

The Government appointed the Committee on Countermeasures for Contaminated Water Treatment that is playing a crucial role in assessing the efficacy of these countermeasures and advising on their implementation. TEPCO has also established a "Contaminated Water and Tank Countermeasure Division" in order to have a more focussed approach to the management of contaminated water.

Clearly, resolving the contaminated water issue is of crucial importance to ensuring the stability of the plant over the long term and to minimising the risk of uncontrolled releases of contaminated water to the environment. The main findings of the IAEA team, including highlights of important progress and some advices for further enhancement of the efforts, are discussed below.

Main Findings

A major focus of on-going activities at the site is treating large volumes of accumulated water for removing caesium isotopes, desalinating the treated water, using the treated and desalinated water for cooling of the damaged reactor cores, and storing the remaining water in numerous over ground tanks.

Treatment of contaminated water for removing caesium isotopes has been a successful operation, due to the consistent performance of the caesium removal system. More than 800,000 m^3 of contaminated water have been treated so far.

The total volume of radioactive water accumulated and stored at the site is enormous, approximately 500,000 m^3 at the time of the mission. This includes approximately 400,000 m^3 stored in numerous (more than 900) over ground tanks and approximately 100,000 m^3 accumulated in the basements of the reactor buildings, turbine buildings, underground trenches and radioactive waste treatment buildings. TEPCO is also installing new tanks to increase storage capacity. According to information provided during the mission, storage capacity is planned to be increased from the current approximately 410,000 m^3 to approximately 500,000 m^3 by the end of fiscal year 2013. Further increase in storage capacity, up to approximately 800,000 m^3, is planned by the end of fiscal year 2015. It is important to note that the adequacy of this storage capacity rests on the assumption of timely and effective implementation of several countermeasures, including pump-up and discharge of groundwater with groundwater bypass and sub-drains (discussed further in Section 3.2.4).

The volume of contaminated water accumulated in the sea-side underground trenches is relatively low, but the activity concentration is very high. Considering that some of these trenches are damaged and pose a significant risk of contamination to the surrounding environment, as was evident from the recently reported leaks, it is imperative to remove or treat the accumulated water urgently. TEPCO has recognized this urgency, as was evident during the site visit from the use of mobile treatment systems for reducing the activity in the water accumulated in the trenches connected to Units 3 and 4. These mobile systems are being operated in recirculation mode and with continued use it is expected that the radioactivity content of the accumulated water and associated risk from possible leakage will be reduced substantially.

Out of the total volume stored in over ground tanks, approximately 300,000 m^3 is the concentrate stream from reverse osmosis desalination process. This water has substantial radioactivity due mainly to the presence of beta-emitting ^{90}Sr-^{90}Y and relatively small amounts of other radionuclides. As part of its strategy for managing contaminated water stored on-site, TEPCO plans to use the advanced Multi-Nuclide Removal System (ALPS) for removing all fission products, activation products and actinides (except tritium) to below detectable levels, thereby significantly reducing the risk of storing high inventory of radioactive material in liquid form in numerous over ground tanks. This treatment system, having three parallel lines each capable of processing 250 m^3 of contaminated water per day, is undergoing hot tests to establish stable operating conditions and performance. From the information provided to the mission, it is understood that some corrosion problems encountered in the pre-treatment sections have now been addressed. TEPCO also reported that all three lines have been operating. So far, about 30,000 m^3 of contaminated water have been treated by this system. According to the information provided, out of the 62 target radionuclides, it has been possible to remove 58 radionuclides to below detectable levels. There is residual low activity in the treated water due to the remaining 4 radionuclides (Co-60, Ru-106, Sb-125 and I-129), which are removed, but still detectable. It is understood that TEPCO is making efforts to adjust operating conditions and sorption media to more efficiently capture the residual traces of the remaining radionuclides. The IAEA team also learned about plans to establish two more ALPS treatment systems, one funded by TEPCO and the other funded by the national government. With further improvement of performance and augmentation of throughput capacity, it is expected that these systems will accelerate the treatment of the large volume of contaminated water stored in the tanks.

As noted above, the ALPS treatment system is not able to remove tritium that is also present in the contaminated water to the level of several thousand Becquerel per cubic centimetre. In fact, removing this level of concentration of tritium from hundreds of thousands of cubic metres of water is technologically challenging and yet to be demonstrated. In the opinion of the IAEA team, a path forward for further management of the treated tritium-bearing water is necessary in order to reach a sustainable solution to the contaminated water problem. This would require careful consideration of all options, including dilution and controlled discharge to the ocean conforming to applicable discharge standards.

Acknowledgements

Acknowledgement 6:

The IAEA team acknowledges the proactive steps taken by the Government of Japan to address the contaminated water issue, including the formulation of policies and the establishment of the Committee on Countermeasures for Contaminated Water Treatment. The IAEA team had an opportunity to meet with this Committee and exchange information and views on this topic.

Acknowledgement 7:

The IAEA team acknowledges the continued successful use of the caesium removal system to treat contaminated water accumulated in the reactor and turbine buildings, with consistently high system availability and performance. This has made it possible to remove caesium isotopes very efficiently, the major gamma emitters in the contaminated water, thereby enabling the recycling of part of the treated water for cooling of the damaged reactor cores, and the storing of the remaining part in above-ground tanks.

Advice

<u>Advisory point 5:</u>

The IAEA team believes it is necessary to find a sustainable solution to the problem of managing contaminated water at TEPCO's Fukushima Daiichi NPS. This would require considering all options, including the possible resumption of controlled discharges to the sea. TEPCO is advised to perform an assessment of the potential radiological impact to the population and the environment arising from the release of water containing tritium and any other residual radionuclides to the sea in order to evaluate the radiological significance and to have a good scientific basis for taking decisions. It is clear that final decision making will require engaging all stakeholders, including TEPCO, the NRA, the National Government, Fukushima Prefecture Government, local communities and others.

<u>Advisory point 6:</u>

TEPCO's strategy for managing contaminated water stored on-site depends heavily on the consistent and high performance of the Advanced Liquid Processing System (ALPS). The IAEA team encourages TEPCO to continue, and even intensify, its efforts to improve the performance and enhance the capacity of ALPS to be able to meet these goals as planned.

3.2.2.2 Leakage issues including review of root cause analysis and countermeasures

In addition to providing an overall review of the treatment and storage of contaminated water activities associated with planning and implementation of TEPCO's Fukushima Daiichi NPS decommissioning, the IAEA team was specifically asked to review the challenges recently encountered by the leakages from the water storage tanks. The scope was to review the root cause analysis and countermeasures performed by TEPCO.

Background: On 19 August 2013, TEPCO discovered water accumulating on the concrete foundation, as well as on the ground near two drain valves, in tank storage section H4. The next day, further investigations identified Tank No. 5 in the H4 section as the source of the leak, releasing approximately 300 m^3 of contaminated water. In the following weeks, while taking immediate countermeasures for mitigating the event consequences, TEPCO also conducted an apparent cause investigation. TEPCO explained to the IAEA team that the direct cause was determined as the failure of flange packing due to thermal expansion/contraction caused by temperature change and due to tank water pressure.

Team's Review: TEPCO performed a detailed Apparent Cause investigation for this incident, focusing on physical causes, rather than a Root Cause evaluation. The IAEA team reviewed the provided information in TEPCO presentations on that investigation, in addition to reviewing past leak incidents and their published investigations. The IAEA team was not asked to perform a Root Cause investigation on leakage issues, but it identified several factors that should be considered if a Root Cause investigation would be conducted.

Main Findings

The IAEA team agrees with TEPCO's apparent cause findings and countermeasures taken for correctable causes. In particular:

- TEPCO acknowledged that the main causal factor to this event is the reliability level of flanged-typed tanks. As such, TEPCO has accelerated plans to replace all flanged-typed tanks with more reliable welded-type tanks. These plans are part of site-wide reliability improvement (discussed further in Section 3.2.9 of this report);
- In response to the Tank No. 5 in H4 Section incident, TEPCO also correctly recognizes the challenges in these plans and is actively considering countermeasures to be taken to resolve those challenges and potential setbacks during implementation. Specifically, TEPCO is aware of the constraints regarding the procurement and installation of the replacement tanks. And, more importantly, TEPCO recognizes the challenges of replacing existing tanks while simultaneously installing new tanks to store the volume of contaminated water that accumulates daily; and
- The IAEA team sees TEPCO's corrective actions in eliminating the main causal factor as a sign of the utility's progress toward taking a more proactive role in identifying and controlling issues instead of a reactive role that focused on mitigation of the consequences and treatment of symptoms by provisional countermeasures. Compared to the April 2013 mission by IAEA, the team has observed progress in transitioning from an emergency response organization to a controlling organization both on- and off-site. Although an end point for this transition period cannot be predicted due to the dynamic and large scale situation, this trend is encouraging.

However, the IAEA team emphasizes the strong integration of implementation of countermeasures and corrective actions with the Implementation Plan, and further, with the execution of the Roadmap for the following reasons:

- As mentioned above, the timing and sequence of implementation of replacing flanged-type tanks may be negatively (or positively) affected by other Roadmap activities, possibly creating the need to revisit interim actions or other requirements.
- The interim countermeasures to minimise the risk of leak from the tanks do not eliminate the risk. As such, future leaks can be expected and should be considered when planning and executing other tasks in the Implementation Plan and the Roadmap. For example, a major leak from the tanks, which are located at a higher elevation, may adversely affect the effectiveness of the measures being taken for preventing the groundwater and seaside contamination.

Additionally, the IAEA team reviewed the incident and subsequent investigation with the Tank No. 5 in H4 Section, based on good practices and lessons learned in the investigation of significant issues and developing corrective actions. Those good practices and lessons learned have been documented in various IAEA documents, such as TECDOC-1600 "Best Practices in the Organization, Management and Conduct of an Effective Investigation of Events at Nuclear Power Plants". The IAEA team made the following observations:

- Some significant events necessitate a formal root cause investigation to identify human and organizational causes and to take corrective actions to prevent recurrences. For example in the leaking of Tank No. 5 in H4 Section incident, the IAEA team observed that although the physical cause is associated with flanged-type tanks, there are other contributing causes, such as programmes and procedures to ensure the reliability of those tanks. Immediately following the accident, the flanged-type tanks were appropriately selected and installed as a prompt and provisional response to the accident sequence, hence the basis for the specifications, procurement and installation, as well as the technical and regulatory review and approval, of those tanks was on short-term use rather than the extended term. As such, they would require programmes and procedures for tracking the service life and performing preventive maintenance, as well as suitably adjusted performance monitoring periodicity for the remaining life of the SSCs.

- This condition of unforeseen service lifetime seemed evident to the IAEA team by the review of causes of previous leak events (both in pipe connections and tanks) and the associated corrective actions taken by TEPCO to minimise the reoccurrence of those leaks, especially for the Tank No. 5 in H4 Section leak, such as increased monitoring and installation of level gauges, enhanced maintenance (caulking and sealing), and identifying the lack of drains in horizontal tanks.
- Similarly, a thorough root cause analysis would be helpful to identify the extent of causes. Although the IAEA team agrees with TEPCO's main causal factor being applicable to flanged-type tanks, but cannot conclude whether there are other contributing causes that can extend to the other type of tanks. Consideration and formal elimination of contributing causes for other tanks would be a good practice in determining whether the other tanks would require programmes and procedures for maintenance and the extent of condition monitoring.
- As a part of the corrective action programme, a review of the effectiveness of countermeasures, especially in case when they are taken as interim measures, is as critical as the implementation. The IAEA team considers that this point is illustrated by the occurrence of another leak (in the G Section on 15 November 2013) which followed the Tank No. 5 in H4 Section leak and the related countermeasures. Also, the IAEA team observed in the field that lack of lighting in the tank sections reduces the effectiveness of monitoring patrols in the night.

The IAEA team acknowledges that although the fundamentals of a thorough root cause evaluation do apply to the events at TEPCO's Fukushima Daiichi NPS, the methods of implementation may vary. For example, setting graded approach criteria maybe challenging due to the prevailing dynamic state of the site.

Acknowledgements

<u>Acknowledgement 8:</u>

TEPCO has taken a more proactive role in identifying and permanently controlling leakage issues instead of a reactive role that focused on the mitigation of consequences and the treatment of symptoms by provisional countermeasures.

Advice

<u>Advisory point 7:</u>

The IAEA team emphasizes the importance of establishing a thorough and structured impact review process. Such a process should identify the effects of the individual countermeasures, which have been taken to address on-site issues, on the overall Roadmap activities and schedule (or vice versa). This would help to ensure compliance with the Implementation Plan.

3.2.3. MANAGEMENT OF RADIOACTIVE WASTE

3.2.3.1 Management of secondary waste from treatment of contaminated water

Main Findings

The large-scale processing of contaminated water is resulting in the generation of significant volumes of secondary waste streams, e.g.:

- Spent sorbent columns; and
- Chemical sludge from co-precipitation and pre-treatment processes.

Spent sorbents include zeolites and a variety of selective exchangers. The composition of sludge is different depending on the particular process in which the sludge is generated. Till now the radioactivity in these secondary waste streams is mainly due to caesium isotopes but with continued operation of ALPS systems, strontium and other radionuclides are also going to be present in significant quantities.

The spent columns loaded with caesium isotopes are presently stored in a separate area, the columns being either self-shielded or placed inside concrete boxes. The sludge generated from the pre-treatment steps in ALPS is being stored over ground in high integrity containers.

Operation of existing and planned water treatment systems is expected to result in the generation of large volumes of such secondary waste streams, possibly in the range of several thousands of cubic metres, loaded sometimes with very high levels of radioactivity.

From the information provided during the mission, the IAEA team considers that adequate facilities and arrangements are in place to temporarily store these secondary wastes. However, these secondary wastes will have to be disposed of eventually after processing. The IAEA team was informed that activities have been planned and are being pursued for detailed characterization of the secondary waste streams and development of processing options.

Acknowledgements

<u>Acknowledgement 9:</u>

The on-going treatment of contaminated water is resulting in the generation of large volumes of secondary waste streams that have high levels of radioactivity. The IAEA team was informed that adequate facilities and arrangements are in place for safely storing these wastes on a temporary basis. Efforts are also being made by TEPCO and other Japanese organizations to characterize these wastes and develop options for their processing in preparation for future disposal.

3.2.3.2 Management of solid waste

Main Findings

The radioactive solid waste includes radioactive contaminated soils, felled trees due to contamination caused by the hydrogen explosion and also from the land preparation to gain space for construction of necessary infrastructure for the decommissioning of the power plant, as well as contaminated debris from the buildings. TEPCO identified storage places on-site and some of them are already in operation or under construction. As of 31 August, TEPCO had collected and segregated 65,000 m^3 of debris on 10 sites and 51,000 m^3 of felled trees on five sites. Compared to the volume reported at the last IAEA mission in April 2013, this is an increase of 16,000 m^3, which demonstrates the intensive effort for the management of the waste from the dismantling.

As expected, the accumulated waste up to now is already much higher than the estimated 10,000 m^3 per reactor for a normal decommissioning of nuclear power plant. Following the estimation from the IAEA mission in April 2013, up to 800,000 m^3 of material is included only in the Units 1 – 4. As most of the material is expected to be contaminated, a strategy for reducing the material for disposal is necessary. As the volumes of the radioactive waste and thus the necessary storage volumes highly depend on the overall waste management concept for the site, TEPCO also started to develop a mid-and-long-term roadmap towards the decommissioning regarding the solid waste management. This includes a continuous improvement of the waste reduction and storage management, as the volume for storage on-site is limited.

The reduction of waste volume by evacuation from the site or by applying efficient volume reduction techniques should always be considered in order to minimise the releases or environmental impact due to leaching even for low contaminated waste. For example, metal should be either decontaminated or melted rather than piled up. This could prevent costly intermediate storage and unexpected leakages or ground pollution. Melting of metals also traditionally allows a 70-80% volume reduction of this type of waste, also reducing unexpected air or soil pollution.

Plans exist to recycle non- or low-contaminated wood and concrete for reuse in construction work on-site. For the scrap metal, a concept of melting after surface cleaning and reusing the material for shielding or storage containers was developed. In addition, TEPCO presented first concepts to further prevent the new generation of operational waste by sharing material on-site. These efforts should be closely integrated with those of the waste management programme.

The process of developing a scheme for radiological classification of the waste to enable a separation based on the degree of contamination and material is under development. To foster these efforts, a clear decision about the end-state of the facility would be highly useful. To optimise radiological protection of the workers and the environment, future handling of the waste has to be avoided as much as possible without slowing down the clean-up and dismantling process. A segregation of the waste from the beginning, based on a sound radiological characterization and a concept for possible future use is known to be a feasible way in standard decommissioning projects of nuclear power plants.

The overall concept of the waste management for the moment is to store the debris and felled trees on-site for about 20-25 years before they are processed and transported to a disposal site. At the present time, waste with a high radiation dose is being stored in the existing solid radioactive waste storage facilities and soil-covered temporary storage facilities with additional shielding by sand bags if necessary, in order to reduce radiation exposure to workers and radiation dose at the site boundaries. Felled trees (branches, leaves, and roots) with a higher dose rate than the surrounding background are being stored in felled tree temporary storage facilities. In line with the waste storage management policy in the Roadmap, in order to store these trees more appropriately, a new storage facility that can store 23,000 or more drums is being designed and planned to operate in FY2015. Conceptual design of other storage facilities is also planned, taking into consideration the storage conditions of waste and forecast of waste generation. As noted above, it is envisaged that a disposal facility will be available after 20-25 years. The whole process of decommissioning and dismantling of the buildings will most likely take much more time. The timeframe of the transportation of the waste to a disposal facility will depend on the availability of such a facility. Based on the global experience, the schedule for the process of siting, design and construction of such disposal facilities is difficult to predict. Therefore, the possibility that waste may have to be stored at the site for longer than 20-25 years will have to be considered in designing the new storage facilities.

With regard to the described actions and developments, TEPCO has made significant progress since the first IAEA mission in April 2013 in developing a long-term strategy, estimating volumes, types and characteristics and developing first concepts for reducing the volumes of waste streams. Further improvement of the overall strategy is needed as soon as a decision is made for the end-state of the facility and further information about the final destination of the waste after storage is available. Those strategies can only be developed and decided in cooperation with the policy-makers and regulators and should include a dialogue with other stakeholders in the society.

Acknowledgement

Acknowledgement 10:

The IAEA team acknowledges that TEPCO is on the way to optimising the classification and handling of the solid waste to minimise volumes by reducing generation and recycling non- or low-contaminated waste.

Advice

Advisory point 8:

As radiological characterisation and waste classification are important for developing a long-term waste management strategy, establishing an on-site or near-site facility for radiological characterisation of the waste should be accelerated. Based on a sound radiological characterisation of the waste, it will be possible to establish a useful waste classification scheme, which will enable TEPCO to further develop its strategy for the processing, storage and final disposal of the waste.

Advisory point 9:

As decommissioning activities progress, large amounts of waste will continue to be generated and may require on-site storage for a long period of time. Therefore, careful planning of storage facilities for the whole decommissioning period should be in place. Design life of waste storage facilities should take into consideration the expected long decommissioning period. Due to limited space at the site, appropriate measures for waste minimisation and volume reduction should also be implemented.

3.2.3.3 R&D to support waste management activities

Main Findings

There has been significant progress reported in the area of R&D to support current and planned activities towards decommissioning of TEPCO's Fukushima Daiichi NPS Units 1-4.

During the mission, a special session was devoted to presentations and discussion related to the ongoing and planned R&D activities in the area of waste management.

The Agency of Natural Resources and Energy is playing a leading role in compiling a budget for R&D activities and managing R&D projects in cooperation with Ministry of Education, Culture, Sport, Science, and Technology. The Japan Atomic Energy Agency is supporting the R&D projects with its expertise and facilities.

The revised Roadmap emphasizes the necessity of establishing "an international collaboration department", to implement R&D programmes in an efficient and effective manner, and in cooperation with international community. Consequently, an organization named "International Research Institute for Nuclear Decommissioning (IRID)" was established on 1 August 2013. In addition, prior to the last revision of the Roadmap, the "Research and Development Roadmap for Decommissioning Units 1-4 of TEPCO's Fukushima Daiichi Nuclear Power Station" was published as a separate document. At present the R&D Roadmap is an integral part of the revised Roadmap.

Characterization, processing and disposal of radioactive waste that has been generated after the accident give rise to unique technical challenges, particularly due to the presence of radionuclides originating from damaged fuel and salt from sea water. As there is no experience in managing such waste in Japan, studies have been initiated with extensive cooperation from related industries, research institutions, academic societies, and universities in Japan and abroad. To understand the unique characteristics of the waste and the options for its safe management, studies are currently being conducted at some existing facilities including Tokai Research and Development Center of the Japan Atomic Energy Agency.

The R&D activities for management of radioactive waste are directed towards:

- obtaining and understanding the data about waste characteristics;
- investigating safety and stability for the long-term storage of waste;

- researching and developing processing technologies for different waste classes and streams;
- investigating and developing related to safe disposal of waste; and
- developing related databases.

Acknowledgements

Acknowledgement 11:

The IAEA team acknowledges further progress in developing and implementing a comprehensive research and development (R&D) programme to support the management of waste generated during the emergency phase and during pre-decommissioning and decommissioning activities at TEPCO's Fukushima Daiichi NPS. A clearly demonstrated intention to take into account international experience and to benefit from international cooperation by involving the IRID has been recognized.

3.2.4. MEASURES TO STOP OR REDUCE INGRESS OF GROUNDWATER INTO REACTOR AND TURBINE BUILDINGS

Main Findings

The inflow of groundwater at the TEPCO's Fukushima Daiichi NPS Reactor and Turbine buildings of Units 1, 2 and 3 is producing approximately 400 m^3 of radioactively contaminated water each day. The problem of the increased accumulation of contaminated water, stored in tanks on site, continues to be one of the most serious issues confronting the efforts to decommission the site.

Before the accident at Fukushima, groundwater were being pumped from sub-drains (wells) located in the area around the power plant buildings to reduce the groundwater levels in the vicinity of these buildings and to reduce buoyancy of the buildings. These sub-drains and pumping equipment were damaged by the 11 March 2011 tsunami and ceased to operate. As a result, the combination of groundwater level in the surrounding area rebounding and damage to pipe penetrations and trenches resulted in approximately 400 m^3/day of groundwater flowing into the buildings, as the level of the base of the reactor and turbine buildings is below the external groundwater level. This inflowing groundwater has mixed with the contaminated water that has collected at the bottom of the buildings, resulting in an increasing volume of contaminated water.

However, the solution to this issue is not as simple as stopping or reducing the ingress of groundwater into the reactor and turbine buildings, but has to be seen in the context of the wider decommissioning activities. In particular, water levels in the reactor and turbine buildings are currently being maintained to suppress the spread of high levels of activity in these structures. Groundwater inflow is maintained to prevent natural water outflow and further contamination from the buildings into the surrounding soil. This is achieved through pumping water from the turbine buildings, so that water levels in the reactor and turbine buildings are maintained below water level in the ground surrounding the buildings. As long as the current cooling of fuel and fuel containing material is continued it is necessary to establish control over the amount of water entering the buildings. Therefore throughout the decommissioning process there is a balance between the objective of a) optimizing radiation levels for the purpose of decommissioning; b) maintaining the water level in these buildings to make sure there is not an outflow from these structures (i.e. to ensure contaminated water does not migrate to the sub-surface); c) minimising the unnecessary ingress of groundwater into these structures to reduce the net generation of contaminated water; and d) preventing contaminated water outflow to the sea.

TEPCO is in the process of planning and implementing a complex programme for control of groundwater levels. The following were presented by TEPCO:

- A groundwater bypass abstraction system installed at the upstream to reduce the volume of water flowing into the buildings;
- Reinstating existing and constructing new sub-drains around the perimeter of the buildings to lower the groundwater levels sufficiently to prevent (or substantially reduce) the inflow of water into the turbine and reactor buildings and trenches;
- Sealing of some specific inflow points in the reactor and turbine buildings;

- Ground improvement by chemical injection in select areas for the purpose of reducing groundwater permeability;
- Maintaining a suitable water level in turbine hall and reactor buildings to ensure contaminated water does not flow into the sub-surface;
- Constructing an impervious frozen wall around the perimeter of Units 1-4 using soil freezing technology to provide an additional countermeasure to stop (or further reduce) groundwater ingress to reactor and turbine buildings; and
- Constructing an impervious oceanside sea wall.

TEPCO provided information on the proposed approach to install the frozen wall. There is a Task Force for Land-side Impermeable Wall as a sub-entity to the Committee on Countermeasures for Contaminated Water Treatment established by METI. This group consists of experts with background in the development and application of this technology and has full management responsibility for delivery of the project. There is currently preparation for a test freeze trial at the site aimed at establishing the freeze design parameters and overall verification of the approach.

Acknowledgements

<u>Acknowledgement 12:</u>

TEPCO has provided a comprehensive and multi-barrier approach to control the flow into and out of the reactor and turbine buildings. This multi-barrier approach to control groundwater flow appears to be underpinned by project planning, information and data gathering, testing of the proposed methods, and peer review by the Committee on Countermeasures for Contaminated Water Treatment. TEPCO has made a good beginning to address these issues in preparation for decommissioning. For example, there is a comprehensive plan for the feasibility, design and implementation of a frozen wall around the reactor buildings of Units 1-4. The lead technical role is handled by an expert task group with good planning of test activities that are to establish the feasibility and design parameters of the wall.

Advice

<u>Advisory point 10:</u>

The IAEA team encourages TEPCO to advance the implementation and careful monitoring of its measures to reduce the ingress of groundwater into reactor and turbine buildings and to prevent radioactive releases. In preparation for this, TEPCO should continue to evaluate and optimise the selected strategy for reducing water inflow into Units 1-4. The approach using the simultaneous operation of the proposed freeze wall, active sub-drain and water recharge -- in light of the limited space on site and the complex radiological environment -- should be carefully re-evaluated at each stage of the project as more data is collected.

Advisory point 11:

The IAEA team encourages TEPCO to continue to ensure that during the detailed planning stage an evaluation is performed (as a series of 'what if' scenarios) of the resilience of the overall approach to controlling the flow of groundwater into and out of the reactor and turbine buildings (and trenches). The IAEA team encourages TEPCO to consider the potential implications and possible mitigation measures arising from these scenarios. For example, such scenarios may include: the presence of higher-than-expected contamination levels observed in the groundwater removed from one or more of the sub-drains; the possibility of continued hydraulic connection between buildings at different elevations; and the incomplete effectiveness of an individual barrier.

3.2.5. REVIEW OF THE PUBLIC RADIATION EXPOSURE IN THE SURROUNDING AREAS FROM ON-GOING ACTIVITIES AT THE SITE

Main Findings

The current limit for exposures arising from the sum of gaseous and liquid discharges and the solid radioactive materials generated and accumulated at the site of TEPCO's Fukushima Daiichi NPS, as a consequence of the on-site activities, is 1 mSv effective dose per year for a member of the public at the boundary of the site. This limit applies to the additional exposures of the public that could arise from the current activities at the site towards the decommissioning of the plant, considering all the exposure pathways, and it is independent of the "legacy doses" caused by the accident itself. The actual exposures attributable to gaseous releases is much lower than the limit namely from cloudshine (approximately $1.8x10^{-6}$ mSv/year), from groundshine (approximately $2.8x10^{-2}$ mSv/year) and from inhalation and ingestion (approximately $1.8x10^{-4}$ mSv/year). As there is no regular discharge of liquid radioactive wastes it has no contribution to the total exposure. Since April 2013 as a consequence of transferring Reverse Osmosis (RO) concentrated water stored in the underground water tank to ground tank, the external exposure component from the direct gamma rays and sky shine increased considerably. The effective dose currently at the different site boundaries is in the range of 0.47-7.8 mSv/year. As a consequence the limit of 1 mSv/year at the site boundaries is not currently satisfied due to this high direct external exposure. A stricter imposition/interpretation of this limit at the border of the site is imposing significant constraints to the practical development of the decommissioning Roadmap, with special consideration to the mentioned storage of radioactive solids and liquids on site. In addition, the constraints are especially significant for liquids, as liquid discharges are not actually allowed, despite to the theoretical limit defined for all exposure pathways. This situation increases the dangers derived from the accumulation of contaminated liquids, raising additional difficulties for the control of the doses to workers and increasing the risks of accidental leakages to the environment.

Defining who the "*public*" is around nuclear facilities is a good practice, because it is important to identify a "reference person" who will represent the most potentially exposed person in the public (see Publication 101, ICRP 2006a), who is living in realistic conditions at a given distance from the border of the nuclear installation.

Advice

<u>Advisory point 12:</u>

As advised by the April 2013 mission, the IAEA team reiterates that the Government of Japan and TEPCO should establish constructive discussions with relevant authorities and stakeholders, including the NRA and local authorities, to assess and balance the risks and benefits of the dose limit at the boundaries and its practical implementation, particularly from direct exposures at the site-boundary arising from contaminated solids and accumulated liquids on the site and for the possibility of controlled liquids discharges from the site. The discussions should include an assessment of the balance of off-site and on-site exposure risks, as well as the consideration of the parallel progress of the off-site remediation programme and the roadmap for on-site decommissioning and their mutual interaction. The discussion *should also include the definition of representative members of the public to be considered in the assessments of individual doses in different areas, taking into consideration the real and evolving off-site situation.*

Advisory point 13:

Considering that controlled water discharges to the sea could be necessary in the future to achieve the long-term stable situation on-site and to reduce risks of accidental leakages as well as exposure to workers, the IAEA team encourages TEPCO to prepare safety and environmental impact assessments of this possible practice based on the limit of 1 mSv/year established by the NRA for the population, and to submit it to the NRA for the necessary regulatory review. In addition, the IAEA team encourages the Government of Japan, TEPCO and the NRA to hold constructive discussions with the relevant stakeholders on the implications of such authorized discharges, taking into account that they could involve tritiated water. Because tritium in tritiated water (HTO) is practically not accumulated by marine biota and shows a very low dose conversion factor, it has therefore an almost negligible contribution to radiation exposure to individuals.

For this purpose, the IAEA is ready to offer further advice to Japan on the suitable methodology to conduct the safety and environmental impact assessments associated with controlled discharges, as well as assistance for training experts in the involved parties (namely TEPCO and the NRA).

3.2.6. SPECIFIC DECOMMISSIONING PROGRAMMES AND DECOMMISSIONING PLANNING

Main Findings

The general strategy for defining decommissioning programmes is described in the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Plant Units 1-4" revised on 27 June 2013.

During the mission the IAEA team received presentations related to the Roadmap, to the radioactive waste management and decommissioning challenges and to the "Implementation Plan of Measures to be taken for the Specified Reactor Facilities at Fukushima Daiichi Nuclear Power Station".

This global approach indicated that the Japanese officials took into account the main phases to define a decommissioning plan for Fukushima units 1-4 such as:

- Physical and radiological inventories: to define quantities and types of waste to be managed, techniques to be employed, and the requirements for protection of workers;
- Waste management: to define dedicated temporally on site depositories, reducing volume and quantities as much as possible, beginning to think about definitive outlets;
- Defining adequate dismantling scenarios based on assessment of risk (for example remote handling or not) in order to reach the aim of reducing the source term and the corresponding dose rate on site.

Compared to the previous roadmap issues, the input and the knowledge or experience accumulated during the short period of the past six months have shown that Japanese officials have improved their initial phased approach to planning of decommissioning.

The revised Roadmap is now based on the following:

- A target schedule comprising three milestones from 2013 onward which should lead to:
    - The compilation of technical studies dealing with waste management (including sorting, volume reduction techniques, production of waste packages, treatment, packaging), definition of operation, safety evaluation methods including basic tests for decommissioning technologies, decontamination of concrete and metals;
    - A wide range of decommissioning scenarios should be prepared and reviewed in line with the IAEA Safety Standards, and where appropriate, relevant international expert organizations should be consulted so as to establish a comprehensive decommissioning plan. Since decommissioning of TEPCO's Fukushima Daiichi NPS is greatly different from a normally shutdown reactor facility, various scenarios have to be studied and created, so that decommissioning can be rationally conducted;
    - Obtaining a consensus among various stakeholders around 2018 on the decommissioning scenario, in due consultation with international organizations. The aim of Japanese authorities is to complete decommissioning in 30 to 40 years.

- A set of holding points to be identified to establish safety concepts and processes to define multiple decommissioning scenarios.

Nevertheless, to increase the efficiency of the dismantling and to enhance public confidence in the solutions performed on site, it is necessary to quickly be able to prove a better control of the dose rate through minimising the environmental impact as well as through visible progresses in the site remediation.

To this end, the success of a decommissioning programme is usually based on:

- The definition of an adequate end state considering:
    - the aim of the future use of the site; and
    - the balance between risks and impacts issued from risks assessments analysis which will lead to rational achievable status (including transparency through a clear communication to a non-technical audience).
- The definition of the adequate scenarios and means (technical and human) for these scenarios; and
- The commitment arrived among the government, the regulator, the operator and the population.

Thus, the IAEA team recommends for reducing waste volumes and minimising the total source term as much as possible, for example, by getting rid of rubble and debris. Then it could be easier to concentrate on remaining sources that need a specific scenario (remote handling or not) to be treated efficiently regarding the corresponding “waste routes” and outlets. These specific scenarios will be defined by estimating the type and quantity of waste, prospects of disposal, techniques and processes to be applied, environmental impact, as well as exposure of workers to radiation.

The combination of these scenarios will progressively bring clarity about the definition of a Fukushima radiological end-state, the success of which will have to be assessed periodically, taking into account the enhancement of the on-going decommissioning programme. Japan should continue to seek international advisory support from specialised organizations for all these tasks.

In addition, stakeholders will be able to conduct reviews devoted to the decommissioning technologies including remote dismantling techniques, decontamination materials such as concrete or metals, and volume reduction technologies.

These operations and the corresponding reviews could be the opportunity to gather and accumulate necessary data, such as the contamination status of structures, equipment or environment. The examination of all these data will allow a more accurate definition of a technically achievable end-state.

Taking into account end-state considerations from a number of past projects (TMI, Chernobyl, US and European decommissioning programmes etc.), the IAEA can provide its assistance to Japanese contributors in defining the most suitable end-state for Fukushima as a specific case.

Fukushima's decommissioning is a unique case, for which there are needs to develop and conduct specific R&D programmes, as well as analyse and utilize the best worldwide practice and know-how from decommissioning activities. This approach could enable Japan to consolidate the schedule and to effectively optimize extra time needed to qualify new devices from R&D.

Acknowledgements

Acknowledgement 13:

The IAEA team acknowledges all the Japanese stakeholders for the tremendous work they are performing on Fukushima's activities towards decommissioning and particularly for beginning discussion about the end state of decommissioning process, even if it involves a several decades schedule.

3.2.7. PREPARATION FOR LICENSING AND REGULATORY REQUIREMENTS

Main Findings

During the mission, limited new information on licensing issues was provided to the review team, from the information made available during the previous mission in April 2013. This issue was not discussed extensively. Information was obtained from the Roadmap and from the presentation "Implementation Plan of Measures to be Taken for the Specified Reactor Facilities at Fukushima Daiichi Nuclear Power Station" (dated April 15, 2013). New information was found in the presentation "Status of Efforts to Remove Fuel from the Unit 1-4 Spent Fuel Pools", where the licensing steps for the removal of spent fuel from Unit 4 were explained. A brief meeting with representatives of the NRA was organized during the mission, but the scope of the discussions was limited to the sea water monitoring issue only. This part of the mission report is based on the information provided by METI and TEPCO only. The representatives of the NRA took an active part in the final discussion session held on 3 December 2013.

On 7 November 2012, the NRA designated the reactor facilities of the TEPCO's Fukushima Daiichi NPS as "Specified Reactor Facilities". Such facilities are required to conduct special safety management depending on the situations at the facilities. At the same time the NRA provided TEPCO with a "List of the Matters to be Addressed", with an objective to reduce risks and optimize efforts in ensuring safety of workers, public and the environment. As a consequence of that decision, significant changes in the licensing regime of the units of TEPCO's Fukushima Daiichi NPS and for other activities on the site occurred.

In response to the abovementioned NRA decision, TEPCO prepared an "Implementation Plan" and submitted it to the NRA on 7 December 2012. While the Roadmap is the main strategic document, the Implementation Plan is the main licensing document, supported by a number of other documents, assessments and procedures for specific activities.

The transition of the licensing regime, the set of safety requirements to be fulfilled by the operator of a Specified Reactor Facility, as well as the content of the Implementation Plan were addressed in the Mission Report from the previous mission conducted in April 2013.

The Implementation Plan will be reviewed on a continuous basis, reflecting the situations in the field and the results of research and development activities. For the review of the Implementation Plan and its amendments a "Supervision and Evaluation Committee for the Specified Reactor Facilities" will be formed, involving NRA staff and external experts. The review process will be open to the public.

The licensing approach for new activities is subject to a regulatory authorization by the NRA based on submissions of revisions and amendments to the Implementation Plan. The first example of that process was the authorization for the removal of spent fuel from Unit 4.

In November 2012, the NRA provided TEPCO with the requirements for removal of fuel from the spent fuel storage pools in reactor buildings to the Common Spent Fuel Pool, under the Act on Regulation of Nuclear Source Material, Nuclear Fuel Material and Nuclear Reactors:

- to maintain the subcritical condition of the fuels;

- to take measures to prevent the fuels from falling down and to mitigate radiation effects to the environment in case of falling down; and
- to store the removed fuels in appropriate conditions, including cooling them.

Based on these requirements, TEPCO prepared the "Implementation Plan on Fuel Removal from the Unit 4 Spent Fuel Storage Pool" and submitted it to the NRA for review and approval. As part of the package, details on equipment design for the spent fuel removal and technical procedures for the work implementation were submitted to the NRA. After a review, the NRA approved the "Implementation Plan on Fuel Removal" on 30 October 2013 with some modifications to the methods of fuel-integrity assessment.

Subsequently, pre-operational inspections of operation trainings of the workers, administration system of safety, emergency response measures and inspections of other safety aspects of fuel removal were conducted by NRA staff on site. The spent fuel removal operations started on 18 November 2013, and are inspected regularly by the NRA.

Ongoing activities related to the management of contaminated water, clean-up activities (including rubble removal), radiological characterization and all other pre-decommissioning activities on site are conducted based on the approved Implementation Plan and its supporting documents.

The current approach is to apply a similar licensing regime for the future activities on fuel removal from Units 1-3, fuel debris removal and on the subsequent decommissioning of Units 1-4. This is consistent with the approach recommended by the IAEA, where the "Implementation Plans" has equivalence to the decommissioning plans, as required by the IAEA Safety Standards.

The challenging situation at the TEPCO's Fukushima Daiichi NPS site, and the unique nature of the operations to be performed for preparation and retrieval of the fuel debris and for decommissioning of damaged facilities, make the application of established regulations and criteria for normal situations difficult. It was recognized that specific regulations and safety criteria should be developed for the case of TEPCO's Fukushima Daiichi NPS decommissioning. The revised Roadmap (June 2013) in its section 3.3 briefly addresses the preparations for developing new regulations and criteria. TEPCO has proactively made commitment to have a role in developing such specific safety criteria.

Acknowledgements

Acknowledgement 14:

Authorization process for the fuel removal from the spent fuel storage pool of Unit 4 to the Common Spent Fuel Pool was conducted in an efficient way between TEPCO and the NRA. Modifications to the initially submitted "Implementation Plan on Fuel Removal" were discussed and agreed in a timely manner, which enabled TEPCO to get the authorization to commence the activities with no delay. This is a good example to be followed in the future.

A thorough assessment of risks during the fuel removal operations at Unit 4 and identification of preventive and mitigation measures was performed and was included in the related

"Implementation Plan on Fuel Removal". Such an evaluation of safety, and demonstration of the adequacy of the proposed safety measures, contributed to the efficiency of the interaction with the regulator and to the timely completion of the authorization process.

Advice

Advisory point 14:

The Roadmap introduces hold points prior to the commencement of some of the activities. These hold points were introduced mainly due to the need to make technical decisions and to select and develop technical options for implementing activities. The IAEA team suggests that the licensing hold points should be integrated into the Roadmap or its implementing documents to include points of important regulatory decisions and to account for the time needed for regulatory reviews and approvals prior to commencing certain activities or implementation phases.

In addition to its involvement in the review of the official submissions by TEPCO and in the inspections of activities, the NRA should be more actively involved during the planning and preparatory process and should be kept informed about the options considered for the future activities. This will help the NRA to plan its activities and resources more efficiently, and to better respond to public expectations.

3.2.8. TECHNOLOGIES FOR REMOTE DECONTAMINATION, TECHNOLOGIES FOR INVESTIGATION OF PCV/RPV INTERIORS, ETC.

The high radiation levels and complex conditions resulting from the accident, combined with difficulties of access inside the PCV and RPV, create a need for many remote technology applications now and in the future. For many tasks, because of complexities unique to the TEPCO's Fukushima Daiichi NPS conditions, a number of development will be required to design and provide the suitable equipment. For other tasks that are similar to standard decommissioning work, the existing commercially available devices within Japan and from abroad can be applied. In some cases, appropriate modifications may be required to adapt to the specific Fukushima situation.

Main Findings

The presentations to the IAEA team and the site tour illustrated several remote technologies that have been successfully applied. These applications include decontamination and debris removal for clearing rubble from the refuelling floor of Unit 3, which were being operated from a central control room. Other remotely operated decontamination devices are in development.

Another important function is characterization with the Unit 1 drywell for locating PCV water leaks with a small boat, a water-level measurement robotic crawler, and plans for a quadruped robot with attached car for photographic and audio data. Other remote controlled survey devices and drones are envisioned based on the latest worldwide improvements in these fields.

Presentations to the IAEA team and subsequent discussion about the remote handling devices under development as well as those in use demonstrated that TEPCO is conducting comprehensive operator training, including the use of mock-ups for training and testing. Due to similarity of design of Unit 5 to that of Units 1 to 4, Unit 5 is being used to test the new remote handling devices. This provides assurance of their adequacy in the most representative conditions while avoiding unnecessary operator exposure dose rates in a very economic manner.

Acknowledgements

Acknowledgement 15:

The IAEA team visited the remote-control room for operating robotic equipment that is being used for clearing rubble from the top floor of Unit 3. This is an excellent beginning for what will be ever-increasing needs for remotely operated equipment for many diverse future tasks. This real-time experience will provide valuable lessons for the expansion of capacity.

Acknowledgement 16:

Establishing a working group for developing remotely operated equipment has resulted in shortening the time between identification of a specific need and delivery of individual remote technology equipment. For example, after the working group was established, the subsequent devices for leak location within the drywell have taken only seven to eight months. The participation of the plant representatives in the working group is a good practice that will contribute to success of development.

3.2.9. PROGRAMME AND PROCESSES TO MAINTAIN AND ENHANCE STABILITY AND RELIABILITY OF STRUCTURES, SYSTEMS AND COMPONENTS UNTIL DECOMMISSIONING

In addition to the Roadmap, the IAEA team was asked by the Government of Japan to perform a peer review of TEPCO's programmes and processes as well as the activities to maintain and to enhance reliability of structures, systems and components (SSCs). The IAEA team conducted the review in two folds: the incorporation of reliability area and associated activities into the Implementation Plan, and the progress of TEPCO's programmes and procedures towards enhancing stability and reliability of SSCs. The latter part was advised during the previous mission in April 2013 on the failures of essential systems and components to maintain safe and stable conditions in TEPCO's Fukushima Daiichi NPS Units 1-4.

Main Findings

General Findings on TEPCO's Reliability Improvement Programmes, Procedures and Organizational Effectiveness: TEPCO presented an update on the activities of the organization "Immediate Response Headquarters for Reliability Improvements at Fukushima Daiichi NPS" which was established in April 2013 following the frequent failures of equipment. Since the organization has been put in place, it has performed reviews of plant documents to identify vulnerabilities and common-cause failures. Its teams have also conducted targeted facility walkdowns to confirm the assurance of reliability and to identify any potential issue that would affect essential functions of the equipment to keep the safe and stable conditions. TEPCO reported that the primary functions targeted for this effort were: controlling radioactive material release, cooling the reactors and spent fuel pools, preventing hydrogen explosions, and preventing criticality. For the potential issues identified by the new organization, over 300 preventive and/or mitigating corrective actions (countermeasures) were determined and those were organised on immediate (within 6 months), short-term (within 1 year) and mid-term (beyond 1 year) implementation schedules. The IAEA team also observed improvements in physical protection measures around the essential equipment.

TEPCO management also stated that the initial potential problem identification efforts by the above organization are being transformed into standard practice for the employees for problem observations and reporting.

The IAEA team sees the efforts that have been implemented by the Immediate Response Headquarters for Reliability Improvements organization and the site personnel as a sign of the utility's progress toward taking a more anticipatory role in identifying and controlling SSC issues instead of a reactive role. The IAEA team has found that TEPCO is handling a very large volume of activities aimed at improving the reliability of SSCs.

TEPCO also explained the established programmes which were reviewed and approved by the NRA to ensure equipment safety in the Implementation Plan. The Implementation Plan was prepared as required by the NRA under the "Specific Reactor Facility" designation issued in November 2012. TEPCO's response is reviewed by the NRA. After the evaluation and approval of the Plan's appropriateness, the regulatory framework requires NRA inspections to assess compliance with the Implementation Plan including the measures to ensure reliability of the SSCs.

Specific Findings on the Reliability of Sample SSCs: TEPCO presented information on work related to different SSCs and their approach to ensure their performance and reliability. The SSCs included: fuel cooling system, tanks for the collection of contaminated water, spent fuel cask storage facility, storage facility for secondary waste from contaminated water treatment, solid waste storage facilities.

<u>Seismic and tsunami hazard re-evaluation:</u> For assessment of seismic and tsunami hazards TEPCO has voluntarily chosen to apply the new regulations for power plants that came into effect this summer and that present the most stringent requirements intended for operational power plants. This re-evaluation of seismic and tsunami hazards is currently underway.

<u>Fuel cooling system:</u> TEPCO is continuously working to improve the reliability of the fuel cooling system and to reduce its vulnerability to hazards.

<u>Tanks for collecting contaminated water:</u> TEPCO has decided to depart from the use of bolted water storage tanks (1000 m^3) and to start replacing this storage capacity with welded tanks that will provide higher reliability. The analysis on which this decision is based is discussed in section 3.2.2.3.

<u>Spent fuel cask storage facility:</u> The spent fuel cask storage facility is constructed to accept casks as the removal of spent fuel progresses.

<u>Solid waste storage facilities:</u> There are a number of facilities for different types of waste and in different phases of planning, design, construction and operation. TEPCO has designed and constructed facilities for storage of secondary waste from contaminated water treatment byproducts (slurry). Design of storage facilities for dry solid waste has also been performed and some are already built, with more planned. The dry solid-waste storage facilities are intended to maintain safe storage until transportation to disposal site (in around 20-25 years). The facility has an inspection hole to verify lack of water ingress. There is borehole downstream from the facility to monitor groundwater.

The IAEA team observed that the assumptions on service lifetimes and other technical specifications of the SSCs, which were placed immediately following the accident to restore essential functions and contain radioactive material, may be constrained for longer terms use. In the same manner, it is prudent for TEPCO to use conservative lifetime assumptions in designing new SSCs. For example, for waste storage facilities, as a minimum, the design lifetime should be aligned with the end of decommissioning for the station or until terms for waste storage strategy (see Advisory point in Section 3.2.3.2) are established. For TEPCO to be able to consider proper reliability levels in the design of their waste storage facilities, it is recommended to consider implementation of the above mentioned Advisory point of this report.

The IAEA team also notes that TEPCO has considered the advice on structural integrity from the April 2013 IAEA mission, that it was able to relate directly with the Roadmap and is implementing that advice in the revised Roadmap.

Risk assessment: METI and TEPCO presented to the IAEA team an overview of the risk identification and reduction programme activities by the recently established organizations: the Committee on Countermeasures for Contaminated Water Treatment and the Contaminated Water and Tank Countermeasures Division. Both organizations solicited the IAEA team's advice on the efforts. The IAEA team views the establishment of focused organizations for both controlling the conditions and assessing/prioritizing the overall contaminated water issues as an appropriate measure. The establishment and responsibilities of these organizations are consistent with the advice given in the April 2013 review for separating responsibilities of reactive, problem fixing organization and proactive, problem identifying organization. The IAEA team was presented with an overview and examples of risk assessment of contaminated water SSCs and associated ranking. However, an in-depth assessment of those required more time and review of details to form an opinion. Nevertheless, the IAEA team agrees with TEPCO's and METI's resolution and exigency on this topic towards minimising risks from hazards associated with the contaminated water.

Acknowledgements

Acknowledgement 17:

The IAEA team acknowledges the efforts that have been implemented by the focused reliability improvements, quality assurance, countermeasure project, contaminated water treatment organizations and the site personnel as a sign of the utility's progress toward taking a more anticipatory role in identifying and controlling equipment issues instead of a reactive role. TEPCO has made proactive and diligent attempts and has demonstrated visible processes and efforts trying to identify areas of concern and measures to maintain and improve performance and reliability of SSCs, and minimising risk.

Advice

Advisory point 15:

The IAEA team suggests that TEPCO revisit the assumptions, especially on service lifetimes and other technical specifications, of the SSCs placed as a prompt action immediately following the accident as well as to consider conservative lifetime assumptions in design of new SSCs.

Advisory point 16:

The IAEA team suggests that specific measures to control and to sample run-off storm water from each storage facility are taken to minimise the potential dispersing contamination through ground/storm water. This suggestion is in line with good industry practices and with TEPCO's commitment for implementation of preventive measures.

3.3. MARINE MONITORING AND ASSESSMENT OF POTENTIAL RADIOLOGICAL IMPACT

Marine monitoring has not been included in the "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4", but the activity scope of the IAEA Mission includes marine monitoring. Therefore, the IAEA team provides findings, acknowledgements, and advice as follows:

Main Findings

Marine Monitoring Programme

Intensive monitoring of the marine environment is one of the essential activities in Japan, because the effluents since March 2011 from the TEPCO's Fukushima Daiichi NPS site have brought high concern to the public in Japan and internationally. However, it must also be stated that the discharge rates and the subsequent concentrations have dropped significantly since 2011 by about five orders of magnitude to present values. The relevant radionuclides in respect to potential doses via the marine pathway are Cs-134, Cs-137 and Sr-90, and during the initial accident period until July 2011 also I-131. Tritium is also monitored although it only gives a minor contribution to potential radiation exposure via the marine pathway, because it is practically not accumulated in marine biota and its general dose factor is quite low.

Still, discharges could occur from the TEPCO's Fukushima Daiichi NPS site and might be necessary under controlled conditions to mitigate the continuous problems regarding contaminated water management on the site. In addition to direct discharges, some discharges from highly contaminated groundwater could also occur to the sea port.

The NRA has taken the responsibility for the marine monitoring. Marine monitoring is carried out by seven different organizations and comprises seawater, sediment and marine biota samples. The monitoring is described in the Implementation Guides on *Sea Area Monitoring in FY2013* and adopted 1 April 2013. Monitoring sea areas are separated in different zones according to the distances from the accident site:

- Sea area close to the power plant;
- Coastal area;
- Off-shore area; and
- Outer sea area.

In addition to these sea areas, Tokyo Bay is also monitored.

For sea water and sediment, there are approximately 180 sampling positions. Radionuclide, detection limit, monitoring frequency and monitoring organizations for each sampling point are defined in the Implementation Guides.

For marine biota, monitoring is conducted in the sea areas mainly facing Fukushima Prefecture with reference of the previous monitoring guidelines. In addition to these observations, a comprehensive monitoring programme for commercially exploited species has been established and maintained by the national government, including the Ministry of Health, Labor and Welfare and the Fisheries Research Agency, for 18 prefectures including Fukushima.

In line with the Implementation Guides, seven organizations including the NRA are monitoring sea water, sediment and marine biota in a cooperative way.

The sea area within a 2-kilometer zone to the plant is monitored by the operator TEPCO. The other areas are monitored by seven organisations:

- Nuclear Regulation Authority;
- Fisheries Agency;
- Ministry of Land, Infrastructure, Transport and Tourism;
- Japan Coast Guard;
- Ministry of the Environment;
- Fukushima Prefectural Government; and
- TEPCO.

In addition to these organisations, universities and research institutions perform measurements of radioactivity at sea, e.g. Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and, as far as fishery products are concerned, the Fisheries Research Agency.

Marine monitoring has been conducted since March 2011 and a systematic plan was established in October 2011. The presently valid "Implementation Guides on Sea Area Monitoring in FY2013", which is a part of the Comprehensive Radiation Monitoring Plan, were revised on 1 April 2013, the beginning of the fiscal year in Japan.

The objectives of the Comprehensive Radiation Monitoring Plan[4] concerning sea area monitoring are as follows:

- To estimate the current exposure doses (external and internal exposure doses) of people who are living and have lived near TEPCO's Fukushima Daiichi NPS and their potential exposure doses in the future;
- To develop and evaluate procedures for reducing exposure doses including decontamination activities to be taken;
- To develop reference data for health management of persons who are living and have lived near TEPCO's Fukushima Daiichi NPS and the assessment of effects on their health; and

[4] The Monitoring Coordination Meeting, which was established under the Nuclear Emergency Response Headquarters, has been chaired by the Minister of the Environment. This meeting developed the "Comprehensive Radiation Monitoring Plan" and the "Implementation Guides on Sea Area Monitoring in FY2013" on 1 April 2013.

- To figure out the dispersion, deposition, and migration of radioactive materials that were released into the environment.

The marine monitoring programme is designed to contribute to the understanding of the concentrations of radio-caesium and other radionuclides and their temporal trends in seawater and biota, and for sediments, to understand the spatial and chronological migration of radioactive substances.

The analyses of the marine samples are performed in several analytical centres such as TEPCO's three laboratories, the Japan Chemical Analysis Centre in Chiba, and the Analytical Radioactivity Monitoring Centre of Fukushima in Fukushima City. In addition to these laboratories, which were visited during the Review Mission, laboratories at research centres of universities also take part in marine monitoring. According to the information provided during the mission, no interlaboratory comparison or cross check of samples has so far been carried out to assure the comparability of the produced data. At least the analytical centres at Chiba and in Fukushima are accredited according to ISO 17025 for the applied procedures.

Marine monitoring results

Marine monitoring results are available to the public nationwide and internationally by means of information dissemination to international organizations and nuclear regulatory bodies, as well as by websites of the monitoring organizations in a prompt way, and indicate improving situations in sea areas and are currently relatively stable as described below:

Sea water: The highest levels of radionuclide concentration were observed close to TEPCO's Fukushima Daiichi NPS directly after the accident and release in April 2011, however since then a continuous decrease of discharge and consequently concentration has been observed. The main radionuclides detected were Cs-134, Cs-137 and, during the first few months, I-131[5]. Recently, Sr-90 became more significant due to additional input from contaminated groundwater.

In the meantime, the levels of radio-caesium dropped significantly in the vicinity of the plant by about five orders of magnitude due to lower input and dilution in the huge volume of the sea. Presently, the activity concentration of Cs-137 is around 1 or 2 Bq/L in the sea area close to the NPS, mostly even below 1 Bq/L. In most of the sampling points along the coastal areas, the values for Cs-137 are less than 0.1 Bq/L or 100 mBq/L. In remote off-shore areas the levels came even closer to levels prior to the accident in the order between 0.001 and 0.003 Bq/L. It can be ascertained that the initial high concentrations of the contamination will be transported along the Kuroshio extension in eastern direction across the Pacific Ocean and diluted to lower levels over the years to come.

There was the observation of some other radionuclides than radio-caesium, but these are

[5] I-131 has a half life of only eight days and decayed in the meantime and is no longer detectable. Cs-137 has a half life of 30 years and will be observable in the Pacific Ocean according to its transport pattern with ocean currents over the next decades. Cs-134 has a half life of about 2 years and will be detectable only for a few years in ocean waters.

mostly due to global fallout in the 1960s from atmospheric nuclear weapon tests and not necessarily attributed to the Fukushima accident. Generally, the concentrations of Pu-isotopes or Sr-90 or tritium have been found extremely low.

Sediments: Caesium has some affinity to be adsorbed by suspended particulate matter in the water column and is therefore partly accumulated in the sediment. Contamination of sediments depends mainly of the type of the sediment and is therefore highly variable. Re-suspension and mixing of sediments will decrease the initial activity in surface layer in the future, but the sediment will act as a certain source to the water column in the future.

Marine biota: Focus on measurements is given to commercial species and species that have recorded more than 50 Bq/kg (fresh weight) in combined Cs-134 and Cs-137. Japan adopted a limit of 100 Bq/kg in combined Cs-134 and Cs-137 for food products in 2012, which also applies for marine fishery products, to keep public dose below the international standard level (1mSv/year, the Codex Alimentarius, http://www.codexalimentarius.org/codex-home/en/). Accordingly, the comprehensive monitoring system has been developed by Japan, both for seawater and for the products in the food chain. Additionally, Japan has introduced limits for food controls that are based on the international standard level. This systematic approach, together with the distribution restrictions by relevant local governments, ensures the safety of the marine fishery products in the market. In the Fukushima prefecture, from 2011 to December 2013, 15,144 samples of marine fishery products were analysed. 2,016 of them had levels of more than 100 Bq/kg. The portion of levels of more than 100 Bq/kg dropped from 57.7 % (average value for period from April to June 2011) to 1.7 % in December 2013. In other prefectures since 2011 to December 2013, 21,606 samples of marine fishery products were analysed. 174 of them had levels of more than 100 Bq/kg of combined Cs-134 and Cs-137. The portion of levels of more than 100 Bq/kg in these prefectures dropped from 4.7% (average value for period from March to June 2011) to 0.1% in December 2013[6].

Acknowledgements

Acknowledgement 18:

A comprehensive "Sea Area Monitoring Plan" was established with a detailed description of sampling positions, including depth distribution, frequency of sampling, detection limit of the analysis to be performed, and indication of the responsible entity. The plan is kept flexible in space and time for reaction on special events when additional inputs to the marine environment can occur or would be expected. The Plan will ensure a comprehensive overview of the environmental situation in the marine environment and the data will provide sufficient background for dose assessments for radiation exposure from marine pathways.

The analytical centres visited by the IAEA team are accredited according to ISO 17025 and should therefore produce reliable, and thus comparable, data. The marine monitoring results are made public nationwide and internationally by means of information dissemination to international organizations and nuclear regulatory bodies, as well as by websites of the monitoring organizations in a prompt way.

[6] Data covering period up to December 2013 were provided after the mission.

<u>Acknowledgement 19:</u>

Wherever possible, a number of countermeasures were implemented in order to protect further contamination of the marine environment, such as isolating and removing the contamination sources and preventing leakages. Thus, the initial levels of concentrations in the sea area have dropped significantly since 2011 and are found near the plant outside the port to be around 1 Bq/L for Cs-137. The levels further off-shore between 2 and 20 kilometres away are now mostly below 0.1 Bq/L, and beyond this region, the levels are almost near those prior to the accident of 0.001–0.003 Bq/L for Cs-137. The decrease of activity concentration in seawater is also reflected in the levels in biota and seafood.

Advice

<u>Advisory point 17:</u>

Because about 10 Japanese institutions are involved in marine monitoring, it is advised to perform interlaboratory comparisons to ensure the high quality of data and to prove the comparability of the results. This can be done by splitting and sharing samples or by a proficiency test (PT). The IAEA Environment laboratories would be pleased to organise such tests in collaboration with responsible authorities in Japan.

International partners could be included in the analyses of samples collected by Japanese institutions to enhance the credibility of the data. The IAEA would be ready to recommend good laboratories to take part in this exercise based on the recently performed PT in relation to the determination of Cs-134, Cs-137 and Sr-90 in seawater. Other radionuclides, such as tritium, could also be included in these exercises.

Such activities could contribute to more confidence in the results produced and improve the credibility of the results produced by the involved institutions. It will also help to show higher transparency of the monitoring activities.

<u>Advisory point 18:</u>

Interpreting the data and presenting it to the public in an understandable, but scientifically correct, way is extremely important but not always simple. Just to show the concentration of radionuclides in the environment without interpretation is not sufficient to gain trust from the public. One possibility could be to refer these data to doses arising from natural radionuclides or to show the temporal trend since the accident. By this, the improvement of the general situation can be demonstrated.

The IAEA team encourages Japan to continue with public seminars or workshops as done in the past and to involve relevant stakeholders (in particular fishermen, consumers and market traders) in data interpretation.

Advisory point 19:

The IAEA team encourages relevant counterparts to consider installing underwater in-situ measurement detectors close to the TEPCO's Fukushima Daiichi NPS site to measure continuously the concentration of gamma-emitting radionuclides in seawater. This would complement the monitoring strategy with separate sampling from ships and only in a limited time scale due to discontinuous sampling. Based on present concentration in the port and near to the port, the detectors will allow detecting Cs-137 in seawater continuously by gamma-spectrometry. This data could also be made available to the public by Internet. These systems would allow detecting any sudden increase of inflow from unknown sources, such as from contaminated groundwater. However, it needs to be mentioned that structures must be found to install these systems properly and transmit the data and spectra. The systems also need to be cleaned from biological fouling growing on the containment. Underwater systems are commercially available in the meantime.

APPENDIX I – MISSION PROGRAMME

Monday, 25 November, Tokyo

09:30 – 09:50 Team leader media interview

10:00 – 10:30 Opening meeting (remarks by METI, TEPCO, IRID and IAEA Team leader)

11:00 – 16:00 Plenary meetings

11:00 – 12:30 Plenary meeting 1
Revised Roadmap (including contaminated water countermeasures)
Introduction of IRID

13:30 – 14:45 Plenary meeting 2
Unit-specific schedule toward the decommissioning

15:00 – 16:00 Plenary meeting 3
Communication efforts

Tuesday, 26 November, Fukushima

09:15 – 18:15 Plenary & Parallel meeting

09:15 – 09:30 Greeting from TEPCO

09:30 – 10:45 Plenary meeting 4
Status of Efforts to Remove Fuel from the Unit 1~4 Spent Fuel Pools

11:00 – 12:15 Plenary meeting 5
Measures for Processing of Accumulated Water at Fukushima Daiichi Nuclear Power Station

<Fuel and fuel debris removal issue>	**<Contaminated water issue>**
13:00 – 17:45 Parallel meeting 1-1 Procedure ,Risk management for 1F-4 fuel removal work	***13:00 – 17:45 Parallel meeting 2-1*** Measures to stop or reduce ingress of groundwater into reactor and turbine buildings Semi-annual report on the tank installation plan Replacement policy for tanks Response to water accumulated in the tank area weir

17:45 – 18:15 Briefing of the Site Visit

Tuesday, 26 November, Chiba (Marine Monitoring Issue)

10:10 – 11:40 Visit of Japan Chemical Analysis Center

14:00 – 16:00 Meeting

Wednesday, 27 November, Fukushima Daiichi site visit

09:00 – 18:00 Site Visit of Fukushima Daiichi

Thursday, 28 November, Fukushima

09:15 – 18:30 Plenary & parallel meetings

09:15 – 12:00 Plenary meeting 6
Status of Activities of the Immediate Response Headquarters for Reliability Improvement at Fukushima Daiichi Nuclear Power Station

13:00 – 14:00 Plenary meeting 7
Fuel debris removal preparations -Building Internal Decontamination-

<Fuel and fuel debris removal issue>	**<Contaminated water issue>**
14:15 – 18:30 Parallel meeting 1-2 Fuel debris removal preparations -PCV Internal Survey- Fuel debris removal preparations - Survey and repair toward filling PCV with water – Preparation for Fuel debris Removal - Flowing out prevention from Reactor Building -	***14:15 – 18:30 Parallel meeting 2-2*** Radioactive Waste Management (Toward the decommissioning of Fukushima Daiichi Nuclear Power Station Unit 1-4)

Thursday, 28 November, Fukushima (Marine Monitoring Issue)

15:00 – 16:00 Visit of Environmental Radioactivity Monitoring Center of Fukushima

Friday, 29 November, Fukushima

09:15 – 11:45 Plenary & Parallel meetings

<Fuel and fuel debris removal issue>	**<Contaminated water issue>**
09:15 – 10:30 Parallel meeting 1-3 Discussion about fuel removal from 1F-4 spent fuel pool	***09:15 – 10:30 Parallel meeting 2-3*** Boundary radiation level evaluation Evaluated dose from facilities and areas at site boundaries

10:45 – 11:45 Plenary meeting 8
Discussion for the works in the site

Transfer to Fukushima Prefecture Building

16:00 – 17:30 Meetings at Fukushima Prefecture (including 30 min courtesy visit to Governor of Fukushima)

Saturday, 30 November, Tokyo

09:00 – 18:00 This day is reserved for drafting the preliminary report.

Sunday, 1 December, Tokyo

09:00 – 18:00 This day is reserved for drafting the preliminary report.

Monday, 2 December, Tokyo

09:30 – 16:00 Parallel meetings

<Fuel and fuel debris removal issue, R&D issue>	**<Contaminated water issue>**
09:30 – 16:00 Parallel meeting 1-4 R&D programs of Roadmap	***09:30 – 12:00 Parallel meeting 2-4*** Sea water monitoring issue with TEPCO ***13:00 – 16:00 Parallel meeting 2-5*** Sea water monitoring issue with the NRA and relevant organizations

16:15 – 18:15 Plenary meeting 9
Decommissioning scenarios after fuel debris removal

Tuesday, 3 December, Tokyo

09:30 – 18:00 Plenary meetings

09:30 – 12:30 Plenary meeting 10

Discussion for finalising the mission and future work.

10:00 – 11:00 Some experts will join Discussion with Committee on Countermeasures of Contaminated Water Treatment

14:00 – 18:00 Plenary meeting 11

Discussion for finalising the mission and future work.

Wednesday, 4 December, Tokyo

13:30 – 14:00 Deliberation of the preliminary report to METI Minister Motegi

15:20 – 16:00 Press conference organised by IAEA
Venue: Foreign Press Center/Japan

APPENDIX II – LIST OF PARTICIPANTS

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