Nuclear Energy and Nuclear Waste Governance
Perspectives after the Fukushima Nuclear Disaster

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1 Introduction[1]

In the 1950s and 1960s, when commercial nuclear energy was first being developed, it was portrayed as an almost miraculous and limitless form of energy that would in the future be able to meet the world's growing energy demands. While nuclear energy did indeed grow to become an important element of electricity systems in some countries, it has been plagued by many problems and challenges. Today, the nuclear energy industry is facing challenging times that are linked to past failures in nuclear reactors, in energy utilities' planning, competition from alternative sources of energy, concerns about safety, and the Achilles' heel of nuclear waste.

The global use of nuclear power has been declining since 2006. There has been a drop in both the number of operational nuclear power plants (NPPs) worldwide and in total global nuclear power capacity. The industry's woes have been exacerbated by governmental announcements in several countries of plans to abandon nuclear energy all together. According to the World Nuclear Industry Status Report 2012 the industry is "suffering from the cumulative impacts of the world economic crisis, the Fukushima disaster, ferocious competitors and its own planning and management difficulties" (Schneider and Froggatt 2012: 5; 2013; 2014). The factors behind the industry's problems emerged well before the catastrophic incident at the Fukushima Dai-ichi nuclear power facility in March 2011. There are many processes which are changing the energy world order dramatically and threatening further nuclear energy development.

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To explain the ongoing decline of nuclear energy in many, if not all parts of the world this chapter reflects on challenges facing the nuclear energy industry, including changes in the architecture of the world energy system, new economic realities, societal scepticism, and court orders and regulatory decisions requiring that solutions are found for high level radioactive waste (HLW) disposal. A brief overview of national nuclear power policies with a focus on the five biggest nuclear electricity producers is followed by brief overviews of nuclear energy developments in other countries, ranging from plans for new nuclear power stations to plans for complete nuclear phase out are also presented.

A second major focus of the chapter is the emerging responses to the global crisis in nuclear waste management. For decades, decisions makers have proved unable or unwilling to take on the nuclear waste challenge. They have allowed nuclear waste storage to continue for decades in temporary facilities that were not designed as long term waste repositories. With global stockpiles of HLW accumulating, there is growing pressure to address this unresolved problem.

For those countries newly considering adding nuclear energy to their power supply, the failure of early nuclear energy states to tackle this problem from the start should be a powerful warning lesson. For those countries continuing with nuclear energy, developing safe and secure HLW storage must be given priority. For countries that are planning to phase out nuclear energy, the nuclear energy "problem" cannot be considered solved until the nuclear waste challenge has been addressed in a satisfactory manner.

Nuclear energy can be considered a *wicked problem* (Bergmans et al. 2008; Brunnengräber et al. 2012; 2014) that can not be untangled from highly complex safety and security risks, complicated financial questions, and the major societal challenges of trying to identify nuclear waste sites and building adequate facilities for low, intermediate and especially high level radioactive waste (respectively, LLW, ILW, HLW). Siting processes tend to be accompanied by conflicts, disagreements, delays and financial calculations that underestimate actual costs. Most significantly, there is no perfect solution. One of the biggest dilemmas with nuclear waste is its longevity. Highly radioactive waste remains dangerous for tens of thousands of years. Thus, it is necessary to store it safely for periods of time that are essentially beyond human comprehension. What will be necessary under such difficult condititons is to develop the best possible solutions – from technical and safety perspectives as well as in terms of societal acceptance given current understandings and state of knowledge.

There is still considerable public mistrust regarding nuclear waste management in most countries. Governments are partly to blame. Governments pursued nuclear power development but pushed off the waste question into the future. This, however, cannot be done indefinitely. The unwelcome truth is that the international community is still a long way off from having adequate solutions to the backend problem of nuclear energy use. Worldwide there has been little progress in site selection due to various wicked challenges. As the chapter will show however, efforts to find solutions are intensifying.

2 Talk of a nuclear renaissance

The massive explosions at the Chernobyl NPP in the former Soviet Union (now, the Ukraine) in April 1986 led to a global slowdown in the building of NPP. The explosions at the Chernobyl nuclear facility sent radioactive plumes across parts of the Soviet Union and Europe. In Europe, this led to decisions to strengthen nuclear safety standards and institutions, such as the International Atomic Energy Agency (IAEA). Internationally, the World Association of Nuclear Operators (WANO) was established to improve global operating standards and "to achieve the highest possible standards of nuclear safety".[2]

The nuclear accident sent a chill through the industry, but at the same time, was portrayed as a problem of Soviet-era technology. Many assurances were given that a similar accident could not happen in the West. These assurances began to have some effect. Nuclear energy began to win renewed support from governments, interest groups, and publics. The nuclear industry began to talk of a nuclear renaissance and from 1995 on received support at annual United Nations conferences on climate change and from some national governments looking for ways to implement climate mitigation plans. Nuclear energy was portrayed as a "clean" energy and promoted as a good way to combat greenhouse gas (GHG) emissions. This clever campaign made inroads, and even some non-governmental organizations (NGOs) – especially in the United States – began to support nuclear energy out of their concerns about climate change. The Intergovernmental Panel on Climate Change (IPCC) has lent support to this ongoing debate, calling nuclear energy a zero- and low-carbon energy technology, which "does not contribute to direct GHG emissions" (IPCC 2014, chapter 7: 23, see below). According to the "Energy Technology Perspectives" published by the International Energy Agency in June 2008 for the G8 summit, if in addition to other measures, 32 new NPPs were built per year, they could reduce harmful GHG emissions by 50% by 2050 (International Energy Agency (IEA) 2008).

Plans began to be set in several countries to strengthen, revitalize or newly launch nuclear power programs. As we will show below, however, for a variety

2 See http://www.wano.info/en-gb/aboutus/, last accessed 20 September 2014.

of reasons, including but not limited to the Fukushima nuclear accident in 2011, this nuclear renaissance has failed to materialize (Mez 2011). According to the World Nuclear Industry Status Report 2014, the 388 operational reactors in the world as of 1 July 2014 are 50 fewer than their peak number, which was in 2002.[3] Total installed capacity reached a high of 367 GWe in 2010, but then a process of decline began. Annual nuclear electricity generation which was at 2,660 TWh in 2006 was only at 2,359 TWh in 2013. There was a stabilization of the situation in 2013 (+0.6 percent) after two consecutive years of significant decline (-4% in 2011, -7% in 2012) (Schneider and Froggatt 2014: 7). While about three-quarters of the drop between 2006 and 2013 is due to the nuclear shut downs in Japan, 16 other countries have decreased their nuclear generation (Schneider and Froggatt 2013: 6). The reasons for the decline's start in 2006 are many-fold, as will be discussed later.

National rates of dependence on nuclear energy vary considerably. The "big five" nuclear generating countries in installed capacity are the United States of America (99 GWe), France (63 GWe), Japan (44 GWe), the Russian Federation (24 GWe), and the Republic of Korea (21 GWe). Together they represented 68% of total global nuclear capacity as of September 2013 (IAEA 2013; Schneider and Froggatt 2014: 8). In the United States there are 100 NPPs in operation (with five under construction) (World Nuclear Association (WNA) 2014b), 58 in France (WNA 2014c), 33 in Russia, 23 in South Korea and 21 in India; most countries with nuclear power have fewer than 10 NPPs. Nuclear energy generates about 75% of France's electricity, 19% of the United States' and 15% of Germany's (Power Reactor Information System (PRIS) 2014).[4] These countries are also the major suppliers of nuclear energy technologies, dominate nuclear energy research and development, and are the largest exporters of nuclear energy equipment. Below developments related to nuclear energy and waste in these countries are briefly considered.

3 The "big five" nuclear generating countries

United States of America

The United States is the world's largest producer of nuclear power, accounting for about one-third of global nuclear energy output (PRIS 2014, WNA 2014b).

3 The IAEA's list of 437 operational nuclear reactors, includes the reactors in Japan, even though in 2014 they were not in use see: http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx, last accessed 10 October 2014.

4 See http://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx, last accessed 13 October 2014.

Its reactors are aging as there has been little new NPP construction since the 1979 Three Mile Island and 1986 Chernobyl nuclear reactor accidents. In the 1990s, acceptance of nuclear energy did begin to resurface due to energy security and climate change concerns. The first signs of change began with the granting of contract extensions to nuclear reactors, beginning with the application by Baltimore Gas & Co. for its two reactors at Calvert Cliffs in Maryland in 1998. This approach to maintaining nuclear capacity has since spread across the country. As of 2014 three-quarters of the USA's reactors had been granted extensions to their operating licenses (United States Nuclear Regulatory Commission (U.S.NRC) 2014). The extensions mean that at least some reactors of this existing capacity could be operating until the middle of the century.

With growing concerns about long-term energy security, the Energy Policy Act of 2005 offered financial incentives (a 2.1 cents/kWh tax credit for the first 6,000 MW of capacity in the first eight years) for the construction of new NPPs and federal loan guarantees. The United States Department of Energy put the program in place in 2008 and in the ensuing months received applications for 21 nuclear reactors. In January 2012, the U.S.NRC approved permits for two reactors at a new nuclear power facility to be built in eastern Georgia, the first new approvals since 1978. Subsequently, several other applications were approved.

Yet, with the energy situation rapidly changing in the United States, several of the construction plans have been put on hold or withdrawn for economic reasons. Some plans for extensions of operating licenses were also withdrawn and a few plants are beginning to be shut down. The Vermont Yankee NPP which began operations in 1972 and received a 20-year operating time extension in 2011, will shut down on cost competitiveness grounds (The Guardian 2013). Wisconsin's Kewaunee reactor has been shut down for economic reasons but its owners are holding off on decommissioning plans.

Democratic Congressman Edward J. Markey has raised a point of concern: "Once these old nuclear reactors shut down – as we're seeing now – it will take 60 years and hundreds of millions of dollars to decontaminate them. Taxpayers should have assurances that these nuclear relics don't outlive their corporate owners and their ability to fund nuclear cleanup costs, leaving ordinary Americans to foot the bill" (Wald 2013). Two other plants (San Onofre in California and Crystal River in Florida) are being shut down as repair costs are considered too high. Several more plants could be shut down in the coming period for similar reasons. The combination of the Fukushima meltdowns and low natural gas prices tied to the extensive extraction of shale gas has dampened expectations in the industry. Thus, despite very strong industry and political support at the highest levels, including from President Barack Obama, the outlook for the U.S. nuclear industry is shaky.

France

France is one of the leading producers and consumers of nuclear energy, with nearly three-quarters of its electricity generated in nuclear reactors. In 2013 403.7 TWh of electricity was produced by nuclear power, 73.3% of total electricity generation (PRIS 2014). The French nuclear group, Areva, has strong backers in the French government, both within the conservative and the socialist parties. Nevertheless, the government of President François Hollande is pursuing a policy of diversification for the electricity system. During very cold or hot periods demand exceeds supply due to the lack of more flexible generating plants, and France needs to import electricity from its neighbors, often at very high prices. The Fukushima nuclear accident was a powerful warning to France. Diversity is therefore being pursued. Goals have been set to raise the share of renewable electricity to 23% in 2020 and 40% by 2030 in order to enhance energy security. And after François Hollande's victory in the 2012 presidential election, a partial nuclear phase-out and the closure of the oldest 24 reactors by 2025 is on the agenda. Plans for the shut down of specific plants remain vague; currently only Fessenheim 1 and 2 at the German border, have been identified for shut down at the end of 2016. Yet, one-third of France's nuclear reactors will have been in operation for 40 years or more in 2022, thus even if operating-time extensions are granted, France, like the United States, will have an increasingly old nuclear fleet (Broomby 2014a). Currently, France is building a new generation reactor in Flamanville; grid connection is scheduled for December 31, 2016. Like Finland's reactor Olkiluoto 3 of similar design, Flamanville 3 is suffering from cost overruns and repeated delays. France will face costly decisions in the coming years as it is forced to decide whether to build new nuclear plants or to instead shift to other power sources. Decisions about extending the operating life-time of the existing NPP will only be made at the end of this decade.

Japan

Japan invested heavily in nuclear energy in previous decades and became the world's third largest producer of nuclear power after the United States and France. As a major component of its efforts to combat climate change, the Japanese government envisioned sharply increasing the share of nuclear energy in the electricity mix. Its 2010 Basic Energy Plan set out plans to expand nuclear energy to meet 50% of electricity production by 2030. Those plans were badly shaken by the Fukushima nuclear accident. Four reactors at the Fukushima

Dai-ichi NPP were severely damaged by the earthquake, tsunami, subsequent hydrogen explosions and nuclear meltdowns and permanently shut down in May 2011. It is estimated that their dismantling and decommissioning will take several decades and cost the country trillions of yen. Due to the dire situation in Fukushima, the other two reactors at the Dai-ichi Nuclear Facility in Fukushima were also permanently shut down in December 2013 (PRIS 2014) and designated for decommissioning.

Of the remaining operational 48 NPPs, all have been shut down for safety checks and are awaiting decisions about their restart under new safety guidelines.[5] At the time of the Fukushima nuclear accident in March 2011, nuclear power supplied 27% of Japan's electricity. After the Fukushima catastrophe, the nuclear share dropped to 1.7% of total electricity production in 2013 due to shut downs (PRIS 2014). Between March 2011 and the end of 2014, Japan has functioned on a greatly reduced share of nuclear energy and long periods when there was nearly and even no nuclear energy connected to the grid. The loss of electricity production from nuclear reactors has been compensated by energy efficiency improvements, energy conservation and greater reliance on imported coal and gas. Japan's carbon dioxide emissions have risen sharply, but its energy demand has also dropped substantially (Schreurs and Yoshida 2013).

In December 2013, a newly elected conservative government led by Shinzo Abe presented a new energy plan. The plan states that nuclear energy remains an important energy source, but that Japan will strive to decrease dependency on nuclear energy while expanding reliance on renewable energy. The plan does not give a percentage for nuclear energy in the future as it is unclear how many of Japan's remaining NPP will pass new safety standards established after the Fukushima nuclear accident. The Japanese nuclear industry, the powerful Ministry of Economy Trade and Industry, and other nuclear supporters have argued that Japan will face soaring energy costs, rising GHG emissions, and economic decline without nuclear energy. Nuclear opponents argue that Japan can survive without nuclear energy by promoting renewable energy and energy conservation and point to the country's ability to function after the Fukushima nuclear accident with no nuclear energy connected to the grid.

While the government of Shinzo Abe is eager to restart the country's NPPs, opposition in the country remains strong. Plans to restart two reactors at the Oi NPP in Fukui were set back by a local court decision that said the plant's owner had not adequately shown the plants were safe given their location in a possible earthquake zone (Muroya 2014). In the meantime, renewable energy is back on the agenda in Japan. In the summer of 2012, a feed-in-tariff was

5 See http://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=JP, last accessed 10 October 2014.

introduced to incentivize renewable energy, and especially photovoltaics (PV). A target of 33 GW of PV and 9 GW of wind was set for 2020. Japan has become an attractive photovoltaic market, and by 2013 had over 10 GW of installed capacity.

The Japanese government and the nuclear industry envision a closed nuclear fuel cycle despite significant international opposition. The Rokkasho Reprocessing plant, with the capacity to reprocess 800 tons of uranium or 8 tons of plutonium, is scheduled to open in late 2014. The start up of the plant is highly controversial due to concerns about nuclear proliferation (Tirone and Adelman 2014).

Russian Federation (Russia)

Despite the meltdowns at the Chernobyl reactor and the Fukushima Dai-ichi NPP, Russia has indicated its intentions to expand nuclear energy capacity by 2020, develop new reactor technologies, and export NPPs. Russia presently has 33 operational reactors totalling 24,164 MWe, 10 reactors under construction and 5 in permanent shutdown (PRIS 2014); in addition, most reactors are being given operating extensions (WNA 2014d). Russia's nuclear power production peaked in 2010 but the Russian industry has expanded its export policy with financial backing from the state. Russia is cooperating with countries that are building reactors for the first time (Belarus, Turkey and Bangladesh) and with countries like Finland and Hungary that already have NPPs. A deal for a Russian loan to finance a nuclear plant expansion project in Hungary was approved by the Hungarian parliament in June 2014 (although the plan awaits consideration by the European Union). Under the agreement, Russia's state-owned Rosatom will build 2,000 MW of additional capacity at Hungary's state-owned MVM Paksi Atomeromu (Gulyas 2014). Russia has also signed a deal to build a NPP in Bangladesh (Russia Beyond the Headlines 2014). Despite these potential markets, Russia is currently only constructing reactors at home and in China, and Belarus (Schneider and Froggatt 2014: 48).

Republic of Korea (South Korea)

In South Korea, 23 nuclear reactors with an installed capacity of 20.7 GWe provided almost one-third of South Korea's electricity in 2013. Five reactors are under construction (PRIS 2014). Korea's aim is to provide about half of the electricity from over 30 units by 2022 (WNA 2014e). A year before the Fukushima accident, South Korea sold four nuclear power reactors to the United Arab Emirates and in January 2010, the South Korean Ministry of Knowledge Economy launched NuTech 2030, a plan to develop indigenous reactor technology (Innovative, Passive, Optimised, Worldwide Economical Reactor

(I-Power)). The goal is to export 80 NPPs by 2030 and to make South Korea the third largest supplier of nuclear technology in the world. Six new reactors are to be completed by 2016. The government's plans, however, are under scrutiny. The natural disaster and ensuing nuclear crisis in Japan have opened a debate about Korea's energy future and led to calls to invest more in energy efficiency improvements and renewable energy development.

Comparing across the Big Five Producers

Despite the Fukushima nuclear accident, there is political support for continuing with nuclear energy in the big five nuclear energy producers. Yet, the impacts of the accident can be felt in these countries as well. The industry is struggling and the high growth expectations of the past have been dampened. In the United States, both the Republican and Democratic parties continue to back nuclear energy, but the economics of nuclear energy could make it difficult to do more than continue with existing plant capacity for the foreseeable future. New construction may not be able to offset the decline in operational nuclear NPPs. The Japanese government wishes to continue the use of nuclear energy, but there is strong public apprehension. Japan is the first country in the world to have a large nuclear energy fleet that was forced to shut down entirely for an extended period of time due to safety concerns. France is planning a major cut back in the share of nuclear energy in its electricity mix. South Korea and Russia have the most ambitious plans for nuclear energy expansion of the big five, although in South Korea there is now more opposition to nuclear energy than there was in the past. All five countries are in competition with each other in terms of exporting nuclear energy technologies, but there are relatively few buyers.

4 Challenges facing the nuclear energy industry

There are many challenges facing the nuclear energy industry. The most obvious is the lack of public trust in the safety of nuclear energy after the nuclear accidents at Three Mile Island, Chernobyl, and Fukushima. They occurred despite government and industry assurances of safety. After each major accident, the industry has suffered major setbacks with loss of public confidence in the industry's assurances of the technology's safety (Schreurs 2013b). After the Fukushima accident, the European Commission ordered stress tests for all NPPs operating in the European Union. Peer reviews took place in 2011 and 2012. Many other countries and territories also conducted comprehensive nuclear risk and safety assessments, based on the EU stress-test model. These included Switzerland and the Ukraine (both of which fully participated in the EU stress tests), Armenia, Turkey, Russia, Taiwan, Japan, South Korea, South Africa and Brazil. The peer review performed by the European Commission and the European Nuclear Safety Regulators' Group (ENSREG) identified weak spots and called for action to make the NPP more robust.[6]

An aging nuclear fleet

Apart from a few countries that have continued to build NPPs (like South Korea) or that have only in the last decade started to heavily invest in nuclear power (like China), many of the world's nuclear facilities are getting older. With age come greater concerns about plant safety and added costs for upgrades. Few countries in the west have built new NPPs since the Chernobyl nuclear accident; a majority of the nuclear facilities around the world are within one or two decades of the end of their original licensed operating times. NPPs in most countries are only allowed to operate for 30 or 40 years, even though some are getting operating extensions for an additional decade or two. Worldwide there are 39 reactors that have run for over 40 years. As there has been little new construction, the global NPPs fleet is aging. At the end of 2014, the average age of operating NPPs in Europe is 30 years, in the United States, 34 years (United States Energy Information Agency (EIA) 2013) and globally, 28.5 years (Schneider and Froggatt 2014: 6). Clearly, the global nuclear power fleet is aging and this leads to additional costs and risks (Haverkamp 2014).

A rapidly changing global energy structure

Nuclear energy is but one of many forms of energy in a rapidly changing global energy structure. As the International Energy Agency (IEA) has noted: "the rise of unconventional oil, gas and renewables is transforming our understanding of the distribution of the world's energy resources" even if the situation differs between countries and regions (IEA 2013a: 3). Demand for energy is expected to grow by as much as one-third in the coming decades (through about 2035), triggered mainly by the enormous thirst for energy in China, India and the Middle East. These regions account for about 60% of the growth in energy demand globally. While one might expect these tendencies to speak in favor of nuclear energy, the situation is quite complex. On the one hand, energy security concerns have led countries like China and India to pursue all forms of energy development, including nuclear power. Growing energy demand and the desire for greater energy independence are also attracting other countries to consider developing nuclear energy, such as Bangladesh, Belarus, Poland, Turkey and Vietnam, or to maintain nuclear energy, such as the Czech Republic.

6 For more information see http://ec.europa.eu/energy/nuclear/safety/stress_tests_en.htm, last accessed 20 March 2014.

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