NUCLEAR FUNDAMENTALS REMAIN

by

*Zoran V. STOŠIĆ**

AREVA NP, Erlangen, Germany

Original scientific paper
DOI: 10.2298/TSCI120305059S

For Japan, the situation has become extremely difficult since counter-measures to deal with the nuclear accident had to be carried out along with dealing with the broader disaster caused by earthquake and the tsunami. In terms of damage, the Tohoku earthquake and the tsunami have caused the most fatalities and the largest economic loss ever from an earthquake and/or tsunami. The impact of this natural disaster is present not only in Japan but world-wide. The state of affairs in the global energy sector is affected by the consequences which may be lasting for decades. These effects are subject of this article dealing not with the nuclear accident at Fukushima Daiichi NPP itself, but rather with the world-wide consequences and after effect on nuclear energy development. This includes: environmental damages, socio-economic effects, actions of safety authorities, extended protective measures against external events, the impact on global nuclear energy, triggered nuclear phase-outs and changes in new build plans as well as the sustainability of energy mix itself and an outlook.

Key words: *energy policy, nuclear energy*

The giant March 11 tsunami – a direct cause for Fukushima Daiichi accident

The 2011 Tohoku earthquake (Great East Japan Earthquake) with a magnitude of 9.0 occurred at 14:46 JST (Japan Standard Time) – 05:46 GMT – on Friday, March 11^{th}, 2011, lasted approximately six minutes. It occurred near the north-eastern coast of Honshu, resulted from thrust faulting on or near the subduction zone plate boundary between the Pacific and North American plates. It was the most powerful known earthquake to hit Japan and the 4^{th} largest earthquake in the world since modern record-keeping began in 1900. The earthquake moved the main island of Japan by 2.4 metres and the eastern parts of Japan by 3.65 metres closer to North America, speeded up the Earth's rotation, thus cutting day by 1.8 microseconds due to redistribution of the planet's mass and shifted the Earth's figure axis by 0.25 meters. The devastating tremor was powerful enough to reduce the gravity field by slightly thinning the Earth's crust under the affected area. The ground between two tectonic plates slipped as much as 50 metres. This massive movement is one of the main reasons why the Japan quake produced such large and powerful tsunami waves, which reached heights of up to 40.5 metres in Miyako, travelled up to 10 kilometres inland in the Sendai area. The Tsunami wave height was estimated at approximately + 15 metres over the OP (Onahama Port) base tide level.

* Author's e-mail: zoran.stosic@areva.com

At the time of the quake, 11 reactors in operation in the affected area (Onagawa 1–3, Fukushima Daiichi 1–3, Fukushima Daini 1–4, and Tokai Daini) automatically shut down, while three units were under periodic inspection (Fukushima Daiichi 4–6). About 50 minutes later, a tsunami (in fact there had been a couple of extremely huge waves in total) hit the NPP in the area and all reactors went to cold shut down, except Units 1–3 of Fukushima Daiichi. The initiating occasion was a combination of exceptional and sudden natural events and the loss of the reactor cooling function. Hydrogen development led to explosions. Following plant contamination made on-site intervention very difficult. Counter-measures were insufficient and crisis management was difficult due to the wideness of the catastrophe.

Consequences for the Fukushima Daiichi NPP (6 BWRs – Boiling Water Reactors – commissioned between 1970 and 1979 with installed capacity of 4,698 MW_e made Fukushima Daiichi one of the 15 largest nuclear power stations in the world):

(1) It was a Beyond Design Basis earthquake. The moment-magnitude was 9.0 and Design Basis value was 8.2. Based on the seismic energy, each step on the magnitude scale is 10 times more powerful than the previous one. So the moment-magnitude was by factor of 10(9.0-8.2) = 6.3 higher than of Design Basis. The measured accelerations were up to 26% higher than the quake Design Basis values.

(2) It was a Beyond Design Basis tsunami. Original design predicted maximum water level caused by tsunami equal to OP + 3.1 metres. Design Basis review performed in 2002, estimated higher maximum tsunami height of OP + 5.7 metres, which was the levee height on March 11th, and the actual tsunami height was at least OP + 14 metres. This was the "direct cause" of the accident at the Fukushima Daiichi NPP, concluded in December 2011, an official investigation report of TEPCO (Tokyo Electric Power Company). It dismissed the idea that earthquake damage was a major factor in the accident.

(3) It was a multi-unit accident.

According to the JAEC (Japan Atomic Energy Commission):

– The root cause of the Fukushima Daiichi accident seems to be operators' and regulators' weakness in the establishment of safety culture, the responsibilities of the operating organization, and the provision of regulatory control and verification of safety related activities.
– Nuclear regulator failed to request NPP operators to satisfy the internationally recognized need for defence-in-depth features that will prevent a disproportionate increase in radiological consequences from an appropriate range of events which are more severe than the Design Basis event (cliff-edge).
– "Japanese nuclear regulator and operators, being shy with probabilistic analysis, failed to recognise the necessity of having information about a tsunami that has a frequency of exceedance of less than 1 in 10,000 years", as well as to define the historical maximum tsunami height at a given site as a limiting one for Design Basis.

In this regard, 16 large tsunamis with wave heights of at least 10 metres were observed around Japan in past 513 years. Even with earthquake magnitudes as low as 7.4–7.7 (Design Basis magnitude of Fukushima Daiichi was 8.2) large tsunamis with a maximum height of much more than 12 metres were produced. Thus, within a 30 years period one large tsunami must be expected around Japan and within a 100 to 1,000 years period one large tsunami must be expected at every coastal location in Japan [1]. In 2001, at the AGU (American Geophysical Union) Meeting, it was reckoned that there was a high likelihood of a large tsunami hitting the Sendai plain, as according to statistics (recurrence interval: 800 to 1,100 years), such a large tsunami had already been "overdue" some 1,100 years. In 2007, at the AGU Fall Meeting, the probability of an earthquake with a magnitude of 8.1–8.3 was estimated as 99% within the following 30 years.

The Japanese government's response saw “flawed organisation and communication, while the site was inadequately prepared and operators made mistakes”. The conclusions were issued at the end of December 2011, in an interim report of the Investigation Committee on the crises at the Fukushima Daiichi and Daiini NPP after the March 11th earthquake and tsunami [2]. The Report stresses that an overall failing of TEPCO, NISA (Nuclear and Industrial Safety Agency), METI (Ministry of Economics Trade and Industry) and its predecessors was to fail to plan for very large tsunamis. The site was licensed in the 1960s and 1970s on the basis of a 3.1 metres tsunami wave and although later studies indicated that much larger waves were possible, no concrete steps were taken by any of the bodies to plan for that eventuality. Furthermore, external risks like tsunami and earthquake were not part of a government analysis of measures against severe accident made in 2002 – and the recommendations from that were voluntary and not part of regulatory requirements. In this context the report stated that “TEPCO had put in place inadequate measures to cope with station blackouts, and had no plans for the seawater injection technique on which it relied”.

On December 16th, 2011, the Japanese government announced that the three reactors of Fukushima Daiichi that suffered meltdowns in March had officially reached “cold shutdown”.

Environmental damage, social and economic effects

On March 18th the disaster at Fukushima Daiichi NPP was classified as a Level 5 on the INES (International Nuclear Event Scale) [3], *i. e.* “Accident with Wider Consequences”, based on combined “Radiological Barriers and Control” and “People and Environment” criteria (like TMI – Three Mile Island – accident in 1979). On April 12th, 2011, the Fukushima Daiichi NPP accident was revised to Level 7 based on the “People and Environment” criteria, as a result of the amount of radiation released in the month since the plant was severely damaged by the earthquake triggered tsunami. Level 7 stands for: “A major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures,” according to the IAEA (International Atomic Energy Agency). But, when authorities raised Fukushima to Level 7 as a “Major Accident” on the INES – a Level up to that time assigned only to Chernobyl – millions around the world promptly concluded that they were witnessing a human catastrophe of immense proportions, disregarding the fact that Fukushima was a very serious incident but Chernobyl was a catastrophe.

According to JAIF (Japan Atomic Industrial Forum), total release of radioactive material in the air is estimated to be 0.3–0.6 × 10^{18} $Bq_{(I131,eq)}$, which is less than 10% of the case of the Chernobyl accident. Contaminated water is estimated to be of total volume about 110,000 m^3 with most contamination coming out from Unit 2 with 20 MBq/cm^3 versus Unit 1 and 3 with contamination of about 0.4 MBq/cm^3.

The social consequences from Fukushima are far from clear or settled even at the moment. For now, what is clear is that a major disaster that could have threatened the long-term liveability of approximately 25% of the Japanese island nation has been averted, but the long term impact from radiation releases into the environment is unknown.

The 2011 Tohoku earthquake has caused the largest economic loss ever from an earthquake, surpassing the 1923 Great Kanto earthquake. In terms of fatalities, the expected total of around 27,500 deaths for the Tohoku earthquake is the highest by over four times for a country with HDI (Human Development Index) of over 0.8. The previous highest was Kobe earthquake, with 6,434 deaths.

Once the magnitude was raised from 8.9 to 9.0 and the JMA (Japan Meteorological Agency) and USGS (US Geological Survey) intensities were audited, a loss estimate of between US$ 100–500 billion was released. Some models with high indirect effects even predicted up to US$ 1.1 trillion loss.

In the immediate aftermath of the earthquake, Japan's Nikkei stock market index saw its futures slide 5% in after-market trading. On March 15th, news of rising radiation levels caused the Nikkei to drop over 1,000 points or 10.6% (16% for the week). Stock markets around the world were also affected by the accident; the German DAX lost 1.2% within minutes. Hong Kong's Hang Seng index fell by 1.8%, while South Korea's Kospi index slumped by 1.3%. By the end of trading on the day of the earthquake, the MSCI Asia Pacific Index had dropped by 1.8%. Major US stock market indexes rose between 0.5% and 0.7%. Oil prices also dropped as a result of the closure of Japanese refineries, despite the ongoing violence in Libya and expected demonstrations in Saudi Arabia. US crude dropped as low as US$ 99.01 from US$ 100.08 by lunchtime, with Brent Crude falling US$ 2.62 to US$ 112.81.

On August 9th, TEPCO reported a US$ 7.4 billion quarterly loss due to a massive provision to compensate victims of the nuclear disaster, soaring fuel costs and a dive in sales. TEPCO's chances of survival improved after Japan's parliament early August 2011 passed a bailout scheme backed by taxpayer funds and contributions from other utilities to help shoulder a compensation bill analysts estimate could climb as high as US$ 130 billion. In the first nine months after the catastrophe, shares of TEPCO have lost more than 80% since the disaster.

Mid of August 2011, the government estimated only the direct economic damage of the earthquake at around US$ 204 billion. Japan's GDP (gross national product) has been at US$ 4-5 trillion per year since 1995 with little real growth in the economy. The 2010 GDP was slightly higher at US$ 5.5 trillion. Thus the direct economic damages are about 3-4% of the Japan's GDP. Not included in this estimate are medium-term costs such as bottlenecks in energy supply, as well as the JAIF estimation from June 2011, of the costs of decommissioning the Fukushima Daiichi facility that could be as much as $250 billion, which is another sizable percentage of the GDP.

The future of Japan's commercial nuclear reactors is probably of more economic significance than all the other economic factors at play following the disaster. Before March 11th, 2011, about 1/3 of the national energy demand was met by a fleet of 54 nuclear plants. As of July 20th, 2011, 37 nuclear reactors in Japan, or nearly 70% of them, remain shutdown. As reported by Bloomberg News, on January 25th, 2012, only four Japanese reactors were in operation, with a capacity of 3.958 GW_e, or 8.1% of the total Japan nuclear capacity of 48.96 GW_e. Due to the government's new "stress test" requirements announced in July 2011, it is unknown at which time any of the disconnected reactors will resume operations. For the time being reactors already shutdown have a great economical impact for the energy sector of the world's third-largest economy and for nuclear technology companies such as Toshiba, Hitachi and MHI (Mitsubishi Heavy Industries) and a possible future shutting-down of all of Japan's nuclear reactors could have far-reaching implications.

Role of the media, public communication and opinion

According to the IAEA, at Chernobyl a combination of operator error, reactor design error and a lack of safety culture resulted in a runaway power surge followed by steam and hydrogen explosions and a sustained fire in the reactor. The explosions propelled a huge amount of radioactive material from the reactor core high into the atmosphere in a very short space of time and across eastern and Western Europe for at least 10 days, according to NEI (Nuclear

Energy Institute). The great Tohoku earthquake and tsunami were catastrophic events beyond the Design Basis of the Fukushima Daiichi NPP. The tsunami damaged the plant's power systems and diesel generators, causing cooling systems to fail. A series of hydrogen explosions followed and the spent fuel pools ran low of water.

Hence, comparing the Fukushima accident with the Chernobyl event was not appropriate and contributed to disqualification of nuclear power generation. The importance of effective public communications was evident. At times, the media almost made it look like the nuclear accident being worse than the natural disasters. The nuclear accident outcome, although there are no direct fatalities and continuing expectations of no significant radiological health effects, resulted in a major environmental disaster regionally, and a traumatic curtailing of nuclear power generation across Japan, and wider.

As Peter Sandman (one of the preeminent risk communication experts and speakers as well as consultants in the US) said in the interview to FUTURIST magazine [4], regarding external events – like Tohoku March 11th earthquake and tsunami as well as the resulting nuclear crisis at Fukushima Daiichi NPP – and regarding the crisis itself – the three key questions by the public are always:

(1) What happened – and what are you doing to respond to it, and what should we (the public) do?
(2) What do you expect to happen, or what's likely to happen next – and what are you doing to prepare for it, and what should we do?
(3) What are you worried might happen, or what's not so likely but possible and scary, your credible worst case scenario – and what are you doing to prevent it (and prepare for it in case prevention fails), and what should we do?

According to Sandman, by far the biggest crisis communication error of the Japanese government has been its failure to answer the second and third questions satisfactorily: its failure to forewarn people about tomorrow's and next week's probable headlines, and its failure to guide people's fears about worst case scenarios. In fact the Japanese government didn't shy away from reassuring speculation, only from alarming speculation. Officials were happy to predict that they would probably get power to the pumps soon and would then be able to cool the plants properly, for example. But they failed to predict some for public important events and after each of these events occurred, the government told that they were predictable and not all that alarming. But it failed to predict them. Officials not only failed to speculate responsibly about their gloomy but still tentative expectations. Because the government avoided alarming speculation, the people of Japan (and the world) kept learning that the situation at Fukushima was "worse than we thought." This violates a core principle of crisis communication. In order to get ahead of the evolving crisis instead of chasing it, crisis communicators should make sure their early statements are sufficiently alarming that they won't have to come back later and say things are worse than we thought. Far better to be able to say instead: "It's not as bad as we feared." Among the reasons why officials have been reluctant to speculate alarmingly is, undoubtedly, a fear of panicking the public. But there was little evidence of nuclear panic in Japan or elsewhere: nuclear scepticism, nuclear distrust, nuclear dread … but not nuclear panic. The Japanese government's failure to speculate alarmingly didn't "protect" the public from alarming speculation. It simply left people speculating on their own, and listening to the speculations of outside experts (and outside non-experts).

The interim report from the Japanese Investigation Committee issued December 26th, 2011, wrote also about communication failure. This was exacerbated by the lack of "pro-active" information gathering by NISA and the METI. They were meant to report the latest information from TEPCO to the national response headquarters, but did not act to establish proper lines of communication, such as TEPCO's effective teleconferencing system. They also failed to send staff to collect information in person what the report called "a major concern" when considered the overall failure of the government in communicating with the public. Regarding the government's public communication "the following tendency was observed: transmission and public announcement of information on urgent matters were delayed, press releases were withheld, and explanations were kept ambiguous. Whatever the reasons behind this, such tendencies were not appropriate, in view of the communication of an emergency."

A "global snap poll" of more than 34,000 people in 47 countries around the world indicates that those in support of nuclear energy still outnumber those opposed, despite the Fukushima accident. The poll – conducted by WIN-Gallup International between March 21st and April 10th, 2011, and published on April 19th – asked respondents about their attitude to nuclear energy, both before and after the accident. Prior to the March 11th earthquake and tsunami, some 57% said they held favourable views on nuclear energy, while 32% held unfavourable views. Following the accident, 49% of people said they favoured nuclear energy, while those opposing it numbered 43%. Unsurprisingly, Japan saw the biggest drop in support for nuclear energy, with the number of people in favour dropping from 62% before the accident to 39% afterwards. In June 2011, those saying they were opposed to nuclear increased from 28% to 47%. A majority in the US, France or China still favours the nuclear option.

A second world-wide poll made end of April 2011, by IPSOS in 24 countries has shown an opposite result. Nonetheless, a sizeable share of the "against" are not in favour of closing existing plants, their confidence must be regained. IPSOS poll repeated in 24 countries in June 2011, showed favourable opinions on continued nuclear constructions. Regarding New Builds 31% of questioned showed favourable opinion in global. In September 2011, 54% of the British questioned accept nuclear New Builds if it helps to tackle climate change. In October 2011, 62% of the questioned in the US were in favour of the use of nuclear energy.

Safety authorities' actions world–wide

Regulatory authorities world-wide immediately launched appropriate measures and safety measures were adopted in various parts of the world.

Following the accident at the Fukushima Daiichi NPP in March 2011, the Japanese government decided that all reactors would be subjected to "stress tests" to be conducted in two phases before approval for restart could be given:

(1) The first step will be applied to those reactors which have been taken offline for periodic inspections to determine whether they could withstand large earthquakes and tsunamis. Utilities are required to examine the safety margin of important pieces of equipment in accordance with guidelines set by the NISA and NSC (Nuclear Safety Commission). Based on the results of these initial tests, the government is to decide whether a reactor shut for inspections can or cannot resume operation;

(2) The second step of the tests will involve a comprehensive safety assessment of all reactors and will be conducted to enhance the reliability of regular safety checks. These tests will be similar to the "stress tests" coordinated by the European Commission.

In addition to government approval to restart reactors, Japanese utilities must also get permission from local authorities.

Consequently, for the purpose of decentralizing the regulatory system and ensuring a thorough safety culture, the Japanese government has decided to establish "The Nuclear Safety and Security Agency" around April of 2012, by separating off the NISA from the METI.

Considering the accident at the Fukushima NPP the Council of the EU declared that "the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk assessment ("stress tests"); … the assessments will be conducted by independent national authorities and through peer review; … the EC (European Council) will assess initial findings by the end of 2011, on the basis of a report from the Commission".

- March 22nd and 23rd: WENRA (Western European Nuclear Regulators Association) members decided to provide "an independent regulatory technical definition of a "stress test" and how it should be applied to nuclear facilities across Europe";
- March 25th: EU Energy Council asked that "voluntary tests based on common standards" be prepared by the Commission, Member States and National Regulators;
- April 21st: WENRA Task Force proposed the "stress tests" specifications. A "stress test" is defined as "a targeted reassessment of the safety margins of NPP in the light of the events which occurred at Fukushima: extreme natural events challenging plant safety functions and leading to a severe accident";
- May 13th: Based on April 21st WENRA proposal, ENSREG (European Nuclear Safety Regulators Group) and Commission agreed on the scope and methodology for "risk and safety assessments" of NPP in the EU;
- May 24th: The ENSREG and EC agreed on the scope and methodology for planned "comprehensive risk and safety assessments" of power reactors in the EU;
- June 24th: Armenia, Belarus, Croatia, Russia, Switzerland, Turkey, Ukraine as well as Japan and Brazil expressed their willingness to undertake checks following the "EU Model".

On the June conference in 2011, the IAEA's role on harmonisation of safety standards, transparency and emergency support coordination was stressed. The action plan, adopted by the IAEA board in September, asks for a methodology to be developed.

In the US the near-term NRC (Nuclear Regulatory Commission) Task Force report was published on July 13th, 2011. A package of 12 "overarching" recommendations and 35 detailed recommendations for near-term and longer-term actions, associated with seismic and flooding events, station black out, Beyond Design events was issued. On September 8th the NRC Chairman proposed that plant owners should review earthquake hazards at least once in a decade. Major effort by the US NRC and industry to rapidly assess improvements needed for Beyond Design Basis events, are embodied in the US NRC "Recommendations for Enhancing Reactor Safety in the 21st Century", and multiple addenda and related documents.

Initial survey of Chinese NPP (in operation and under construction) was completed on August 5th, 2011. Details on the results and proposed improvements are to be made public by mid 2012. Review of reactor safety and emergency preparedness is being performed.

Globally a reexamination of the safety and role of nuclear power is initiated.

Response and commitment of nuclear industry

Emergency aid and relief supply to the region of Fukushima as well as immediate technical support to TEPCO was essential in times after incipience of the devastation of the natural disasters. Important and helpful in the Fukushima crisis mitigation was to mobilize as soon as possible unique expertise from international networks of industry and different vendors around the world.

One of the first implications of the vendors around the globe was the necessity of as much as possible reliable analysis of the accident at Fukushima Daiichi NPP. There is still a lot to be done in the next future for such an analysis, but the vendors world-wide have taken into account following important issues:

(1) The vendor industry must be more represented in organs and forums world-wide, which play a role in the overall nuclear energy decision processes (*e. g.* politics, safety standards);
(2) Working groups must be set up in order to enable industry experts to collaborate internationally on a full range of key topics;
(3) Countries like China and India must be put on board in international nuclear conferences;
(4) Social media have turned out to be a more and more important factor regarding public information. What are the consequences for the vendor industry?

These diverse items require a common course, which includes also information-sharing within the industry and information platforms, that can be accessed from "outside".

All vendors see the necessity that their plants and new designs have to be robust enough in order to cope with various natural disasters or other events (*e. g.* black-outs) even in countries, where Fukushima–like events can be practically excluded. In addition, discussions on airplane crashes were re-initiated. The complete plant checks have shown optimization potential for the future, from back-fitting measures to new approaches for new designs.

An important and integral aspect of the industry's response is the awareness and involvement of the industry's stakeholders, including plant owners, vendors, architect-engineering companies, industry owners' groups and national nuclear standards organizations. This will ensure that the interests of each stakeholder group are considered, understood and communicated to the public and policymakers.

Enhancement of the protective measures regarding external events

The nuclear industry is learning from the Fukushima accidents, making improvements toward a new, even higher safety level. The new level will enhance the existing safety paradigm and include additional protection against severe external events, which will be integrated into the designed defence-in-depth and risk insights, establishing a stronger safety network, including accident and emergency preparedness. The main enhancements will first focus on seismic and flooding protection, strengthening capabilities to deal with a station blackout, installation of filtering systems for containment venting as well as passive hydrogen recombiners. In addition, enhancing spent fuel cooling capabilities, strengthening on-site and off-site severe accident and emergency capabilities including installing of a backup control room, *etc.*, is also on agenda.

According to the US NRC Fukushima Task Force, the bottom line is to:

– Ensure that seismic and flood hazards (external events) are properly evaluated and considered in a new Design Basis or by additional measures with similar protective effects;
– Ensure that station blackout is covered under severe accident conditions and protection is provided commensurate with the capability to provide power and cooling;
– Ensure hydrogen control and mitigation inside containment or other buildings;
– Ensure emergency operating procedures (severe accident, extensive damage) and matching emergency preparedness capabilities are in place, including training;
– Ensure that multi-units events are covered.

After Fukushima, most countries continued operation of existing plants and activities on planned reactor development, but they also initiated measures such as "stress tests" to assure the safety of operating plants and reviews of the accident to identify lessons learned and incorporate necessary changes. This includes measures to enhance:

– the capability to restrict radioactive releases from the containment and fuel pools,
– accident management capabilities,
– the capability to maintain containment integrity, and
– the robustness of the plant.

These measures can be achieved through the implementation of several improvements:

- Increase of the strength of fire fighting systems, severe accident management systems, and fuel storage pools against earthquakes of Beyond Design Basis;
- Means to enhance the safety margin against flooding;
- Sufficient diesel generators and fuel reserves on site for a long term disturbance of electrical power supply;
- Sufficient DC power for a long term disturbance of electrical power supply;
- Sufficient reserves of water (demineralised) during a long term disturbance of sea or river water cooling in extreme external conditions;
- Additional means to remove decay heat from the spent fuel storage pools, or to supply additional water to those pools during a long term accident situation in extreme external conditions;
- Installing additional monitoring instrumentation to spent fuel pools;
- Increase the capability and possibilities for mobile power supply and pumps in accident situations;
- Securing the availability of personnel and material resources in extreme external conditions.

After the Fukushima accident many operators of NPP have already identified possible short term improvements and performed several modifications in the plants which add alternate possibilities for electrical power supply and cooling of reactor and spent fuel pool in case of Beyond Design Basis accidents.

Some NPP are in front of the process of planning the modification to improve the robustness and safety of the plant. Discussions on this topic will help recognizing, how other plant owners deal with this matter, learning about their plans for upgrades and their long term plans. For the plant owners there are huge modifications ahead, which need serious preparation before design and installation.

Impact on nuclear power around the globe

After the TMI LWR (Light Water Reactor) accident on March 28th, 1979, and the Chernobyl (Graphite moderated Reactor) disaster occurred on April 26th, 1986, 25 years without a severe nuclear reactor accident provided an assurance of safety world-wide. No LWR accident until Fukushima had resulted in significant external radioactive contamination. No external event before Fukushima resulted in core degradation and uncontrolled radioactivity release. Then, on March 11th, 2011, as a consequence of the giant Tohoku tsunami, a multi-unit LWR accident has occurred in one of the world's most industrialized nation, with severe core degradations and large uncontrolled radioactivity releases. The impact of this disaster on nuclear power is present not only in Japan but world-wide.

Nine months after the Tohoku earthquake and tsunami, within the Japanese NPP fleet, only 11 reactors out of 54 were in operation: 14 reactors automatically shut down following the earthquake (including six Fukushima Daiichi reactors); 13 reactors were in outage phase or extended break at the time of the accident, and 16 more have entered programmed outage phase since then.

According to data released by the JAIF, mid of January 2012, just five – with capacity of 5.06 GW_e – of the Japanese 54 power reactors were in operation. 32 units, with capacity of 27.92 GW_e , are not operating as they have been shut for periodic inspection and have not been allowed to restart. A further 17 units, representing 15.99 GW_e of capacity have been shut down due to the tsunami or at the government's request. On January 24th, 2012, TEPCO shut the 1,100 MW$_e$ Unit 5 at its Kashiwazaki Kariwa NPP – the world's biggest nuclear station – for regular maintenance, cutting number of Japan nuclear operating reactors to four. As of February 20th, 2012 only two units (Kashiwazaki Kariwa 6 and Tomari 3) with 2.27 GW$_e$ were in operation, which is 4.6% of the total Japan nuclear capacity.

"Stress tests" have now been completed at a number of plants, and Japan's nuclear safety regulator NISA recently endorsed the findings from the first units to complete the tests – Kansai's Ohi 3 and 4 – although the plants are still awaiting permission to restart.

The impact of Fukushima is causing a great deal of turbulence around the globe for the future of nuclear power.

In 2011, according to IAEA PRIS (Power Reactor Information System) [5], seven new nuclear power reactors (two in China plus one Chinese Experimental Fast Reactor, one in India, Iran, Pakistan and Russia) were connected to the world's electricity grids, adding 4,017 MW$_e$ of generation capacity, 13 units were closed permanently, all but one as a direct result of the accident at Fukushima Daiichi. Capacity up-rates at plants in the Czech Republic, Finland, Mexico, Spain and the US added in excess of 440 MW$_e$ to the world's total nuclear generation capacity, and by December 31st, 2011, the world had recorded 14,713 reactor-years of nuclear power generation. In total some 11,272 MW$_e$ of nuclear capacity were lost through the permanent closures of nuclear reactors. Although 13 reactors shut down in 2011, only one of those had reached the end of its natural life: the UK's 217 MW$_e$ Oldbury-2 Magnox unit. The physical damage caused by the tsunami created by the Tohoku earthquake added four Japanese units to the list of reactors removed permanently from the world's grids, with the loss of 2,719 MW$_e$. The political response to the Japanese experience prompted Germany to enforce the permanent closure of eight of its nuclear reactors, wiping 8,336 MW$_e$ from Germany's generation capacity. Only for two reactors the construction formally began in 2011: Pakistan's Chashma-3, a 340 MW$_e$ PWR (Pressurised Water Reactor) in May, and India's Rajasthan-7, a 700 MW$_e$ PHWR (Pressurised Heavy Water Reactor) in July. Construction had been scheduled to begin on at least three new Chinese units during the year 2011, but the country, which has more than 25 reactors currently under construction, temporarily suspended issuing approvals for the start of construction of new NPP after the Fukushima accident.

Nuclear phase–out and attitude towards new builds

Most countries have confirmed the importance of nuclear in their energy mix and carry on supporting nuclear energy, but four countries (Germany, Switzerland, Italy and Belgium) decided to take specific measures against nuclear. Each case is very different:

(1) GERMANY: Chancellor Merkel announced on March 15th, 2011 an immediate production stop – for at least three months – at the seven oldest NPP (start of operation before 1980). On May 30th, the government adopted the decision to phase-out nuclear by 2022, (ratified by Parliament on June 30th) and on June 6th it made amendments to the country's Atomic Energy Act. On August 6th, 2011, eight reactors were declared permanently shut down, although first results of the safety checks issued by RSK (Reactor Safety Commission) stated that plants are safe;

(2) SWITZERLAND: The Federal government has suspended the approval process for the construction of three new NPP in order to review safety standards. The Swiss ENSI (Federal Nuclear Safety Inspectorate) has also been required to carry out safety evaluations at country's existing NPP. On May 25th, the government decided not to replace ageing

nuclear reactors and to gradual phase-out nuclear by 2034, which marks the start of a long legislative process before a definitive decision is taken;

(3) ITALY: The government approved on March 23rd, 2011, a one-year moratorium on the construction of the country's first NPP by 2020. On April 19th, an amendment was tabled that indefinitely puts on hold New Build plans. On June 12th and 13th, Italian citizens voted against the reintroduction of nuclear power in a referendum;

(4) BELGIUM: After the Fukushima accident, the decision to extend the lifetime of the country's NPP was put on hold until "stress tests" had been carried out. In November 2011, Belgium's main political parties reached an agreement to shut down the three oldest reactors by 2015, and on a complete exit by 2025, provided alternative energy sources are able to replace the nuclear share in order to prevent any shortages or sharply rising costs.

The states looking to phase-out nuclear must address the issue of how to do so without negatively impacting existing energy sustainability – both locally and regionally. For example, nearly 25% of Germany's electricity is currently provided by nuclear power. It will be challenging to fill the gap left by nuclear power while not increasing the dependence on carbon-based power generation especially since the renewable energy infrastructure currently does not have the capability to do so. Policy-makers and industry executives must have a clear, robust and well communicated energy vision that considers all aspects of a nuclear phase-out before imposing a wholesale change of a nation's energy mix including the impact on neighbouring countries and energy markets.

Concerning attitude towards New Builds following status across regions is seen:

– EUROPE: UK, France, Czech Republic, Poland, Finland and Netherlands share close position: Nuclear energy is still necessary and lessons from Fukushima may affect requirements for New Build programs. The programs – especially with the closest COD (Commercial Operation Dates) – may be delayed, but no question to cancel or stop current constructions. Safety checks were concluded within the existing fleet by the end of 2011 at national level;
– MIDDLE EAST and AFRICA: United Arab Emirates, Jordan, Egypt and Saudi Arabia confirmed New Build programs – Saudi Arabia with the goal of 16 units by 2030. In the Republic of South Africa the Integrated Resource Plan including nuclear is confirmed;
– ASIA: Indian and Chinese administrations and utilities confirm their will to continue nuclear New Build programs relying on most advanced standards. In China, the new plant authorizations are frozen but units under construction are not halted. NNSA's (National Nuclear Security Administration) safety plan is approved by the Ministry of Environmental Protection. NEA (National Energy Administration) plan is still pending. Indian government decides to set up an independent safety authority;
– SOUTH–EAST ASIA: All New Build programs confirmed long-term nuclear power choice. The Japanese government continues to consider nuclear power as essential, but priority is to restart NPP currently in outage – current New Build constructions halted. In South Korea existing plants are checked and implements plan to improve safety authorities' organization with increased independency are under way;
– NORTH AMERICA: Most provinces of Canada involved in a New Build program confirmed their commitment despite the Japan nuclear crisis and in the US the Administration is supportive of nuclear – Federal Loan Guarantee program is reconfirmed and utilities with New Build plans have reaffirmed their commitment – only NRG Energy (ABWR – Advanced Boiling Water Reactor) has suspended their projects;

– MIDDLE/SOUTH AMERICA: A commitment to nuclear energy in Mexico is reaffirmed, in Brazil there is no change to New Build program, which is currently re-assessed by the government, and in Argentina the New Build program is confirmed.

On January 27th and 28th, 2012 two PWR (each 960 MW_e) were connected to the grid in South Korea. As of March 2nd, 2012, there were 63 NPP world-wide under construction with total of 60,057 MW_e net installed capacities [5]. New NPP are building 15 countries: Argentina (1), Brazil (1), Bulgaria (2), China (26), Finland (1), France (1), India (7), Japan (2), Pakistan (2), Russia (10), Slovakia (2), South Korea (3), Taiwan (2), Ukraine (2) and the US (1).

After more than 30 years (since accident at TMI in 1979), on February 9th, 2012 American safety regulators gave the go-ahead for the construction of two new nuclear power reactors at the Vogtle site (Unit 3 and 4) in Georgia. It is the first combined construction and operating licence issued by the US NRC. The 1107 MW_e PWR are slated for start-up in 2016 and 2017.

End of February 2012 IAEA announced that, in spite of the Fukushima accident, 60 countries around the world evinced in 2011 an interest for a civil nuclear program and at least five countries will start in 2012 constructions of their first NPP: Vietnam, Bangladesh, UAE, Turkey and Belarus. According to Kwagu Aning, deputy of the IAEA Director General, in 2013 Jordan and Saudi Arabia could start their first constructions.

World energy sector

Reliable, economical and environmental friendly produced electricity continues to be indispensable to address the world's needs for a sustainable development, with predictable prices and low carbon emissions.

The "International Energy Outlook 2011" [6] Reference Case, issued on September 15th, 2011, by EIA (the US Energy Information Administration), projects increased world consumption of marketed energy from all fuel sources through 2035. According to UK-based oil and gas giant BP (British Petroleum) and its "Energy Outlook 2030" [7], issued mid of January 2012, the world energy demand will grow by 39% by 2030, "albeit at a slowing annual rate, fuelled by economic and population growth in non-OECD countries". Energy consumption in OECD (Organisation for Economic Co-operation and Development) countries is expected to rise by just 4% in total over the period.

Energy used to generate electricity remains the fastest growing sector, accounting for 57% of the projected growth in primary energy consumption to 2030 (compared to 54% for 1990–2010). According to BP, world electricity demand (+2.6% per year) is projected to grow more rapidly than the total energy demand over the next 20 years, although not as rapidly as GDP (3.7% per year). Efficiency gains in power generation mean that the fuel inputs grow less rapidly than power output, averaging 2.1% per year in the period 2010-2030.

"The growth of global energy consumption is increasingly being met by non-fossil fuels. Renewables, nuclear and hydro together account for 34% of the growth; this aggregate non-fossil contribution is, for the first time, larger than the contribution of any single fossil fuel" noted BP. Renewable energy, without nuclear, is the world's fastest growing form of energy, and the renewable share of total energy use increases from 10% in 2008, to 14% in 2035, in the EIA Reference Case.

Fossil fuels are expected to continue supplying much of the energy used worldwide and according to BP they are forecast to account for 81% of global energy demand by 2030, down only 6% from current levels. In the absence of national polices and/or binding international agreements that would limit or reduce greenhouse gas emissions, world coal consumption is projected to increase at an average annual rate of 1.5% through 2035. Although liquid fuels – mostly petroleum based – remain the largest source of energy, the liquid share of world marketed energy consumption falls from 34% in 2008, to 29% in 2035, as projected high world oil prices lead many energy users to switch away from liquid fuels when feasible.

Global CO_2 emissions will rise by about 28% by 2030, as reported by BP: slower than the current rate of energy demand growth due to the rapid growth of renewables and natural gas. Moreover, according to EIA, world energy-related CO_2 emissions will rise circa 43% over the projected period until 2035. With strong economic growth and continued heavy reliance on fossil fuels expected in most non-OECD economies under current policies, much of the projected increase in CO_2 emissions occurs among the developing non-OECD nations. In 2008, non-OECD emissions exceeded OECD emissions by 24%; in 2035, they are projected to exceed OECD emissions by more than 100%. BP recognises that, "if more aggressive policies than currently envisioned are introduced, global CO_2 emissions could begin to decline by 2030".

There is still considerable uncertainty about the future of nuclear power, and a number of issues could slow the development of new NPP. As stated by BP in its "Energy Outlook 2030", nuclear output is "restored to pre-Fukushima levels by 2020". Although the long-term implications of the disaster at Fukushima Daiichi NPP for world nuclear power development are unknown, some countries have already announced plans to phase-out or cancel all their existing and future reactors. Those plans and new polices that other countries may adopt in response to the disaster at the Fukushima Daiichi NPP, although not reflected in the "International Energy Outlook 2011" projections by EIA, indicate that some reduction in the projection for nuclear power should be expected. In the EIA Reference Case, 75% of the world expansion in installed nuclear power capacity occurs in non-OECD countries. China, Russia and India account for the largest increment in world net installed nuclear power.

Nuclear drivers and sustainability of energy mix

Fundamentals driving the nuclear role in a sustainable energy mix remain unaffected and in the post-Fukushima context, new challenges came up but nuclear perspectives remain solid despite shaken public acceptance.

- GROWING DEMAND: Need for new capacity is unchanged to meet growing energy demand (multiplied by two in overall consumption and an 80% increase in global electricity consumption by 2050);
- REDUCTION OF CO_2 EMISSIONS: Although 50% of world electricity today is generated from burning coal, combating climate change remains a priority and greenhouse gas emissions are to be cut by half by 2050;
- SECURITY OF SUPPLY: Need for an increased security of supply in a changing geopolitical environment;
- FOSSIL ENERGY: Fossil resources are dwindling, remain uncertain and are volatile in prices;
- COMPETITIVENESS: Nuclear remains one of the most competitive low-carbon energy sources and will remain an important option for many countries for a sustainable energy mix.

To supply seven billion people (nine billion in 2030) with secure energy needs infrastructure development. This means huge investments, totalling 1.4% of global GDP per year by 2030, which will have to be made on time and on budget.

World Economic Outlook 2011 (Tensions from the Two-Speed Recovery: Unemployment, Commodities, and Capital Flows) "New Polices" Scenario [8], issued in April 2011, by IMF (International Monetary Fund), predicts 2.2% in annual growth of nuclear output until 2035, stating that the share of nuclear in global electricity production will stay above 13% due 2035. On July 27th, 2011, the IAEA Director General Yukiya Amano said: "Despite Fukushima Daiichi, global use of nuclear power will continue to grow in the coming decades and will remain an important option for many countries".

The "International Energy Outlook 2011" by the US DOE's (Department of Energy) EIA, released on September 15th, 2011, stated that:

1. Global nuclear energy generating capacity is projected to rise from current 368 GW_e to 644 GW_e by 2035, and
2. Electricity generation from nuclear power is projected to increase from current 2.63 GW_h to 4.9 GW_h in 2035.

The World Energy Outlook 2011 [9] published by the IEA (International Energy Agency) on November 9th shows that if nuclear energy supply was halved by 2035, energy prices would sharply increase and it would be nearly impossible to reach the goal of limiting the temperature increase to 2 °C above the temperature in pre-industrial times. The study found that global energy demand is expected to increase by 40% and consumption to rise by 1.3% per year by 2035, driven by economic growth in China and other developing countries. If the production of nuclear power was decreased by 50%, the share of renewables would rise, but coal and gas consumption would increase and the global CO_2 emissions of the power sector would go up by 6.2%. The IEA also estimates that without nuclear keeping the temperature rise below 2 °C would cost 1.1 € trillion extra by 2035. The report confirms that nuclear energy plays a pivotal role in sustainable energy mix as well as in combating climate change and ensuring competitiveness and security of supply.

The World Energy Council stated in a headline on November 15th, 2011: "Nuclear has role in a sustainable mix". A report released November 15th, 2011 "Policies for the future: 2011 Assessment of country energy and climate policies" [10] has determined that a mixture of generating technologies and strategies is best for ensuring sustainable energy production. The report ranks country performance according to an energy sustainability index – how well they perform in the three pillars of energy policy:

1. energy security,
2. environment, and
3. affordability.

The best performers are those which have the most coherent and robust energy polices and which most successfully manage the trade-offs between the three pillars. They all have diversified energy portfolios and promote energy efficiency. Notably, no country leads in all three areas. It is clear that nuclear energy plays a prominent role in the sustainable electricity generation mix of all countries highlighted and that moving away from nuclear could impact their performance. To note is that focusing solely on reducing greenhouse gas emissions and relying only on market mechanisms is not enough to achieve sustainability.

Nuclear power generation should continue to grow and be an important part of the world energy base-load portfolio for its energy security, strategic value, diversification of energy mix, economical and environmental contributions, with an enhanced safety framework.

References

[1] Nöggerath, J., Swiss Nuclear Society, March 28th 2011, www.tsunami-alarm-system.com
[2] ***, Interim report of the Investigation Committee of the Japanese Government on the Crises at the Fukushima Daiichi and Daiini NPP, 2011
[3] ***, INES: The International Nuclear and Radiological Event Scale, IAEA 08–26941 / E
[4] ***, The Futurist Interviews Crisis Communications Expert Peter Sandman on the Fukushima Daiichi Nuclear Meltdown in Japan; www.wfs.org
[5] ***, IAEA Power Reactor Information System; http://pris.iaea.org/public/
[6] ***, International Energy Outlook 2011, U.S. Energy Information Administration, DOE/EIA–0484(2011), 2011
[7] ***, BP Energy Outlook 2030, London, January 2012
[8] ***, World Economic Outlook 2011 (Tensions from the Two-Speed Recovery: Unemployment, Commodities, and Capital Flows) "New Polices" Scenario, International Monetary Fund, Washington DC, 2011
[9] ***, World Energy Outlook 2011, International Energy Agency, 2011
[10] ***, Policies for the future: 2011 Assessment of country energy and climate policies, World Energy Council, London, 2011

Paper submitted: March 5, 2012
Paper revised: March 18, 2012
Paper accepted: March 22, 2012