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Fuel Cycle and Waste Newsletter

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Temporary storage of contaminated material. Examples from clean-up demonstration tests at the the Shimooguni Central Assembly Hall, site of a model remediation project in the city of Date.

IAEA Remediation Mission to Japan

With the progress made already, Japan was encouraged to continue its current remediation efforts and to take into consideration the Mission Team's advice for future remediation activities.

In response to a request made by the Government of Japan, the IAEA organized a fact finding mission, 7-15 October 2011 to support the remediation of large contaminated areas off-site of the Fukushima Dai-Ichi Nuclear Power Station. The Mission Team included 12 international experts.

The Mission had three objectives:

1. Provide assistance related to Japan's plans to remediate large areas contaminated by the nuclear accident;
2. Review Japan's on-going remediation related strategies, plans and activities, including contamination mapping;
3. Share its findings with the international community as part of the joint effort to broadly disseminate lessons learned from the accident.

Change: Don't Fear It, Use It!

As the Greek philosopher Hericlitus wrote in 500 B.C. "Nothing is permanent but change." I give two current examples.

Firstly, the nuclear world continues to change. The accident at TEPCO's Fukushima Dai-Ichi nuclear power plant has left a mark that has changed the nuclear world. Without a doubt we haven't seen the end, but most importantly, it is all for a safer and more sustainable nuclear energy.

Our Division contributed significantly to the Remediation Mission to Japan organized by the IAEA last October. Thus the main theme of this newsletter is the findings of the Mission. To share the outcomes with the international community as part of the joint effort to broadly disseminate lessons learned from the accident was one of the objectives of the Mission.

The Mission Team witnessed important progress. Recovery from the natural disasters and all the terrible consequences was on-going and fast, and commitment in all levels of the Japanese society to reconstruction and remediation was impressive. Japan was encouraged to continue current remediation taking into consideration the Mission's 12 points of advice.

Secondly, the Division's senior management will change. I'll become the next Director General of the Radiation and Nuclear Safety Authority of Finland, STUK, effective 1 February 2012, so, this newsletter is my last. However, I'm confident that I leave the Division — and the newsletter — in good hands.

Gary Dyck will be Acting Director of the Division after my departure. With Gary's extensive knowledge and experience in all fuel cycle matters, in particular uranium production and spent fuel management, his proactive approach, strategic skills, vision, passion, discipline and good heart, this Division continues to deliver! For those who have not already noticed, let me twist the iron: this Division is exceptional. There is so much talent, competence and commitment below the surface, simply excellent people.

The work in the IAEA's Division of Fuel Cycle and Waste Technology was most interesting and rewarding in the changing nuclear world. With mixed feeling of sadness and pride I'm leaving the IAEA, but I'll continue to support and work with the IAEA and all of you to make the nuclear world safer. I hope the message and Tom Richard's wise words in the title will stay in the air after I have gone: we must not fear any chance, big or small, but use it for development and improvement.

Tero Varjoranta, Director (T.Varjoranta@iaea.org)

The mission included an assessment of information provided to the team, open discussions with relevant institutions in Japan, and visits to the affected areas, including several demonstration sites. The team also visited the Fukushima Dai-Ichi nuclear power plant. The authorities of Japan provided comprehensive information on their remediation programme.

Remedial actions are based on how the affected areas are characterized. The isotopic composition of the fallout included mainly volatile radionuclides (e.g. I, Te and Cs), but ^{134}Cs and ^{137}Cs are currently the dominant contaminants and are mainly contained in the topsoil layer. Shorter lived isotopes have already decayed. The remediation programme covers about 500 km^2 where radiation dose levels are above 20 mSv/a and about 1300 km^2 where radiation dose levels are between 5 mSv/a and 20 mSv/a.

Based on the current schedule of activities, the team focused on the remediation of affected areas outside the 20 km restricted area. The team agreed with the prioritization and general strategy being implemented and is of the opinion that additional missions could be beneficial at the appropriate time to (a) confirm the progress made and (b) address the remediation challenges within the 20 km zone.

Main findings

The main conclusions of the mission are reported in the Mission Report (http://www.iaea.org/newscenter/focus/fukushima/final_report151111.pdf). It highlights nine areas of important progress and offers advice on twelve points where the mission team felt that current practices could be improved.

Progress highlights

The progress made to remediate affected off-site areas was extensive. Japan had gone forward very quickly and allocated the necessary legal, economic and technological resources to develop an efficient remediation programme. Priority had been given to children and the areas that they typically frequent.

The team considered the use of demonstration sites to test and assess various remediation methods to be a very helpful way to support the decision making process.

The team acknowledged the impressive monitoring and mapping effort by the Japanese authorities as a good basis for a successful remediation programme. The extensive, real time monitoring system that was being set up and the transparent on-line availability of the resulting data are important measures to reassure the public and the international community.

The team appreciated the fact that some school sites were remediated mostly by volunteers with the technical support and guidance of the JAEA. The team was informed that 400 school playgrounds had already been appropriately remediated (as of 30 September 2011).

In addition to the above mentioned areas, important progress witnessed during the mission concerned stakeholder involvement, remediation of agricultural areas and management of contaminated material from clean-up campaigns. More in-depth discussion of these topics can be found in dedicated articles in this newsletter.

Advice to improve practices

The twelve recommendations given in the report cover improvements in strategy, plans and specific remediation techniques, taking into account both international standards and experience from remediation programmes in other countries. The advice concerning stakeholder involvement, remediation of agricultural areas and management of contaminated material from clean-up campaigns are – again – explained in their respective articles.

The Japanese authorities involved in the remediation strategy were encouraged to cautiously balance the different factors that influence the net benefit of the remediation measures to ensure dose reduction. Though conservatism was a good way to manage uncertainties in the early phases, the authorities were encouraged to avoid over-conservatism which could not effectively contribute to the reduction of exposure doses. This goal could be achieved through the practical implementation of the justification and optimization principles under the prevailing circumstances. Involving more radiation protection experts (and the Regulatory Body) in the organizational structures that assist the decision makers might be beneficial in the fulfilment of this objective.

It was also recommended that coordination among the main actors should be strengthened through the establishment of a more permanent liaison between the organizational structures of the Government of Japan and the prefectural and municipal authorities.

The team noted that access to the "deliberate evacuation area" is free and unmarked. Thus it was encouraged to consider the use of appropriate indications or marking of the routes and simple instructions for the public when entering or leaving these areas. These were considered important tools for informing the public and avoiding unnecessary radiation exposures to individuals.

The management of the collected data should be formally described in a data management plan.

With respect to waste in urban areas, the team was of the opinion that it was obvious that most of the material contains very low levels of radioactivity. Taking into account the IAEA safety standards, and subject to safety assessments, this material might be remediated without temporary and/or interim storage. It is effective to utilize the existing municipal infrastructure for industrial waste.

Before investing substantial time and efforts in remediating forest areas, a safety assessment should be carried out to indicate if such action would lead to a reduction of doses to the public. If not, efforts should be concentrated in areas that bring greater benefits. This safety assessment should make use of the results of the demonstration tests.

The mission team encouraged the Japanese authorities to continue the useful monitoring of freshwater and marine systems.

The mission team encouraged the Japanese authorities to actively pursue appropriate end-points for the waste in close cooperation with stakeholders. The national and local governments should cooperate in order to ensure the provision of these facilities. A lack of availability of such an infrastructure would unduly limit and hamper successful remediation activities, thus potentially jeopardizing public health and safety.

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Putting Plans into Action

The IAEA Ministerial Conference on Nuclear Safety, held from June 20 to June 24, paved the way for an enhanced post-Fukushima global nuclear safety framework. In his closing statement to the meeting, IAEA Director General Yukiya Amano undertook to prepare an Action Plan on the way ahead, to be submitted to the IAEA Board of Governors and General Conference in September 2011. The IAEA Action Plan on Nuclear Safety was subsequently endorsed by 151 IAEA Member States.

The Action Plan contains concrete and achievable actions to make nuclear safety post-Fukushima more robust and effective than before. In the coming months, NEFW will be working hard at putting this plan into action.

One of the key action items is to "enhance transparency and effectiveness of communication and improve dissemination." This action item includes a pledge to organize international experts meetings to analyse all relevant technical aspects and learn the lessons from the Fukushima Dai-Ichi nuclear power station accident. Several IAEA divisions, including NEFW, are working hard to prepare the first such International Experts Meeting this coming March.

The International Experts Meeting will be timely. There is a wealth of technical issues which will need to be considered as part of our implementation of the action plan over the coming months.

Fukushima has pointed to the need to re-examine the design basis conditions considered for nuclear facilities. Do these conditions provide a sufficient set of bounding scenarios for the design of nuclear facilities, such as spent fuel storage facilities?

The effects of extended station blackout (SBO) are key to any consideration of the events at Fukushima. We will need to look carefully at how SBO affects the management of stored spent nuclear fuel. Careful attention needs to be given to providing cooling, make-up water, and monitoring capabilities to spent fuel pools during extended SBO.

Other topics that will interest a large number of member states include the ability to accurately model accidents in spent fuel storage facilities, carefully considered accident management procedures, the implementation of meaningful stress tests, systems for accident prevention and mitigation, and the identification of priority areas for research and development.

As more immediate assistance we hope to provide to Fukushima Dai-Ichi site, we will want to look at handling and long term management of damaged spent fuel (including corium).

The purpose of the IAEA's Action Plan on Nuclear Safety is to define a programme of work to strengthen the global nuclear safety framework in light of the accident at TEPCO's Fukushima Dai-Ichi nuclear power station. NEFW is moving forward in defining *and delivering* that programme of work. You can expect to see results in future issues of the NEFW Newsletter.

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Remediation of Contaminated Agricultural Areas

JAPAN MISSION

In the early phase of the accident, a conservative approach was a good way to manage uncertainties and public concerns related to reference levels in the context of food and agriculture. However, for the next cropping season there is room for reducing some of the conservatism by taking into account data and factors published by the IAEA and the results obtained from the demonstration sites and current surveys.

The target for remediation of farm land is the reduction of the total annual dose to the public by 50% in the next two years. This refers only to the areas where the current dose is between 1 and 20 mSv/year. In the long term the total dose should be reduced to under 1mSv/year.

A threshold as basis for the selection of remedial actions

The selection of remedial actions for agricultural land is linked strongly to the maximum threshold concentration of 5000 Bq/kg of radioactive caesium (^{134}Cs and ^{137}Cs) in the soil. For a radioactivity concentration in the topsoil of up to 5000 Bq/kg, reduction of the related air dose rate and uptake of radioactive caesium by crops will be envisaged by deep ploughing or appropriate agrochemical and agronomic practices. Above this concentration, topsoil removal will be considered in addition to other practices.

Japanese authorities calculated that 6300 hectares of paddy fields and 2000 hectares of upland fields have a caesium concentration in topsoil above the threshold of 5000 Bq/kg.

Remedial options tested and implemented

Over the past months, the Japanese authorities have been testing options on how to remediate agricultural land affected by the nuclear accident. The focus has been on those techniques that are known to be the most efficient, such as topsoil removal (up to 4 cm depth) and deep ploughing (ranging between 30 and 60 cm). Since 16 June 2011, in nineteen sites, at a distance ranging between 30 and 160 km from the nuclear power plant, assessments of the efficiency of remedial options have been carried out and estimates made of the amounts of waste generated (i.e., removed topsoil with elevated caesium radioactivity levels), time needed and costs involved in carrying out a particular remediation.

a) *Removal of topsoil*: Measurements showed that removal of topsoil (a layer between 2 and 4 cm) is the most efficient countermeasure to drastically and rapidly reduce radioactive caesium in the soil. Despite the high

efficient caesium reduction, the disadvantage is the large volume of the disposed soil, with up to 400 tonne/hectare.

b) *Deep ploughing*: A promising and less expensive option for decontaminating soils, in particular for soils with radioactivity concentrations of less than 5000 Bq/kg, is deep ploughing to bury the radioactive topsoil into the subsoil. Several ploughing depths have been tested, ranging from 30 to 60 cm. The biggest advantage of deep ploughing is that it is less time consuming and does not generate soil that needs to be disposed of.

c) *Draining suspended soil from paddies*: A third tested method was a method specifically targeting rice paddies (flooded soils), focusing on the reduction of radioactivity levels in the soil by paddling the thin layer of topsoil under flooded conditions, draining the suspended soil, separating the sediments from water, and finally disposing only the sediments. Although time consuming, an important advantage of this technique was the lower amount of waste that was generated, up to 33 times less, as compared to the technique based on topsoil removal.

d) *Phytoremediation*: Phytoremediation was also tested, using for instance sunflowers to extract caesium from the soil. However, as expected from lessons learnt from the remediation of soils affected by the nuclear accident in Chernobyl, results were not satisfactory, with absorption of caesium concentrations per unit area by sunflowers of only 0.05% of caesium in the soil at planting date.

e) *Agrochemical and agronomic options*: Besides soil-based remedial options, such as topsoil removal and deep ploughing, which are currently the most important focus of the remediation of affected agricultural land in Japan, assessment of the use of potassium fertilizer has been started to further minimize ^{137}Cs transfer into the local food chain. Potassium is known to behave similarly to caesium in the soil. By adding potassium, caesium will therefore be taken up less by the crops.

Holistic and area-wide approach

Planning agricultural countermeasures to remediate affected farmland is a task that needs to take into account radiological, food safety, ecological, socio-economic and cultural issues within a holistic and interdisciplinary frame.

The team agrees with continuing in the same intensive and successful way to screen radioactivity concentrations in foodstuff samples. However, foodstuff analysis should be integrated in all test sites as a parameter to assess the efficiency of the remediation. It will also encourage people to start farming their lands again where radioactive soil contamination can be effectively addressed by the techniques reported above and at the same time increase the confidence of consumers.

To complement the data from the assessment of the efficiency of remediation strategies to mitigate the consequences of the nuclear accident for agriculture, the team advises the establishment of cost-benefit analyses at the different levels of the decision making process. These should consider the relationship between dose reduction and costs, including those costs related with temporary and final disposal of removed soil and crop residues.

An area-wide landscape approach is also crucial as soil redistribution in mountainous catchments, such as in specific areas of the Fukushima prefecture, can lead to the redistribution of radionuclides from the uplands to rice paddies and river systems in the lowlands through erosion of soil from steep barren hill slopes or forest tracks, in particular after extreme rainfall events.

Temporary storage of removed topsoil from Paddy field at the demonstration site in Iitate village.

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Growing Interest in Involving and Informing Stakeholders

Stakeholder involvement has received a lot of attention especially after the nuclear accident in Japan. Wide possibilities for stakeholders to be involved and informed ensure that as remediation planning and implementation proceed, stakeholders' needs and concerns are properly addressed. Based on international experience this has many benefits, such as:

- Timely stakeholder involvement increases the credibility of the whole remediation process and the probability of success;
- Public confidence is improved if issues that are raised by the public are taken seriously as well as carefully and openly discussed and evaluated;
- Stakeholder involvement may result in attention to issues that otherwise might not be identified and addressed;
- Timely stakeholder involvement provides improved opportunities for innovation and an influx of ideas. This may not happen if the stakeholders are not engaged early enough or are not convinced by technology demonstrations, related R&D or debate;
- Stakeholder involvement enhances the possibility of delivering a project on time, within cost estimates and through good performance by providing a unified vision of risks, plans and developments. It reduces costly delays to projects by avoiding and effectively resolving conflicts among interested parties;
- A large scale remediation requires particular project management skills and attention. Early stakeholder involvement provides better identification and mitigation of different project risks, thus enabling an improved risk management process to be implemented in order to ensure the success of the entire remediation operation (including disposal of remediation wastes).

The IAEA, UNSCEAR, the WHO and others have devoted significant efforts to learn lessons from the various ways of involving and informing stakeholders. Especially the Chernobyl aftermath has given important aspects that should not be forgotten:

- Psychological consequences were clearly observed and documented;
- Many people were traumatized by their evacuation and relocation, the subsequent breakdown of their social contacts as well as their fear and anxiety about health effects they might ultimately suffer from;

Media is one important stakeholder group.

- Self perceptions of the people being the ‘Chernobyl Victims or Invalids’ and not the ‘Chernobyl survivors’;
- Over the years, the most significant problems have emerged from the severe social and economic depression of the affected regions in Belarus, Russia and Ukraine and the associated serious psychological problems of the general public and emergency workers.

Recent research also shows that social and economic restoration of the affected regions must be a priority.

Practical level involvement of stakeholders in Japan

There is understandable anxiety in Japanese society about the current radiation situation. The team noted that in the early phases of the accident many doubts were expressed about the accuracy and timeliness of the information provided by the central authorities.

The team observed that revised ways and new efforts to inform and involve stakeholders, in particular the public, were being implemented by the central authorities. The mission team recognized the following important players at the practical level of stakeholder involvement:

- The *Fukushima Decontamination Promotion Team* under the Ministry of the Environment is tasked to communicate and coordinate activities with local municipalities, assisting them in their preparation of remediation plans, by dispatching experts and promoting model remediation projects in twelve municipalities affected by elevated radiation levels.
- Having established a ‘Fukushima office’, the *Japan Atomic Energy Authority* (JAEA) interfaces with relevant Fukushima prefecture organizations and citizens. With regard to technical issues, the JAEA provided a telephone hotline for health consultations, dispatched experts to stakeholders, sent researchers to Fukushima prefecture schools from kindergartens to junior high schools at their request, held briefings on radiation in schools, took time and effort to answer questions from parents and teachers, and prepared written material for the benefit of the local people.
- *Cities, villages and their citizens*: the team visited some school sites, from which the contamination to a large extent had been removed in a well organized manner by volunteers, mostly parents of the pupils. The mission team acknowledged the effort of the city administration and the large number of volunteers as an important and effective clean-up and self help method.

A new ‘Act on Special Measures’, which came into force in January 2012, explicitly stipulates stakeholder involvement. However, the Government has not waited for the Act to come into force, but has already started to implement this aspect of the remediation plan. The mission team encouraged the central and local governments to continue strengthening the involvement of and cooperation between various stakeholders. For example, consolidating the engagement of appropriate universities and/or academia in the process, strategy and implementation methods — based on stakeholder needs and domestic cultural settings — could be further developed.

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The mission team visits the Tominari elementary school, the site of a model remediation project in the city of Date.

Management of Contaminated Material from Clean-up Campaigns

JAPAN MISSION

Large volumes of contaminated material will be generated from massive clean-up/remediation activities in urban, agriculture, forest and aquatic areas that are affected mostly by radioactive caesium releases. The material would include soil, organic material, vehicles, building and road material, aqueous liquids, trees and stumps contaminated with ^{134}Cs and ^{137}Cs. The radioactivity content of the contaminated material ranges from a few to several tens of thousands of Bq/kg. The quantity of contaminated material that would be collected from clean-up depends on the extent and depth of the contamination, the characteristics of the affected environment (urban, forest, agriculture, etc.) clean-up criteria, and the timing of the remediation.

The authorities in Japan are considering nine reference decontamination cases that are based on annual effective dose and the type of area. In the IAEA team's view, it is however clear that, irrespective of which reference case is adopted in practice, clean-up efforts will lead to the generation of huge volumes of contaminated material running into millions of cubic meters. All of this generated contaminated material is to be collected, characterized for clearance or treatment and conditioning as required, stored and finally disposed of.

A relative comparison of the volumes of radioactive waste generated from operation and decommissioning of nuclear power plants and the volumes of 'contaminated material' from post-accident remediation is meaningless since the difference amounts to several orders of magnitude, even if one tries to compare it with all very low level waste (VLLW) and low level waste (LLW) from the life cycle of the existing nuclear power plants in Japan. It is then also possible to conclude that pathways for management of these 'materials' should have different considerations and end-points.

Clearance and waste classification issues

A major proportion of the very large volumes of generated material that are to be collected will likely be only slightly contaminated. At the outset, it is imperative to have clear criteria for what constitutes radioactive waste and which kind of material can be cleared (either conditionally or unconditionally) from the regulatory control.

The following aspects could contribute to the pathways for management of contaminated material from clean-up campaigns:

- Establishment of clearance levels to handle these massive volumes;
- Establishment of criteria and a management system for conditional clearance on a case by case basis;
- Possible revision of regulatory requirements related to the management of municipal solid waste to utilize existing infrastructure and to allow the acceptance of bulk quantities of unconditionally cleared and conditionally cleared material.

Contaminated materials management strategy

The key elements of the current strategy to manage contaminated materials have been formulated by the Government of Japan and they are already considering the three above mentioned pathways for contaminated material management options. These key elements include:

- Collection of contaminated material in dispersed temporary storage facilities at or near the clean-up location;
- Transfer of contaminated material from temporary storage facilities into a smaller number of interim storage facilities;
- Volume reduction of combustible material by incineration in available municipal solid waste incinerators equipped with off-gas cleaning systems for retention of caesium;
- Volume reduction of soil using soil washing techniques to separate caesium or caesium rich soil constituents;

- Final disposal, depending on radioactivity content, in commonly used or specially designated municipal landfills or near surface disposal facilities;
- Establishment of an inventory of collected material to keep track of the activity and the amounts actually generated.

The national strategy for dealing with disaster and clean-up waste is properly established and it is sound. The main technical challenges in waste management strategy implementation and consequently in the implementation and success of clean-up campaigns are:

- Existence of the infrastructure that is required for management of such very large volumes of generated material (including collection and segregation at the source by the activity level);
- Establishment of numerous temporary storage facilities, transportation, capacity for treatment for volume reduction and the needed capacity of municipal landfills for disposal of unconditionally or conditionally cleared material;
- Determination of site locations for interim storage facilities for such volumes and the time frame for storage;
- Establishment of designated final disposal locations for different types of wastes.

The National Strategy rightly includes the use of existing infrastructure for municipal solid and industrial waste. This infrastructure exists and it would be able to handle contaminated material to a significant extent, especially if the following criteria are established to assist in the management of the post-tsunami and post-accident situation:

- Occupational exposure limits for the collection of material for temporary storage and segregation at the point of collection to different streams related to activity;
- Establishment of limits for direct recycle and reuse of slightly contaminated material (e.g. rubble, metal, soil, etc.);
- Transportation of contaminated material to treatment facilities, non-processable contaminated material directly to disposal facilities and soil to either treatment or disposal facilities;
- Acceptance requirements for contaminated material for incineration, radiation protection of workers, effluent release limits, and the transport of radioactive ash to disposal facilities.

Interim storage

Storage in numerous dispersed locations is envisaged as a temporary measure that has to be followed by relocation of the material in a smaller number of interim storage sites. Therefore identification of sites for the location of interim storage facilities is of high priority and this is recognized by the authorities in Japan. The national government discusses this matter with the prefectural authorities to find an agreeable solution.

The technically optimal approach would be to locate temporary storage facilities for combustible material at a reasonable distance from the treatment facilities, to locate treatable soil close to soil washing facilities and to locate storage facilities for waste that needs to be disposed of without any further processing close to locations of existing or purposely designed new disposal facilities.

The design of interim storage facilities should take into consideration key functional requirements, namely, to provide for the safe retrieval from storage pending transfer to a final disposal facility, to ensure water ingress and egress control, to provide an environment such that the waste packages do not degrade during the period of storage and are safe to retrieve and transfer to the final repository, to prevent inadvertent or malicious entry to the store, etc.

Final disposal

The national government is responsible for the final disposal of waste from clean-up operations. Material that cannot be disposed of in conventional or special landfills will require establishing new disposal facilities.

Three scenarios for disposal are usually considered in the clean-up of large areas. The first is fully dispersed disposal of contaminated material that is collected from an area of 1–10 km^2 and concentrated in large piles or natural depressions close to the point of the highest contamination. The second option is the establishment of a limited number of larger disposal sites, and the third option is centralized disposal. Utilization of these scenarios in the case of the clean-up campaign in Japan very much depends on the final decision of the central and local governments on areas to be cleaned up, volumes of waste that need to be disposed of outside of municipal landfills, the availability of locations for disposal sites and the results from stakeholder involvement discussions.

A variety of generic designs are available for the disposal of the very large volumes of contaminated soil and other bulk materials arising from the clean-up operations. These designs incorporate engineered features like covers, liners and leachate collection systems as required.

The IAEA team noted that the landfill facilities being considered by Japanese authorities for the disposal of contaminated material (Figures 1 and 2) are provided with the engineered features mentioned above.

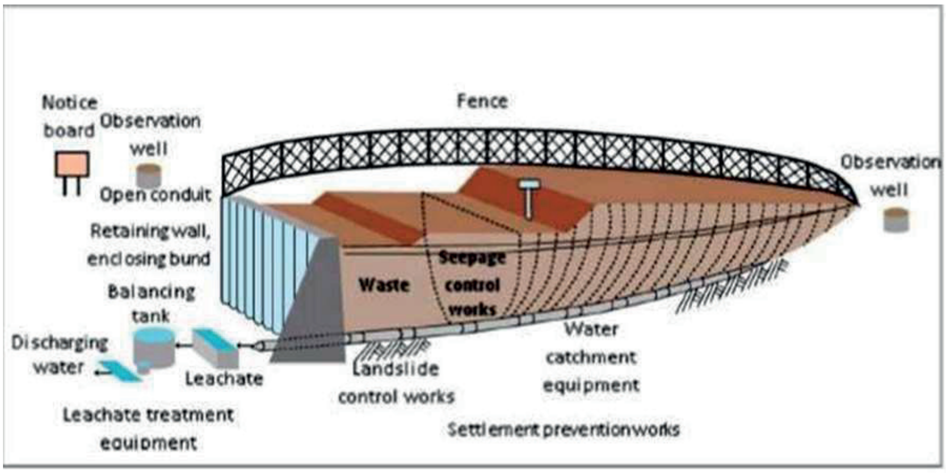

Figure 1: Controlled type of landfill site.

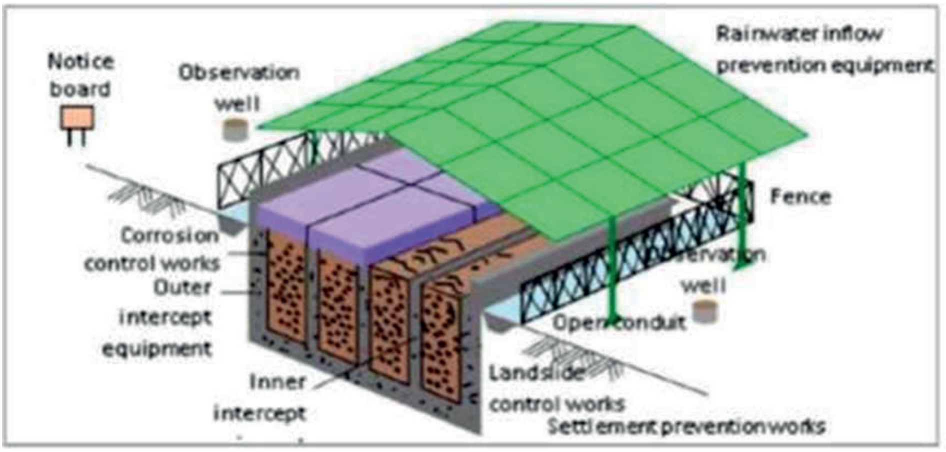

Figure 2: Strictly controlled type of landfill site.

The selection of new disposal site(s) will have to take into account short and long term safety of the public, workers, environment, availability of suitable disposal sites, time required to characterize sites and construct facilities, availability of equipment to construct and operate, long term predictability of performance, establishment of institutional control after closure, consequence of failure, land area, cost and public acceptance, and last but certainly not least the results of stakeholder involvement.

The team encourages the establishment of new near surface facilities for the final disposal of material considered as radioactive waste that needs to be stabilized and properly packaged.

Highlights of important progress

In the IAEA team's view, the approach for using demonstration sites to test and assess various remediation methods is a very helpful way to support the decision-making process.

Advice related to management of contaminated material from clean-up campaigns

It is important to avoid classifying as 'radioactive waste' waste materials that do not cause exposures that would warrant special radiation protection measures. The team encourages the relevant authorities to revisit the issue of establishing realistic and credible limits (clearance levels) regarding associated exposures. Residues that satisfy the clearance level can be used in various ways, such as the construction of structures, banks and roads. The IAEA is ready to support Japan in considering revised, new and appropriate criteria.

The team drew the authorities' attention to the potential risk of misunderstandings that could arise if the population is only or mainly concerned with contamination concentrations (surface contamination levels (Bq/m^2) or volume concentrations (Bq/m^3)) rather than dose levels. The investment of time and effort in removing contamination beyond certain levels (the so-called optimized levels) from everywhere, such as all forest areas and areas where the additional exposure is relatively low, does not automatically lead to a reduction of doses for the public. It also involves a risk of generating unnecessarily huge amounts of residual material. The team encourages authorities to maintain their focus on remediation activities that bring the best results in reducing the doses to the public.

The IAEA mission team encourages the Japanese authorities to actively pursue appropriate end-points for the waste in close cooperation with stakeholders. The national and local governments should cooperate in order to ensure the provision of these facilities. A lack of availability of such infrastructure would unduly limit and hamper successful remediation activities, thus potentially jeopardizing public health and safety.

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Management of Radioactive Wastewater

JAPAN MISSION

The severe accident at TEPCO's Fukushima Dai-Ichi power plant brought into focus significant challenges related to the management of large quantities of radioactive waste in accident situations. Particularly significant is the situation arising at the Fukushima Dai-Ichi Power Plant due to the accumulation of highly radioactive water in the basements of reactors and turbine buildings and trenches.

The radioactivity is picked up during the cooling of damaged reactor cores. The water then finds its way to the basements and trenches through openings in the damaged structures, systems and components. With water levels rising continuously a critical situation was soon reached with impending danger of overflow and leaks to the environment. Indeed, several hundred cubic meters of high activity water did leak into the sea from the trench of unit 2 through a crack until it was sealed. In addition, the presence of this wastewater and the associated high radiation field meant that it was almost impossible to access these areas for servicing of equipment or to identify and eventually plug the sources of leakage. This situation called for urgent measures for removal and temporary storage of the wastewater.

During the initial days after the accident the major effort was focused on utilizing existing storage capacities, viz. turbine condensers, condensate storage tanks and suppression pool surge tanks. With accumulated volumes increasing by the day, these storage capacities were soon found to be insufficient. Wastewater was then transferred to the basements of buildings in the central radioactive waste treatment station on site. All these efforts involved significant water transfer logistics challenges that were successfully handled. However, storage being at best a temporary measure and available storage capacities being insufficient, a more sustainable solution was needed and this was achieved by implementing a plan to treat the water and recycle it for cooling of the damaged cores. The plan also included constructing a large number of tanks for storage of water before and after treatment. This article gives a brief account of the on-going efforts in this direction and challenges that lie ahead. It is primarily based on information provided by TEPCO through its press releases and accompanying photos and handouts.

^{134}Cs and ^{137}Cs are the major radionuclides present in the wastewater. Their activity concentration is of the order of 10^6 Bq/cm^3. With an accumulated volume of more than a hundred thousand cubic meters, the total activity amounts to hundreds of PBq. In addition to the large volume and high activity, the major challenge in treatment is due to the presence of oil and high concentrations of sodium ions from seawater that makes any process for the removal of caesium ions more complex. It goes to the credit of TEPCO and other responsible agencies in Japan who were able to successfully address the treatment challenge by swiftly mobilizing local and international support.

The treatment consists of two main steps, the first step is treatment for radioactivity removal and the second step is treatment for desalination of decontaminated water. A simplified flow schematic is shown in Figure 1.

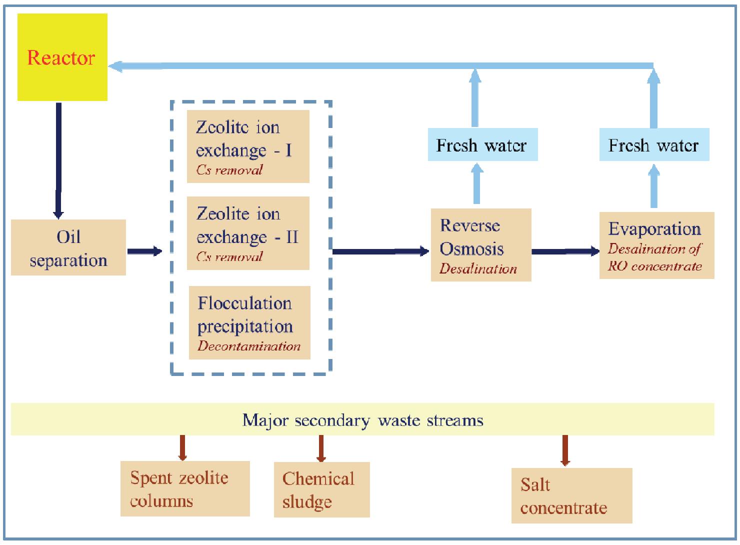

Figure 1: Radioactive water treatment flow schematic.

For the first step, high efficiency and high throughput wastewater treatment systems have been set up in buildings and areas in and around the central radioactive waste treatment station. These systems are custom-designed to special requirements and consist of a range of technologies that are deployed in skid mounted configuration, including oil separators, ion exchange columns and flocculation precipitation equipment.

The removal of oil is essential to ensure effective operation of downstream processes for removal of caesium. Compact industrial oil separators have been used for this purpose that combine the functions of solids

Figure 2: Oil separator (Photo courtesy of TEPCO).

Figure 3: Caesium removal systems I and II (Photo courtesy of TEPCO).

and oil removal (Fig. 2). Solids are removed by settling and oil is removed in a process that involves passing the water through a grid of coalescence plates made of oleophilic plastic media followed by separation based on density difference between oil and water.

Caesium removal follows the removal of oil and un-dissolved solids. This is done by passing the wastewater through a series of columns containing caesium-selective zeolites. The bulk of the caesium activity is captured by ion exchange in the zeolite columns. When exhausted, these columns are replaced with fresh ones. Two independent zeolite based caesium removal systems are presently deployed to enhance processing capacity (Fig. 3).

The flocculation-precipitation process also serves to remove caesium by precipitation of transition metal ferrocyanides that are selective for caesium (Fig. 4). This is similar to the commonly used chemical precipitation process used for treatment of radioactive wastewater but the technology deployed at Fukushima Dai-Ichi NPP incorporates advanced features like, the use of sand ballasted flocculation technology and lamellar separators.

Figure 4: Flocculation-precipitation system (Photo courtesy of TEPCO).

The arrangement of equipment and piping allows for flexible use of the three caesium removal systems (two based on zeolite columns and one based on precipitation) as needed, namely series or parallel and alteration of sequence. In the configuration that is being used at present the two zeolite based caesium removal systems are being used in parallel with the precipitation step bypassed.

The systems are each designed for a processing capacity up to 50 m^3/h. With parallel operation of two zeolite based systems, and taking into account downtime due to maintenance and column change-out, the maximum processing capacity of 70 m^3/h has been attained. To date, in nearly seven months of operation, more than 200 000 m^3 of wastewater has been successfully treated. Very high decontamination factors, of the order of 10^6, have been achieved.

As a result of these efforts, the danger of overflow and leakage to the environment has been averted. With continued operation, it is expected that all accumulated water will be removed from reactor and turbine buildings. This will also pave the way for repairs to the damaged structures and make it possible to fill the reactor and primary containment vessels with water in preparation for defueling operations.

Future challenges resulting from these operations relate to the management of two major secondary waste streams, spent zeolite columns and chemical sludge from the precipitation process. The total volume of these secondary wastes is expected to be in the range of several thousand cubic meters, loaded with very high caesium activity. It is understood that various options are being studied in Japan for the conditioning and storage of these secondary wastes. International technical support can help these efforts.

Figure 5: Reverse osmosis and evaporation systems for water desalination (Photo courtesy of TEPCO).

The decontaminated water resulting from the above treatment is still not suitable for use in cooling of the reactors because of high salt concentration. So the next step is desalination of the decontaminated water. Two technologies—reverse osmosis and evaporation—are being used for this purpose to bring down the salt concentration from several thousand to a few parts per million (Fig. 5). As a result, decontaminated and desalinated water is now being used to cool the reactors.

Water in the spent fuel storage pools located in the reactors is also being treated to remove corrosive salt by deploying smaller capacity mobile systems. An example of a mobile ion exchange system deployed at unit 4 is shown in Figure 6.

It is to be expected that at a later stage compact skid mounted treatment systems will also be used at individual reactor units as part of a closed local cooling loop.

In summary, varieties of treatment technologies have been deployed and are performing well for the treatment of radioactive water at the Fukushima Dai-Ichi nuclear power station. Considering the challenges in mobilization of industry support, design and fabrication of equipment in a short time frame, as well as its installation and operation under difficult conditions, this is a commendable achievement.

Susanta Kumar Samanta (S.K.Samanta@iaea.org)

Figure 6: Mobile ion exchange plant for desalination of unit 4 spent fuel pool water (Photo courtesy of TEPCO).

Three Mile Island Unit 2 Recovery: Lessons Learned Refresher

The 1979 accident at Three Mile Island Unit 2 (TMI-2) in central Pennsylvania, USA left a bowl shaped, hardened mass of core components and fuel in the upper third of the fuel assembly region. The area of core damage was defined by the steam blanketing that had pushed down from the upper head. As the liquefied core mass formed, it began to run down the intact fuel rods and solidified when it encountered reactor coolant water. The liquid core material flowed down into the undamaged fuel rods a short distance prior to solidifying, defining the bowl thickness and anchoring the bowl to the remaining, intact fuel rods. After the bowl formed — creating a container for the liquefied fuel — he remaining, melted core material collected in the bowl. The bowl filled and eventually spilled down to the vessel lower head. As cooling was restored, the liquefied bowl quickly solidified forming a monolith. The rapid cooling fractured the core mass and sent significant quantities of core debris through the reactor coolant system, purification system, reactor coolant pump seal system, decay heat removal system and other inter-related systems. The presence of highly contaminated fuel debris and the subsequent high dose rates from these materials prevented the future use of these systems. The TMI-2 recovery project started in August 1979 and ended in 1990 with a total cost of about one-billion US dollars.

At the time of the accident, the technology and human skills necessary for recovery were non-existent. Even the regulatory structure had to be adapted to, for example, create a TMI-2 defueling senior reactor operator license. Planning and development activities started slowly due to uncertainties including a lack of precise information about the condition of the core. In addition, resources were applied unnecessarily. For example, a completely new decay heat removal system was designed and

Typical defueling entry radiological control dress. The entrant pictured is Dr Russ Green (Photo courtesy of National Geographic).

constructed. However, by the time defueling was initiated, decay heat had decreased to a level manageable by ambient losses alone. So the new system was never used.

Efforts to capture lessons learned from the TMI-2 recovery project generated myriad reports. The quality, accuracy and relevance of each depend heavily on the timing and the connection between individual contributors and the project. In an effort to sort through this information, NEFW invited Dr Russ Green — a TMI-2 defueling operator/engineer throughout the entire recovery project and current TMI-1 engineer — to summarize the most valuable information from several key reports and add detail from his own, unique experience. Dr Green accepted and compiled a detailed paper in Vienna from 10 to 14 October 2011.

The paper discusses the facility itself, the accident, project preparation (reactivity management, use of mock-ups and a critical 1983 core inspection — Operation Quick Look — that accelerated project planning as well as technical and human skill development). It goes on to describe operations to open the reactor vessel (remove the reactor head) and install specially designed equipment to increase shielding for defueling operators, enable the use of specially designed defueling tools and accommodate spent fuel/debris cask handling operation. Next, Dr Green describes the defueling project itself (1986 to 1990), including significant detail on the equipment and tools used in the context of the actual operations. He describes the process to enter and exit the reactor building, the protective clothing and breathing equipment used, the staffing arrangements (including the consideration and limited use of robotic technology available at the time), the round-the-clock work schedule managed in twelve hour shifts, and operations command and control. He describes his direct support of the first core bore operation to cut, remove, package and transport a cylindrical, vertical slice of the core region preserved for later study and analysis. The paper also describes challenges from a radioactivity resistant bacteria plume that threatened early defueling progress.

Following the core bore and subsequent drilling to break apart to remove the core monolith, defueling progress was greatly accelerated after one of Dr Green's teammates used a lasso tool to remove the lower section of a partially melted fuel assembly. Removing this one assembly provided much easier access to the other 176 assemblies in the core. Finally, equipment in the lower core region was removed providing access to the final fuel debris in the reactor vessel. With respect to the debris swept from the core, water was pumped through the systems to return as much material to the reactor as possible. Sections of piping were also cut out to facilitate fuel removal.

A defueling team performing defueling operations on the work platform. The defueling operator on the left with one foot balanced on his toe is Dr Russ Green.

Condition of a TMI-2 fuel assembly encountered during Quick Look.

Following this work, a test for determining the amount of remaining fuel was performed. During accident, fuel assembly melting combined fuel and non-fuel material. Defueling operations could not differentiate fuel from non-fuel, so using a material balance (accounting by weight of fuel material) to determine how much fuel was removed or remained was not possible. A special test, called neutron interrogation, was developed to determine if all fuel had been removed. A neutron source was placed outside the section of piping to be interrogated and a series of neutron detectors were set up near the site. Changes in neutron count rate in the presence of the neutron source indicated the presence of fuel. This test provided an accurate assessment of fuel quantities in the various systems. Once the total amount of remaining fuel was below the minimum required for criticality, TMI-2 was considered defueled.

In his paper, Dr Green goes on to describe waste management activities; water removal from the packaged core material, package preparation and transport across the USA to Idaho National Laboratory, treatment of accident and recovery project generated waste water, decontamination, and the transition of the TMI-2 license to a 'post defueling monitored storage' mode.

The paper includes fourteen specific lessons learned from Dr Green's direct, personal experience, which he offered in addition to those already mentioned in the seventeen reports referenced in the paper. A draft was presented to a small group of IAEA staff on 14 October. Based on comments received, a final version was prepared and presented during the December 2011 GLOBAL conference hosted by Japan.

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A Preliminary Survey of Worldwide Recent Activities in Research Reactor Centres Following the Accident at TEPCO's Fukushima Dai-ichi NPPs

Following the core melting and the radiological consequences as a result of the accident at TEPCO's Fukushima Dai-Ichi nuclear power Station, there has been a worldwide movement to revise safety assessments of nuclear power installations. At the same time, the community of research reactor (RR) stakeholders, operators and regulators publically expressed their readiness to re-evaluate and update the safety status of their facilities in the event of similar external events. Although RRs generate (on average) one per-mil of the energy of NPPs, and accordingly their radioactive source term is reduced, there are important common safety related topics to be checked and revised (e.g. the seismic design, blackout and external events resulting in the loss of the ultimate heat sink, emergency organization/crisis preparedness, etc.).

In June 2011 the Technical Working Group for Research Reactors (TWGRR) asked the Research Reactor Section (RRS) to make a presentation at the November 2011 International Conference on Research Reactors (ICRR) about the impact of the accident on the RR operators community.

As a first step to assist Member States in considering an unprecedented safety event, RRS distributed a questionnaire to collect information from RR managers operating facilities with power greater than one megawatt. This questionnaire gathered information on the activities initiated following the accident last March. In July the questionnaire was posted on the ICRR website. By November 2011, 56 answers had been received, from 29 Member States (out of a potential 56 states operating RRs).

The results received on the first general question "*What was done in your organization following the F-D event?*" are depicted as a pie chart in Figure 1. The chart indicates that 69 per cent of organizations surveyed launched a dedicated activity (all colours except blue) following the accident. Considering the actions performed, many organizations (red & orange & light blue & light green) reported a short re-evaluation of the design base accidents list in the safety analysis report (SAR) and/or a revision in the emergency preparedness programme (EPP). Further comprehensive activities, such as including a complete re-evaluation of the SAR and of the EPP were reported by fewer organizations (green &

What was done in your organization following the F-D event?

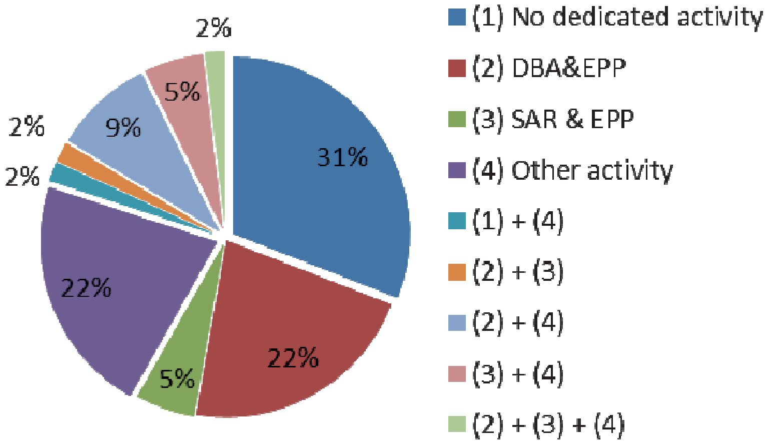


Figure 1

Considering the reactor EPP, what was asked to be done following F-D?

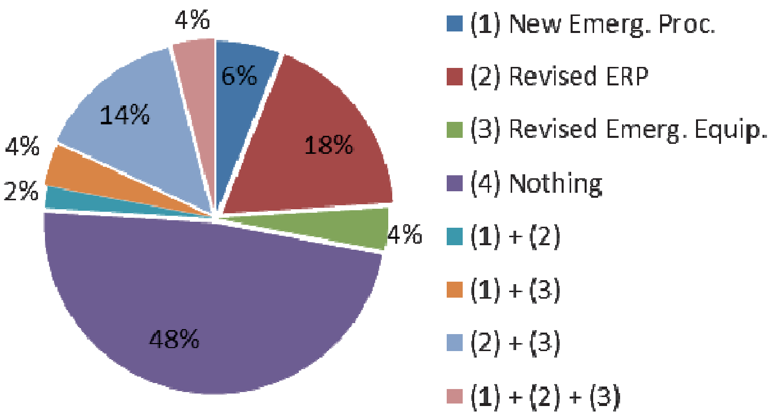


Figure 2

What in the reactor utilization/operating plan was revised after F-D?

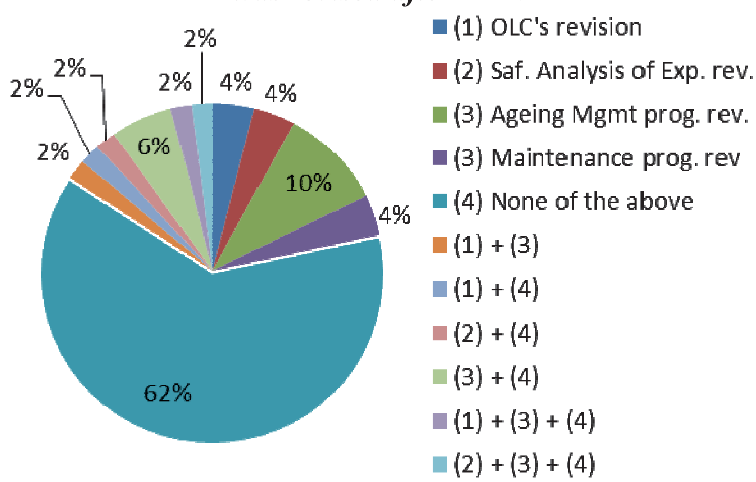


Figure 3

orange & light green), as these considerable changes are usually requested and approved by the regulatory bodies, and therefore are included in a long term and complex process. The rest of the answers (purple & turquoise) mention unspecified activities pertaining to revision of the emergency related systems and/or the emergency procedures.

Another significant response was received to the question "*Considering the reactor Emergency Preparedness Plan (EPP), what was asked to be done after the F-D event?*". The answers, shown in Figure 2, indicate that 18 per cent of the organizations revised the emergency response programme (ERP), 6 per cent (blue) prepared new emergency proceedings and 4 per cent (green) upgraded the emergency equipment. Some of the answers reported combined activities of the above mentioned (orange & light blue and pink), where the most popular activity done by 14 per cent (light blue) was to revise the ERP and to upgrade the equipment accordingly. Nevertheless, 48 per cent decided not to change their existing EPP. It should be mentioned and emphasized that changes in EPPs are requested and approved by the regulatory bodies and therefore are subjected to be completed during a longer process.

Finally, in response to the question "*What in the reactor's utilization/ operation plan was revised after the F-D event?*", the replies are presented in Figure 3. Considering the answers received, 16 per cent (green & light green) reported revision of the ageing management programme only, 2 per cent also changed the OLC's (lavender) and the Safety Assessment (sky blue). Some organizations (blue & light blue) decided to revise only the operating limiting conditions (OLC's), and some (red & pink) only performed new safety assessments. The other 62 per cent of the answers indicate that no action was taken.

Considering the preliminary surveillance, it is concluded that the responses to the questionnaire demonstrate that following the accident many activities were initiated in the RR's facilities worldwide, although it is presently unknown whether they were concluded or not. In the coming months, as additional data is received in the RRS, a more comprehensive examination of the survey results will be done, in order to draw the first conclusions about the IAEA follow-up activity requested on this subject. The updated results of the survey will be presented at the upcoming RRFM/IGORR meeting in March 2012.

Yacov Barnea (Y.Barnea@iaea.org)

Introduction of Authors

Gary Dyck is the head of the Nuclear Fuel Cycle and Materials Section, which covers prospecting for, mining and processing of uranium; fuel engineering; spent fuel management; fuel recycling; and advanced fuel cycles.

Susanta Kumar Samanta is Waste Predisposal Specialist in the Waste Technology Section. His work includes characterization, treatment, conditioning and storage of radioactive waste, to enhance waste predisposal operations.

Gerd Dercon is Crop Scientist/Plant Nutritionist of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. His work covers the development, adaptation and dissemination of isotopic and related research techniques for improving land and water management and crop nutrition.

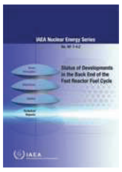
Edward Bradley is a Nuclear Engineer in the Research Reactor Section. His background includes significant nuclear power experience including BWR reactor engineering and as an accident mitigation and transient response specialist at the Three Mile Island Unit-1 reactor.

Hanna Kajander is a Communications Specialist in the Division of Nuclear Fuel Cycle and Waste Technology and is involved in activities that aim at improving public knowledge on radioactive waste.

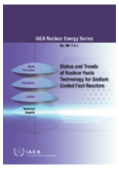
Yacov Barnea is a consultant in the Research Reactor Section. His work includes planning, innovation, ageing of research reactor core structural materials and surveillance programmes for life extension.

Zoran Drace is the team leader of Predisposal Management of Radioactive Waste in the Waste Technology Section. His work includes characterization, pre-treatment, treatment, conditioning, storage and minimization of radioactive waste.

Recent Publications



IAEA Nuclear Energy Series No. NF-T-4.2
Status of Developments in the Back End of the Fast Reactor Fuel Cycle **NEW!**



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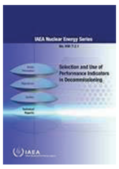
Status and Trends of Nuclear Fuels Technology for Sodium Cooled Fast Reactors (2011) **NEW!**



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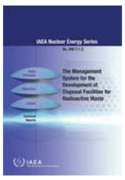

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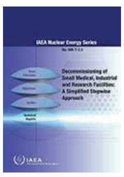

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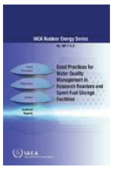

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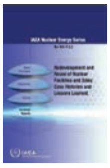

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Delayed Hydride Cracking of Zirconium Alloy Fuel Cladding (2010)

IAEA-TECDOC-1654
Advanced Fuel Pellet Materials and Fuel Rod Design for Water Cooled Reactors (2010)

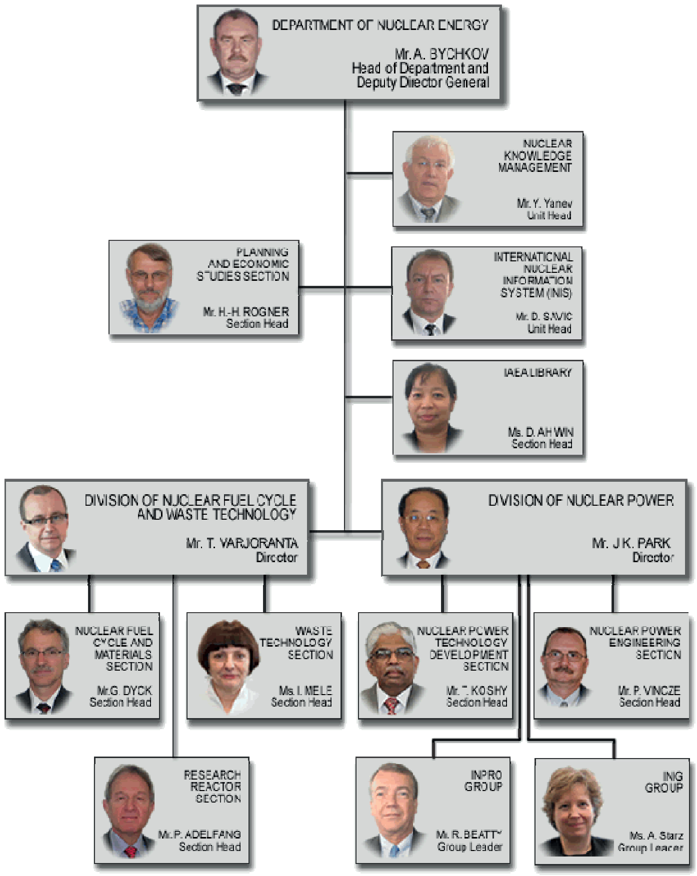
Upcoming Meetings in 2012

Date	Title	Place	Contact
14—16 Feb	TM on potential international centres of excellence based on high flux research reactor facilities	Cadarache France	K.Alldred@iaea.org
12—16 Mar	Third RCM on conversion of miniature neutron source research reactors (MNSR) to low enriched uranium (LEU)	Vienna Austria	R.Sollychin@iaea.org
14—16 Mar	Annual meeting of technical working Group on research reactors (TWGRR)	Vienna Austria	P.Adelfang@iaea.org
27—30 Mar	Annual meeting of the international radioactive waste technical committee (WATEC)	Vienna Austria	I.Mele@iaea.org
10—13 Apr	TM on very long term storage of spent fuel	Vienna Austria	A.Bevilacqua@iaea.org
17—19 Apr	TR/Workshop on geological disposal of high level waste/spent fuel	Lisbon Portugal	P.Degnan@iaea.org
23—26 Apr	TM on miniature neutron source research reactors (MNSR) low enriched uranium conversion working group	Accra Ghana	R.Sollychin@iaea.org
24—25 Apr	Annual TWGFPT meeting	Vienna Austria	V.Inozemtsev@iaea.org
9—11 May	Technical working group on nuclear fuel cycle options (TWGNFCO)	Vienna Austria	G.Dyck@iaea.org
14—17 May	TM on LEU accelerator driven sub-critical system (ADS) and applications	Antwerp Belgium	R.Sollychin@iaea.org
14—18 May	Second RCM on spent fuel performance assessment and research (SPAR-III)	Charlotte USA	A.Bevilacqua@iaea.org
29 May—1 Jun	TM on the origin of sandstone type uranium deposits: a global perspective.	Vienna Austria	T.Harikrishnan@iaea.org
4—6 Jun	First RCM on near term and promising long term option for deployment of thorium based nuclear energy	Vienna Austria	U.Basak@iaea.org
20— 23 Aug	The 48th Joint OECD/NEA-IAEA Uranium Group Meeting	Kirovograd Ukraine	P.Woods@iaea.org
27—30 Aug	TM on In-pile testing and instrumentation for development of G4 materials	Halden Norway	V.Inozemtsev@iaea.org
10—14 Sep	TR on Feasibility of Low-specific-activity Mo-99 production and Distribution	Vienna Austria	A.Carrigan@iaea.org
24—27 Sep	TM on Fuel integrity during normal operating and accidental condition	Bucharest Romania	U.Basak@iaea.org
1—5 Oct	TM on risk management and decommissioning	Vienna Austria	P.Osullivan@iaea.org

Division of Nuclear Fuel Cycle and Waste Technology (NEFW) WebSite Links

Division Introduction – NEFW Home

www.iaea.org/OurWork/ST/NE/NEFW/index.html



Nuclear Fuel Cycle and Materials Section (NFCMS)

- Main activities
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/home.html
- Technical Working Group on Nuclear Fuel Cycle Options (TWGNFCO)
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/twgnfco.html
- Technical Working Group on Water Reactor Fuel Performance and Technology (TWGFPT)
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/twgfpt.html
- Integrated Nuclear Fuel Cycle Information System (iNFCIS)
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/infcis.html

Waste Technology Section (WTS)

- Main activities
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/WTS/home.html
- International Radioactive Waste Technical Committee (WATEC)
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/WTS/WATEC.html
- Databases (NEWMDB, DRCS)
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/WTS/informationsystems.html

Research Reactor Section (RRS)

- Main activities
  http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/RRS/home.html
- Technical Working Group on Research Reactors (TWGRR)http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/RRS/twgrr.html
- Research Reactor Database
  nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?rf=1
- Research Reactor Ageing Database
  www.iaea.org/OurWork/ST/NE/NEFW/AD/index.html

Impressum

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Nuclear Fuel Cycle and Waste Technology

Fuelling the effective and reliable use of nuclear technology

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