Reactor Design and Decommissioning – An Overview of International Activities in Post Fukushima Era[1] -12396

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ABSTRACT

Accidents at the Fukushima Dai-ichi reactors as a result of the devastating earthquake and tsunami of March 11, 2011 have not only dampened the nuclear renaissance but have also initiated a re-examination of the design and safety features for the existing and planned nuclear reactors. Even though failures of some of the key site features at Fukushima can be attributed to events that in the past would have been considered as beyond the design basis, the industry as well as the regulatory authorities are analyzing what features, especially passive features, should be designed into the new reactor designs to minimize the potential for catastrophic failures. It is also recognized that since the design of the Fukushima BWR reactors which were commissioned in 1971, many advanced safety features are now a part of the newer reactor designs.

As the recovery efforts at the Fukushima site are still underway, decisions with respect to the dismantlement and decommissioning of the damaged reactors and structures have not yet been finalized. As it was with Three Mile Island, it could take several decades for dismantlement, decommissioning and clean up, and the project poses especially tough challenges. Near-term assessments have been issued by several organizations, including the IAEA, the USNRC and others. Results of such investigations will lead to additional improvements in system and site design measures including strengthening of the anti-tsunami defenses, more defense-in-depth features in reactor design, and better response planning and preparation involving reactor sites. The question also arises what would the effect be on the decommissioning scene worldwide, and what would the effect be on the new reactors when they are eventually retired and dismantled.

This paper provides an overview of the US and international activities related to recovery and decommissioning including the decommissioning features in the reactor design process and examines these from a new perspective in the post Fukushima -accident era.

FUKUSHIMA DAI-ICHI: NEAR-TERM IMPACT ON NUCLEAR RENAISSANCE

Fukushima area in the eastern coast of Japan experienced a magnitude 9 earthquake and large tsunami waves on March 11, 2011 that caused widespread devastation with more than 20,000 lives lost, and caused the nuclear accident at Fukushima Dai-ichi reactor complex. The loss to Japan's economy (including from the nuclear accident) is estimated in excess of $100 billion. The Fukushima nuclear accident has been categorized at the highest rating on the International Nuclear Event Scale, similar to the Chernobyl rating. The accident severely damaged the reactor complex.

[1]The views expressed in this paper are those of the authors and do not necessarily reflect the views of their organizations.

While a number of other nuclear facilities in the area, including the nearby Fukushima Dai-ini, were impacted by the earthquake and tsunami, these were successfully shutdown by the plant's automatic systems based on the detection of seismic activity. However, the Fukushima Dai-ichi reactors, even though shut down by the safety systems, were severely damaged. The tsunami waves estimated to be larger than 14 meters high were beyond the capability of the plant site's defences that were designed to withstand tsunami waves of a maximum height of 5.7 m. Subsequent assessments have also shown that the coastline also subsided by several feet. Loss of all power sources including emergency diesel generators (except one emergency diesel generator providing emergency power to be shared between units 5 and 6) led to station blackout (SBO) and loss of cooling in Dai-ichi reactor units 1 to 4. Part of the nuclear fuel was severely damaged and a series of explosions also occurred from the hydrogen built up. The explosions caused further damage at the site and led to a spread of radiological contamination. Severe damage was also caused to the six associated spent fuel pools and contaminated water leaked from the site. The recovery efforts are still in progress and studies continue to be conducted to determine the root causes and lessons learned.

Prior to the Fukushima Dai-ichi accidents, the nuclear power industry had been in the early stages of a "renaissance" , and it had been estimated that anywhere from 60 to 130 new power reactors might be built worldwide over the next twenty years. The 437 commercial nuclear power reactors operating in the world currently contribute 377 GWe to world's electricity production. Total global energy demand, including electricity, is expected to grow by nearly 50% by the year 2035 over the energy consumed in 2009, as projected in the Annual Energy Outlook for 2011 DOE/EIA-0383 (2011) released on April 26, 2011 [1]. Note that nuclear reactors currently supply only about 14% of the world's electricity generation.

According to the projections, nuclear power capacity in the United States increases from 101.0 gigawatts in 2009 to 110.5 gigawatts in 2035 for the reference case. [The reader is referred to Reference [1], page iii for the definition of the reference case which lists the many inputs and assumptions. Note also that projections by EIA are not statements of what will happen but of what might happen, given the assumptions and methodologies used for any particular scenario]. The 3.8 gigawatts of expansion is assumed coming from existing plants and the new capacity is estimated at 6.3 gigawatts The new capacity includes completion of the second unit at Watts Bar site where construction has resumed since 2007 on a partially completed plant and where construction had been suspended since 1988. The report also assumes the four new nuclear power plants being completed in the Reference case and brought on line by 2020 to take advantage of Federal financial incentives as stated on page 76 of Reference [1]. It should be noted that this report is based on the data input prior to Fukushima events. In a recently released report, the World Energy Outlook (November 2011) [22], the International Energy Agency includes a "Low Nuclear Case" in response to the Fukushima events to investigate what a rapid slowdown in the use of nuclear power would mean to the global energy landscape. Additionally, in the context of United States and elsewhere, the cost increases for new nuclear plant construction and management make new investments in nuclear power uncertain.

The net effect of Fukushima accident on nuclear renaissance will not be known for some time, but it has slowed the momentum of the nuclear renaissance, at least in the near term. Following the Fukushima event, several countries have put plans for new reactor construction on hold until the safety reviews have been conducted. The effect of the Fukushima event on Europe's nuclear industry has been significant. Germany has not only reversed the earlier decision to extend the service life of the country's seventeen nuclear reactors but has now permanently shut down eight nuclear power plants and plans to close the remaining nine in stages by 2022. In referendum held on June 12 and June 13, Italians overwhelmingly voted against the resumption of nuclear in their country. Switzerland has put all plans to build new nuclear plant on hold, at least temporarily. However, other European countries (e.g. Finland, Russia, United Kingdom and Slovakia) have kept their nuclear program unchanged.

In Asia, China, Korea, and India are expected to continue with their nuclear expansion because of the limited fuel options for energy production and a substantial need for energy now and even greater need projected for the future. In fact, about 50% of future nuclear construction, through 2035, will come from China and India. In many ways, China may provide a pulse of the nuclear renaissance in general because of the projected energy demand growth in China and because it has more than 25 reactors under construction. Another 34 more were also approved by the government, even though since the Fukushima accident, the government has ordered a safety review before proceeding further.

Fukushima events have led to a re-thinking of nuclear power in several countries and some of them may decide not to pursue new build further or may even plan to phase out their nuclear power program or – more realistically- to decommission their older reactors with no life extension. However, in the longer-term, the nuclear energy is expected to continue to play an important role in the world's energy supply.

REACTOR DESIGN AND DECOMMISSIOING

Reactor designs have improved significantly over the past four decades especially with respect to the safety systems and their performance under design basis events. In that regard and related to design of the BWRs, the later Mark III design of BWRs (as compared to the earlier design of Mark I such as those at Fukushima) uses a concrete dome for containment, somewhat similar to PWRs, and has a separate building for storing used nuclear fuel (as opposed to Mark I design where spent fuel is stored in a pool above the reactor; spent fuel pool cooling failures along with the lack of reactor cooling in the post accident period were the key reasons for the consequences at Fukushima).

Even though the debate now focuses on how to provide capability for "beyond-design-basis" events, many design features that enhance safety and that facilitate construction of the systems and structures also facilitate eventual decommissioning. It is also recognized that decommissioning and/or cleanup and recovery efforts under an accident situation such as that at Fukushima are different and extremely challenging as opposed to decommissioning of a reactor in the post operation period. However, in the era when the reactors such as those at Fukushima were built, decommissioning considerations were not a priority during the design process. In fact, one of the key lessons learned from reactors (of various designs) that have been decommissioned is that the lack of decommissioning-oriented design features have made decommissioning more difficult, expensive and lengthy. Related to the subject of reactor design and decommissioning, a summary is provided below of the status on this topic and the key considerations in this regard.

As the nuclear renaissance took hold, the new reactors are being designed and built with the traditional optimization based on capital costs and safety features, and the decommissioning considerations are also being taken into account. Even though the decommissioning of the reactors being built today may be sixty years down the road from the time they go on line, eventually all reactors will be decommissioned and the payback for planning decommissioning features into the designs is substantial. Reactor designs that are prudent and optimized for eventual decommissioning will lead to shorter decommissioning time frames, minimum generation of radioactive waste, and better radiological safety. This in turn ensures that the tail-end costs of the power reactors are manageable and that the public confidence in the nuclear power can be sustained. Based on the extensive decommissioning experience that is now available, it is possible to summarize some key areas where new reactor designs can facilitate future decommissioning of the reactors. The decommissioning "lessons learned" from the past and the present can be utilized in the development of designs for the future. Considerations in this regard include the following:

- Overall reduction in components
- Overall reduction in construction materials and reduction in (eventual) decommissioning waste

- Incorporation of modular concepts that will facilitate eventual deconstruction
- Innovations in equipment, materials, and system layout
- Access to highly contaminated components for decontamination or dismantling
- Addressing major component removal issues, required for both building and decommissioning, at the design stage
- Decontamination technologies of today and future
- Making decommissioning costs a part of the lifecycle planning of the nuclear plants right from the design stage
- Decommissioning-oriented records.

Further discussion of the relevant factors is available in References [2- 4] and the IAEA-TECDOC-1657 [5]. Tables 1 and 2 below illustrate how the newer reactor designs are accomplishing incorporation of the factors described in the first two bullets above.

Table 1: Reduction in Components

Reduction in components for new designs	AP1000	EPR	ESBWR
Reduction in components compared to an existing older design (PWR or BWR)	87% less cable 80% less piping 50% fewer valves 35% fewer pumps	44% fewer heat exchangers 50% fewer tanks 47% fewer valves 16% fewer pumps	11% systems eliminated 25% of pumps, valves and motors eliminated

Table 2: Reduction in Bulk Construction Materials, and Decommissioning Waste

Reeducation in Materials	1970s Era	New Designs
Reduction in Concrete (Construction)	>190 m^3/MWe capacity installed Typical Total PWR (US) Approx. 300,000 m^3	Approx. 90 m^3/MWe capacity installed Typical Total Example: AP1000 <100,000 m^3
Reduction in Rebar (Construction)	>40 t (metric) per MWe capacity installed Typical Total PWR (US) Approx.46,000 t (metric)	<40 t (metric) per MWe capacity installed Typical Total Example: AP1000 10,000 t (metric)
Reduction in Decommissioning Waste (Radioactive)	Typical Total* 18,340 m^3 (647,500 ft^3)	Typical Total* Example: AP1000 Approx. 10,000 m^3 (353,000 ft^3)

*Total figures do not include non radioactive waste or the bulk materials such as concrete/demolition debris.

FUKUSHIMA'S POTENTIAL IMPACT ON DESIGN FOR POST-ACCIDENT RECOVERY AND DECOMMISSIONING

Fukushima events have already led to a re-examination of nuclear programs by the national authorities world-wide. Specific to reactor designs, a re-examination of the safety features of the reactors is being conducted as well as an assessment of the ability of the Systems, Structures and components (SSC) to withstand effects of events that in the past have been considered as beyond-design-basis.

Japan Activities

Recovery activities are being followed and reported on by the regulatory agencies and other organizations in Japan (including the parent company of Fukushima site, Tokyo Electric Power Company). Many national and international organizations, regulatory authorities, and industry groups also continually provide updated information on the Fukushima site. This progress is ongoing and to date no decisions have been made as to if and when the site may be decommissioned.

Relevant to the topic of this paper, it should be noted that post-Fukushima reviews are in progress at many of the reactors. Related to design issues, some of the utilities have started conducting stress tests, with parameters that in the past would have been considered beyond the design basis. The first such example is the Ohi station, where the utility recently performed computer simulations of the beyond-design-basis scenarios based on Fukushima Dai-ichi lessons. In case of an earthquake followed by a tsunami, margins against reactor core damage take into account safety measures of the entire facility and measure that protect fuel from severe damage [6]. Another station in Japan (Ikata3) has reported stress tests in November 2011 [7]. Clearly, such assessments are relevant to the plants located in the coastal areas. In addition, the Japanese government said in July that all reactors would be subjected to stress tests in two phases [23]. In step 1 such tests are being applied to those reactors that have been taken offline for periodic inspections. In step 2, a comprehensive safety assessment will be done of all reactors. As of end of November 2011, only 10 of the country's 54 nuclear power reactors were in operation, with 27 units in outage for periodic inspection and other reasons and 17 shutdown due to tsunami or at government's request [23].

US Near Term Activities

In the Unites States, many of the utilities have initiated examination of the long term SBO readiness to respond to design basis events and beyond- design-basis events, spent fuel cooling, spent fuel storage integrity, and hydrogen control. The US Nuclear Regulatory Commission recently released the report from its Near-Term Task Force [8]. Of the twelve recommendations made, several (summarized and re-paraphrased) are related to the design of the reactors.

- Re-evaluate and upgrade the necessary design-basis seismic and flooding protection of SSCs for operating reactors.
- Potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.
- Station blackout mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events.
- Reliable hardened vent designs in boiling water reactor facilities with Mark I and Mark II containments.
- As part of the longer-term review, identify insights about hydrogen control and mitigation inside containment or in other buildings.
- Enhancing spent fuel pool makeup capability and instrumentation for the spent fuel pool.

Related to Mark I and Mark II designs, it should be noted that out of the fleet of 104 operating reactors, US has 23 BWRs similar to Fukushima reactors with Mark I containments. An additional 12 reactors have the later Mark II or Mark II containment systems. Reassessments at the reactors may result in additional modifications and/or decisions to not operate for re-licensed periods and/or decommissioning in some cases.

United Kingdom

The Office of Nuclear Regulation (ONR) in UK released a report in September 2011 on the implications of the Fukushima events on the UK nuclear industry [9]. Even though none of UK's reactors are of the BWR design (as Fukushima) and all except Sizewell B (a PWR) are gas cooled reactors, several areas are considered important as lessons learned. These include external hazards, accident analysis, spent fuel storage, and emergency planning among others. Two of the many conclusions in the report are relevant and quoted here.

FR-2: "The Fukushima accident reinforces the need for the Government, the Nuclear Decommissioning Authority and the Sellafield Licensee to continue to pursue the Legacy Ponds and Silos remediation and retrievals Programme with utmost vigour and determination".

FR-3: "The mandatory requirement for UK nuclear site licensees to perform periodic reviews of their safety cases and submit to ONR to permit continued operation provides a robust means of ensuring that operational facilities are adequately improved in line with advances in technology and standards, or otherwise shut down or decommissioned".

It is clear that adequacy of the systems will be reviewed and expected to be improved keeping in concert with the advances in technologies and standards.

IAEA Activities

By agreement with the Government of Japan, the International Atomic Energy Agency conducted a preliminary mission to find facts and identify initial lessons to be learned from the accident at Fukushima Dai-ichi and share this information across the world nuclear community. To this end, a team of experts undertook this Fact Finding Mission from 24 May to 2 June 2011 [10]. The results of the Mission was reported to the IAEA Ministerial Conference on Nuclear Safety at IAEA headquarters in Vienna on 20-24 June 2011 [11].

The IAEA also dispatched a Mission to Japan in October 2011, following a request from the country's government, to carry out a preliminary assessment of the strategy and plans being considered by the Japanese authorities to remediate the areas off-site the Fukushima Dai-ichi Nuclear Power Plant that were reported to have elevated levels of radiation. The mission, comprising 12 international and IAEA experts from several countries, visited numerous locations in the Fukushima Prefecture and conducted meetings in Tokyo and Fukushima with Japanese officials from several Ministries and institutions. A summary of the experts' findings is available on the IAEA website [12]

From these Missions and subsequent communications between the IAEA and the Japanese authorities, a number of issues have emerged related to the management of post-accident conditions concerning:

- strategy,
- technologies,
- implementation process,

- organization and management aspects,
- stakeholders' involvement, and
- funding for decommissioning and environmental remediation.

As a result, international organizations such as the IAEA and NEA can expect to be asked to provide guidance to their member state organizations regarding preparation for, and conduct of recovery from, potential future accidents involving nuclear fuel damage, and to plan for eventual decommissioning of the affected facilities. This can be expected to impact*, inter-alia* plant design features. Some of the specific areas to be considered are discussed below.

1. Damaged Fuel and Fuel Debris

Damaged fuel and fuel debris is unlike any customary waste form. The content and shape of debris can vary significantly. It will be a mixture of ceramics, metals, and possible eutectics. The shapes will vary from fine particles to lumps of materials to partially recognizable shapes. There is a possibility of relatively large amorphous masses of glasslike "corium." It is to be expected that a set of criteria will need to be developed for packaging and long-term storage of damaged fuel and fuel debris.

2. IAEA Materials Accountability Requirements and Other IAEA Standards

It is impossible to accurately account for the fuel-related debris - the special nuclear material in a core that has been melted or otherwise massively destroyed. As was the case for TMI-2, normal standards for accountability of these materials will need to be modified to accommodate the condition of the physical plant. The TMI-2 experience provides an example from which to formulate this. In that case, the approach was to measure what remained following fuel removal as well as the weight of material removed. Accounting on an isotopic basis was not required. Other standards and guidelines that apply in normal situations, such as those for clearance of materials and contaminated lands, may also require case-specific application for Fukushima cleanup.

3. Waste Concentrates from Water Processing

There will be ion exchange and filtration media resulting from processing accident- contaminated water. Much of it will contain high concentrations of Cs-137. The presence of sea-water (salinity) has required the design and construction of special liquid waste-processing systems. Highly radioactive isotopes such as Co-60 will also be captured and the concentrates or filters may furthermore contain traces of uranium and plutonium. Highly radioactive sludges that include foreign materials such as silt and organics are also to be expected. How to store, package, and transport this material can all be affected by where it will be sent or whether it will have to be retained on-site indefinitely: in some instances, it will not be possible for such materials to meet the waste acceptance criteria of existing/planned disposal facilities.

4. Record of the Fukushima Recovery and Cleanup

It is highly desirable that the progression of the Fukushima recovery and cleanup be closely followed and authoritatively documented. To achieve this, the IAEA, in co-operation with Japan and other international Agencies, should closely follow and compile experience - identifying good practices and lessons-learned as they emerge (rather than waiting until late in this process to produce a comprehensive report). This practice was initiated in TMI-2 reporting, but the ability to compile and moderate discussion of information emerging using on-line media today suggests an even more proactive approach. The cleanup of the terrain at Fukushima should also be documented in a similar manner.

5. Identification of Post-Accident Cleanup Resource Needs

Resources needed for major cleanup include personnel, equipment, and examination facilities that have previous experience with high radiation materials and damaged fuel. In countries where severe accidents have occurred to date, the technical resources to deal with the cleanup have generally been available. This may not always be the case. It may therefore be appropriate to have strategically located regional centers for such resources. In some cases, this might be incorporated into the design of new facilities or nuclear energy-centers at the time of their design. As a first step in this direction, an effort to assess the various cleanup situations that have involved significant damage to nuclear fuel, and to describe in detail the common post-accident resource requirements should be initiated. This should be done at a functional level leading to detailed capability-descriptions for personnel, equipment, and examination facilities that would be needed, for what they would be used, and the time frame for their deployment.

6. End States

The Fukushima experience demonstrates the importance of developing guidance to address the following questions concerning post-accident decommissioning strategy:

- At what point does the accident cleanup end with the facility either in a monitored storage mode; or ready to proceed to the next phase of decommissioning?
- How might this be applied to part of the overall facility or areas being cleaned up?
- How would such guidance apply to events of lesser severity than that involving fuel damage?
- What are the options for the ultimate end state conditions for the site and facility, including residual radioactivity? What safety and pathways analyses are needed to evaluate these options?
- Should part of the facility be permanently entombed or must all be removed and transported elsewhere?

7. Advance Planning, Information Exchange, and Training

A number of areas requiring the support of the international agencies can be facilitated using modern "Web 2.0" information tools which permit collaboration and rapid sharing of information amongst specialists in many disciplines and locations. In addition to the inventory of experts, equipment, technologies previously noted, such tools could facilitate:

- Moderation of discussions on specific technical topics, such as management of huge volumes of waste including storage and disposal of waste.
- Collaborative planning processes, e.g. integrating all aspects of RWM.
- Training on post accidental RWM.

One such tool – CONNECT [13] - is being deployed by the IAEA, with the assistance of the European Commission to enable the sharing of radioactive waste management information amongst practitioners around the world.

8. IAEA Report Updating

The IAEA has issued a number of reports examining various aspects of severe accidents involving extensive fuel damage and subsequent decommissioning activities [14-18]. Updates to certain of these reports is foreseen following consolidation of the experience from Fukushima. Similarly, the IAEA has prepared publications related to territorial cleanup [19-21]. With a view to the future, both Safety and

Technical documents will require upgrading, and some new documents may be required, such as the compilation of common post-accident resource requirements previously noted. Guidance consistent with the Graded Approach to encourage the relevant authorities to establish realistic and credible limits, e.g. for clearance, is seen as particularly important.

OECD/NEA Activities

Together with the G8 and the IAEA, the NEA has elaborated its specific set of actions based on the needs and proposals expressed by its member countries, the Japanese government, its network of national experts and its Secretariat. Most NEA areas of work have been impacted.

Most recent activities of the NEA regarding the post-Fukushima era include the following:

(a) Two days of meetings co-organized with the French presidency of the G8/G20 in Paris on 7-8 June 2011 on the impact of the accident on the international nuclear safety regime. The first day was a ministerial-level seminar and the second day was a forum attended by heads of nuclear safety authorities. Press releases and conclusions of the international meetings were released on each day and can be consulted at www.oecd-nea.org/press.

(b) An online-forum accessible at www.oecd-nea.org/nsd/fukushima/ to collect and exchange information on activities undertaken nationally and internationally. Information from regulatory authorities from 23 countries, along with 6 regional and international organisations is available. The information includes national response activities, stress test reports as well as complementary activities and assessments to the stress tests. Also available on this page are links to important websites such as the Tokyo Electric Power Company (TEPCO), the Japan Nuclear Energy Safety Organisation (JNES), the Japan Atomic Energy Agency (JAEA), the Japan Nuclear and Industrial Safety Agency (NISA), the IAEA, and the European Clearinghouse on Operational Experience for NPPs.

(c) International Symposium on Decontamination held in Fukushima on 16 October 2011 "Towards the Recovery of the Environment, in Fukushima, Japan". (see www.oecd-nea.org/press/2011/NEWS-07.html).

New projects and new initiatives are afoot in the area of reactor safety, nuclear development, radiation protection, nuclear science, and nuclear law. The waste management and decommissioning community within the NEA have observed that as the situation at Fukushima is still being stabilised, major questions include the definition of "what is waste" and which are remediation goals. While Fukushima Dai-ichi is still away from a classical decommissioning situation the OECD/NEA, Decommissioning Considerations for New Nuclear Power Plants, NEA Report No. 6833 [3] and the OECD/NEA, Applying Decommissioning Experience to the Design and Operation of New Nuclear Power Plants, NEA Report No. 6924 [4] still remain valid.

Overall Impact of Fukushima on Future Decommissioning Scene

Based on the discussion above, some general observation can be made on the future decommissioning scene.

1. Regulatory authorities in many countries are actively assessing the impact of Fukushima events on their national nuclear programs. SSCs are being assessed for their ability to withstand (or limit the effects of) the beyond-design-basis natural hazards.

2. The re-examination of the SSCs against natural hazards may lead to enhancements or additional SSCs that will then need to be considered in the decommissioning planning.

3. In some countries such as Germany, if the current post-Fukushima decisions from the government stand, several reactors may enter the decommissioning phase more rapidly than previously planned.

4. Older reactors such as the BWR Mark I may be re-assessed for their continued operation or decisions may be made for their retirement. At a minimum, it is expected that given the enhanced regulatory requirements related to improved technologies and standards, it may not be feasible to extend their service life.

5. Any expectation for “prompt dismantlement” of these reactors may put pressure on funds, and firms able to do the work.

6. In some cases, retrofits may not be cost-effective and reactors will head to decommissioning.

7. The lifecycle of existing reactors may be re-examined whether life extensions are economically and technically sound or is it better to retire the current reactors at the and of their lifecycle and build new reactors with improved designs.

8. The trend towards minimizing SSCs which not only provides savings in capital costs but also has significant advantages during the decommissioning phase may be re-examined to see where SSCs improvements are necessary to address beyond-design-basis events.

9. Even though any planning (as to what to do) for catastrophic events such as those at Fukushima remain within the purview of Site Emergency Planning and National Emergency Planning, future Decommissioning Plans may have to include updated technologies to provide guidance to cleanup actions such as for contaminated water.

10. The periodic occurrence of severe-core-damage accidents over the past half-century may require measures to pay for decommissioning of these “outlier” events be taken into account by decommissioning funds.

11. As a result of the Fukushima accident, pressure to quickly transfer spent fuel to away-from-reactor storage is likely to increase.

12. It is likely that new, upgraded emergency plans against severe accidents will address the post-accident cleanup and recovery phase rather than the following decommissioning. However, the unpredictable nature of a severe accident may make it difficult to adopt specific solutions. The cost-effectiveness of any proposed measures should be tested under a comprehensive cost-benefit analysis.

CONCLUSIONS

Accidents at the Fukushima Diaiichi reactors in the aftermath of the devastating earthquake and tsunami of March 11, 2011 have slowed down the nuclear renaissance world-wide and may have accelerated decommissioning either because some countries have decided to halt or reduce nuclear, or because the new safety requirements may reduce life-time extensions. Even in countries such as the UK and France that favor nuclear energy production existing nuclear sites are more likely to be chosen as sites for future NPPs. Even as the site recovery efforts continue at Fukushima and any decommissioning decisions are farther into the future, the accidents have focused attention on the reactor designs in general and specifically on the Fukushima type BWRs.

The regulatory authorities in many countries have initiated a re-examination of the design of the systems, structures and components and considerations of the capability of the station to cope with beyond-design-basis events. Enhancements to SSCs and site features for the existing reactors and the reactors that will be built will also impact the decommissioning phase activities. The newer reactor designs of today not only have enhanced safety features but also take into consideration the features that will facilitate future decommissioning. Lessons learned from past management and operation of reactors as well as the lessons from decommissioning are incorporated into the new designs. However, in the post-Fukushima era, the emphasis on beyond-design-basis capability may lead to significant changes in SSCs, which eventually will also have impact on the decommissioning phase. Additionally, where some countries decide to phase out the nuclear power, many reactors may enter the decommissioning phase in the coming decade.

While the formal updating and expanding of existing guidance documents for accident cleanup and decommissioning would benefit by waiting until the Fukushima project has progressed sufficiently for that experience to be reliably interpreted, the development of structured on-line sharing of information and especially the creation of an on-line compendium of methods, tools, and techniques by which damaged fuel and other unique situations have been addressed can be addressed sooner and maintained as new problems and solutions arise and are resolved. The IAEA's new "WEB 2.0 tool" CONNECT is expected to play a significant role in this and related information-sharing activities.

The trend in some countries such as the United States has been to re-license the existing reactors for additional twenty years, beyond the original design life. Given the advances in technology over the past four decades, and considering that the newer designs incorporate significant improvements in safety systems, it may not be economical or technically feasible to retrofit enhancements into some of the older reactors. In such cases, the reactors may be retired from service and decommissioned.

Overall, the energy demand in the world continues to rise, with sharp increases in the Asian countries, and nuclear power's role in the world's energy supply is expected to continue. Events at Fukushima have led to a re-examination on many fronts, including reactor design and regulatory requirements. Further changes may occur in these areas in the post-Fukushima era. These changes in turn will also impact the world-wide decommissioning scene and the decommissioning phase of the future reactors.

REFERENCES

1. Energy Information Administration (EIA - U.S. Government), Annual Energy Outlook –with Projections to 2035, Report #:DOE/EIA-0383(2011), Release Date: April, 2011.
2. Jas S. Devgun, Designing Decommissioning into New Reactor Designs, American Nuclear Society, *Radwaste Solutions*, Vol. 14, No. 5, p. 40-46, September/October 2007.
3. OECD/NEA, Decommissioning Considerations for New Nuclear Power Plants, NEA Report No. 6833, 2010.
4. OECD/NEA, Applying Decommissioning Experience to the Design and Operation of New Nuclear Power Plants, NEA Report No. 6924.
5. IAEA, Design Lessons Drawn from the Decommissioning of Nuclear Facilities, IAEA-TECDOC-1657, Vienna, May 2011.
6. Nuclear Engineering International, Japan's Ohi 3 Station Submits Stress Test Results, 8 November, 2011.
7. World Nuclear News (WNN), Stress Test Results in for Ikata 3, 14 November, 2011.
8. U.S. NRC, The Near Term task Force Report, Recommendations for Enhancing the Reactor Safety in the 21st Century , Review of Insights from Fukushima Dai-ichi Accident, July 12, 2011.

9. UK Office of Nuclear Regulation, Japanese Earthquake and Tsunami: Implications for the UK Nuclear Industry. September 2011.
10. IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East Japan Earthquake and Tsunami, , May 24- June 2, 2011, available at: http://www-pub.iaea.org/mtcd/meetings/pdfplus/2011/cn200/documentation/cn200_final-fukushima-mission_report.pdf
11. IAEA Ministerial Conference on Nuclear Safety, Chairman's Summaries, June 20 - 24, 2011
12. IAEA, October 2011, "Summary Report of the Preliminary Findings of the IAEA Mission on remediation of large contaminated areas off-site the Fukushima Dai-ichi NPP 7 – 15 October 2011", available at: http://www.iaea.org/newscenter/focus/fukushima/pre_report.pdf
13. IAEA CONNECT: available at: http://nucleus.iaea.org/Home/index.html
14. IAEA, Symposium on Recovery Operations in the Event of a Nuclear Accident or Radiological Emergency,(SM-316), Vienna, 6-10 November 1989.
15. IAEA, Management of Severely Damaged Nuclear Fuel and Related Waste, IAEA Technical Reports Series No. 321, 1991.
16. IAEA, Catalogue of methods, tools, and techniques for recovery from fuel damage events, IAEA-TECDOC-627, 1991.
17. IAEA, Cleanup and Decommissioning of a Nuclear Reactor after a Severe Accident, IAEA Technical Reports Series No. 346, 1992.
18. IAEA, Issues and decisions for nuclear power plant management after fuel damage events, IAEA-TECDOC-935, 1997.
19. IAEA, Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident, IAEA Technical Reports Series No 300, 1989.
20. IAEA, Planning for Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident, IAEA Technical Reports Series No 327,1991.
21. IAEA, Disposal of Waste from the Cleanup of Large Areas Contaminated as a Result of a Nuclear Accident, IAEA Technical Reports Series No 330, 1992.
22. International Energy Agency, World Energy Outlook 2011, 9 November 2011.
23. World Nuclear News, Japan Nuclear Generation Dwindles, 28 November, 2011.