AGING NUCLEAR POWER STATIONS AND NEXT-GENERATION REACTORS

Teruhi Fukano

wonder-news.com

September 11, 2017

Contents

Aging Nuclear Power Stations and Next-Generation Reactors

September 11, 2017

Introduction

The nuclear catastrophe in the 2011 Fukushima Daiichi Accident (hereafter, “the Fukushima accident”) delivered a blow to the Japanese people and caused widespread fear of nuclear power not only in Japan but also around the world. The Diet and Cabinet each set up investigation committees on the Fukushima accident, which conducted an investigation of the accident’s causes and released the final reports in July 2012. The International Atomic Energy Agency (IAEA) published “The Fukushima Daiichi Accident” in 2015. According to the reports, natural disaster combined with a series of human, organizational, and technical factors to cause the severe nuclear accident. Before the accident occurred, some Japanese scientists had pointed out the potential for a massive earthquake and huge tsunami along the coast of Fukushima Prefecture, but the additional measures taken to address these concerns were insufficient at the time of the accident. This resulted in the worst nuclear accident at a nuclear power plant (NPP) since Chernobyl.

Right after the Fukushima accident, nuclear regulators worldwide immediately called for their operators to conduct “stress tests” on their nuclear facilities. These tests helped operators reassess the resilience of NPP designs against site-specific extreme natural hazards, analyze their vulnerability to severe accidents, and undertake necessary measures to correct them. This report focuses on the impact of the Fukushima accident on energy policies in the US and Europe, the issue of aging nuclear plants, and a next-generation reactor.

Groundless Safety Myth

Nuclear electricity generates a perilously high density of energy. Despite this fact, the Fukushima accident was predicated on the widespread assumption that Japan's NPPs were so safe that an accident of this magnitude was simply unthinkable. This assumption was accepted by NPP operators, regulators, and the government alike in the interest of propelling the use of atomic power forward in line with Japan's domestic energy policy. Even after the 1986 Chernobyl nuclear disaster, Japanese power companies believed that such a severe accident, involving a massive radiation release into the environment and a meltdown of a fuel reactor, would never happen in Japan because their reactors were of different types than those in Chernobyl. Neither utility companies nor regulators learned from the Chernobyl nuclear accident to improve the nuclear safety of domestic plants. The Fukushima Daiichi accident is now categorized by the IAEA as Level 7, the worst accident on the International Nuclear Event Scale (INES) along with the Chernobyl nuclear disaster. Meanwhile, nuclear regulators in continental Europe issued an order requiring all NPPs to install filtered venting systems.[1] Japanese power companies introduced the system in the wake of the Fukushima accident, twenty-five years after the Chernobyl nuclear accident.

Prior to the Fukushima accident, it was understood that a tsunami could cause fatal damage to the NPP, but the preventive measures proved insufficient at the time of the accident. Before the accident, the Tokyo Electric Power Company (TEPCO) had conducted reassessments of extreme tsunami flood levels, using a seismic model developed by the Japanese Headquarters for Earthquake Research Promotion (HERP) in 2002. Based on the model, tsunami waves could have reached a maximum height of 5.4 – 5.7 meters along the coast of Fukushima Prefecture, so TEPCO took some compensatory measures. HERP carried out another trial calculation in 2008, taking a different approach that envisaged a substantially larger tsunami with a maximum wave height of 9.3 – 15.7 meters in the grounds of Fukushima Daiichi NPP. The latter estimated values were similar to the flood levels recorded in the plant in March 2011. The TEPCO management responded bluntly to the reassessment results. They thought the assessment of natural hazards indicated the mere potential for their occurrence. Hence, TEPCO did not implement the necessary corrective actions or compensatory

[1] Filtered venting systems remove heat and pressure before potential damage to a reactor core occurs, delaying reactor core damage or melting. They can also confine radioactive material that is released when a reactor core is damaged.

measures against a massive tsunami.

The direct cause of the Fukushima accident involved the underlying assumption that there would never be a loss of all electrical power at an NPP for more than a short period. During the accident, hydrogen was released from the reactor pressure vessel, leading to an explosion inside the reactor buildings in Units 1 through 4 that damaged structures and equipment and released a massive quantity of radioactive materials into the environment. The nuclear fuel melted in Units 1 through 3. The earthquake caused damage to the site's electric power supply lines, and the tsunami caused substantial destruction of the operational and safety infrastructure on the site. The combined effect led to the complete loss of offsite and onsite electrical power (i.e., emergency diesel generator and rechargeable batteries). This resulted in the loss of the cooling function at three operating reactor units as well as at the spent fuel pools. The safety myth of NPPs wrought by the Japanese power companies and regulatory body was shattered.

Movement of Other Countries after the Fukushima Accident

Each country decides on the pros and cons of the generation of nuclear power. Immeasurable risks of NPPs were exposed by the Fukushima Accident, impacting energy policies in each country. Some policy revisions reflected a growing distrust in NPPs, while other counties including Japan continued to regard NPPs as a major power source. Demand for NPPs remains strong in China, Russia, and India as well.

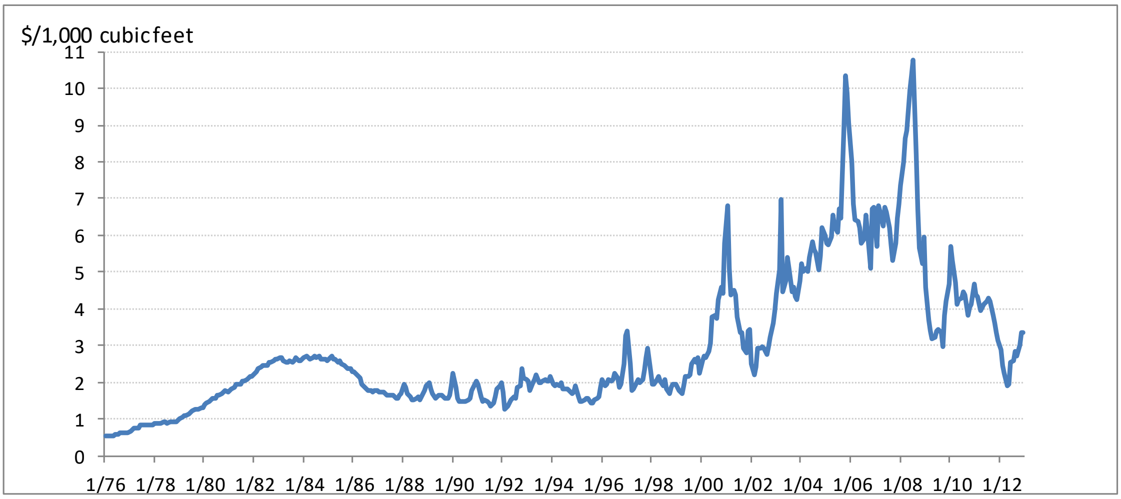
Growing Distrust of Nuclear Power Plants

In July 2011, Germany decided in the aftermath of the Fukushima accident to phase out all of its commercial NPPs by 2022. Germany had 21 reactor units in 1990, accounting for 33 percent of Germany's energy mix. At the end of 2016, Germany had 8 operating reactors accounting for 13 percent of its total energy. These operating reactors launched operations between 1984 and 1989, and are expected to reach the end of the 32 year NPP lifespan by 2022. Switzerland will also phase out all of its NPPs by 2050 in response a referendum that passed in 2017. Both of the countries will replace nuclear energy with renewable energy.

Lithuania called off new construction of an NPP in October 2011 in the wake of the Fukushima accident. The government of Vietnam dropped its plan for building an NPP. Overall, the nuclear catastrophe in Fukushima strengthened the anti-nuclear sentiment worldwide. Policy makers recognized that a severe accident involving the meltdown of a reactor core could spiral out of human control. Risks brought by NPPs and high construction fees dampened plans for new nuclear capacity in these countries.

United States

Figure 1 US NATURAL GAS WELLHEAD PRICE



Source : *US Energy Information Administration*

Forty-seven reactors were approved for construction before 1977 and launched commercial operations in the late 1970s and 1980s. After the 1979 Three Mile Island accident, however, nuclear developments in the US suffered a major setback. Many orders and projects were cancelled or suspended. New NPP construction was nearly halted for more than twenty years due to 1) growing anti-nuclear sentiment, 2) the prospect of many more years of low natural gas prices (Figure 1), and 3) a rise in production costs reflecting tighter regulations on NPPs. Then in the early 2000s, natural gas prices rose sharply and nuclear electricity generation was reassessed in the interest of curbing global warming. Shortly after that, the Fukushima accident occurred. The Nuclear Regulatory Commission (NRC) imposed tighter safety requirements on NPP operators, leading to increased costs of new NPP construction and existing NPP safety measures. Four reactors are currently under construction in the US, all with reactors provided by Westinghouse, a former subsidiary of Toshiba that filed for bankruptcy in March 2017.

Severe Accident Measures

Coherent Information Sharing and Communication

The severe accident management guidelines naturally vary according to plant design, local regulations, and the site's characteristics. Even the IAEA lacks standardized management guidelines for severe accidents. Workers at the Fukushima Daiichi Nuclear Plant who had not taken part in relevant severe accident exercises were forced to confront degraded plant conditions. Information sharing was disrupted between the onsite center, offsite emergency control center, TEPCO headquarters, the prime minister's office, and the regulatory body, which prompted confusion. Communications among relevant authorities come under scrutiny.

The offsite emergency control center, located five kilometers from the Fukushima Daiichi nuclear power plant, was not well prepared for protection from extreme external events and radiation hazards. Relevant authorities should have assembled at the offsite center to guide and support the onsite workers and evacuate residents around the Fukushima Daiichi power plant. Over twenty organizations, including TEPCO and the local government, should have come to the offsite center, but only fifteen people from three organizations actually came[2]. There was no coordinated plan to respond simultaneously to a nuclear emergency and a natural disaster. Roles and responsibilities of the local response organizations and government were not clearly defined. The Fukushima Accident exposed the inadequacies of the severe accident exercises conducted by all relevant parties.

United States

NPP operators and area response organizations must demonstrate they can implement emergency plans and procedures effectively during periodic evaluated exercises. According to the IAEA, the US currently operates 99 commercial NPPs. As part of the Reactor Oversight Process, the NRC reviews the emergency planning procedures and training of licensees. These reviews include regular drills and exercises that identify areas for licensee improvement, such as in the interface of security operations and emergency preparedness. Each plant operator is required to exercise its emergency

[2] "Offsite Center failed to function" NHK, June 6, 2011

plan with offsite authorities at least once every two years to ensure the ongoing proficiency of state and local officials.[3]

The Federal Emergency Management Agency (FEMA) leads the initial review and assessment of offsite planning and response in coordination with state and local governments, while the NRC reviews and assesses the onsite planning and response. The NRC reviews the FEMA findings as well as the onsite findings and makes a final determination on the overall state of emergency preparedness. The NRC uses these overall findings to make radiological health and safety decisions before issuing the initial license, and to continue the oversight of existing reactors. The NRC has the authority to take actions including shutting down any reactor deemed not to provide reasonable assurance of the protection of public health.

France

Emergency workers need to be designated, assigned clearly specified duties, trained adequately, and protected properly during an emergency. France, the second most nuclear-reliant country after the US, operates 58 NPPs. In light of the Fukushima accident, Électricité de France (EDF) worked with French public authorities to set up an emergency nuclear task force called the Fast Action Force in case of Nuclear Accident (FARN)[4] in 2012. FARN intervenes at the site of nuclear accidents in less than twenty-four hours. One of its missions is to reinstate water, electricity, and air supply, and to protect onsite NPP workers from radiation. FARN personnel are trained in radiation protection (RP) and stress management in emergency situations, and one person who specializes in radiation protection is deemed the RP expert. FARN also provides a site doctor. A nuclear emergency is likely to be brought under control or at least improved by dispatching the special task force within twenty-four hours.

---

[3] "Backgrounder on Emergency Preparedness at Nuclear Power Plants", US NRC

[4] "EDF FARN (Fast Action Force in case of nuclear accident) – Focus on radiation protection of workers", IAEA

Restart of Reactors

The Nuclear Regulation Authority (NRA), which reviews the restart of NPPs in Japan, said, “Nuclear safety can’t be completely secured by just meeting the imposed requirements. Measures for nuclear safety require ceaseless efforts and we need to aim at higher levels of nuclear safety all the time.”[5] After the Fukushima accident, all operators were forced to stop the operation of NPPs in Japan. In 2012, the NRA was established and formulated new regulations for NPPs that came into force in 2013. It gave regulators clearer responsibility and greater authority. NPP operators in Japan were required to install additional backup sources of electrical power and water, and enhance the equipment against internal flooding. Sendai Unit 1 of Kyushu Electric restarted operations in August 2015, and other reactors are currently under review to restart nuclear plants. It could be worthless to install costly equipment if workers lack the skills to operate the equipment during a severe accident.

Despite Japan’s higher probability of natural hazards—compared with the US and Europe, it has more earthquakes and active volcanoes—numerous NPPs have been built there (Table 1). According to the Geospatial Information Authority of Japan, about 10 percent of the world’s earthquakes occur in Japan and its surrounding areas. Japan owns 42 reactors and possesses the third-most nuclear reactors, after the US and France. Many more reactors were planned for construction at the end of 2016 (Tables 2 and 3). The deregulation of retail electricity starting from April 2016 may lead to increasingly difficult competition among power utilities. Power companies may have little choice but to increase capital spending to maintain aging nuclear plants.

---

[5] “New regulations”, the NRA

Table 1 OPERATIONAL REACTORS (31 DEC. 2016)

Reactor Name	Type	Capacity (MW)	Operator	NSSS Supplier	Commercial operation	Restart of Reactors	Extended Operation
1 FUKUSHIMA-DAINI-2	BWR	1067	TEPCO	TOSHIBA	1982/04		
2 FUKUSHIMA-DAINI-2	BWR	1067	TEPCO	HITACHI	1984/02		
3 FUKUSHIMA-DAINI-2	BWR	1067	TEPCO	TOSHIBA	1985/06		
4 FUKUSHIMA-DAINI-2	BWR	1067	TEPCO	HITACHI	1987/08		
5 GENKAI-2	PWR	529	KYUSHU	MHI	1981/03		
6 GENKAI-3	PWR	1127	KYUSHU	MHI	1994/03		
7 GENKAI-4	PWR	1127	KYUSHU	MHI	1997/07		
8 HAMAOKA-3	BWR	1056	CHUBU	TOSHIBA	1987/08		
9 HAMAOKA-4	BWR	1092	CHUBU	TOSHIBA	1993/09		
10 HAMAOKA-5	BWR (ABWR)	1325	CHUBU	TOSHIBA	2005/01		
11 HIGASHI DORI-1	BWR	1067	TOHOKU	TOSHIBA	2005/12		
12 IKATA-2	PWR	538	SHIKOKU	MHI	1982/03		
13 IKATA-3	PWR	846	SHIKOKU	MHI	1994/12	○	
14 KASHIWAZAKI KARIWA-1	BWR	1067	TEPCO	TOSHIBA	1985/09		
15 KASHIWAZAKI KARIWA-2	BWR	1067	TEPCO	TOSHIBA	1990/09		
16 KASHIWAZAKI KARIWA-3	BWR	1067	TEPCO	TOSHIBA	1993/08		
17 KASHIWAZAKI KARIWA-4	BWR	1067	TEPCO	HITACHI	1994/08		
18 KASHIWAZAKI KARIWA-5	BWR	1067	TEPCO	HITACHI	1990/04		
19 KASHIWAZAKI KARIWA-6	BWR (ABWR)	1315	TEPCO	TOSHIBA	1996/11		
20 KASHIWAZAKI KARIWA-7	BWR (ABWR)	1315	TEPCO	HITACHI	1997/07		
21 MIHAMA-3	PWR	780	KEPCO	MHI	1976/12		○
22 OHI-1	PWR	1120	KEPCO	WH	1979/03		
23 OHI-2	PWR	1120	KEPCO	WH	1979/12		
24 OHI-3	PWR	1127	KEPCO	MHI	1991/12		
25 OHI-4	PWR	1127	KEPCO	MHI	1993/02		
26 ONAGAWA-1	BWR	498	TOHOKU	TOSHIBA	1984/06		
27 ONAGAWA-2	BWR	796	TOHOKU	TOSHIBA	1995/07		
28 ONAGAWA-3	BWR	796	TOHOKU	TOSHIBA	2002/01		
29 SENDAI-1	PWR	846	KYUSHU	MHI	1984/07	○	
30 SENDAI-2	PWR	846	KYUSHU	MHI	1985/11	○	
31 SHIKA-1	BWR	505	HOKURIKU	HITACHI	1993/07		
32 SHIKA-2	BWR (ABWR)	1108	HOKURIKU	HITACHI	2006/03		
33 SHIMANE-2	BWR	789	CHUGOKU	HITACHI	1989/02		
34 TAKAHAMA-1	PWR	780	KEPCO	WH/MHI	1974/11		○
35 TAKAHAMA-2	PWR	780	KEPCO	MHI	1975/11		○
36 TAKAHAMA-3	PWR	830	KEPCO	MHI	1985/01	○	
37 TAKAHAMA-4	PWR	830	KEPCO	MHI	1985/06	○	
38 TOKAI-2	BWR	1060	JAPCO	GE	1978/11		
39 TOMARI-1	PWR	550	HEPCO	MHI	1989/06		
40 TOMARI-2	PWR	550	HEPCO	MHI	1991/04		
41 TOMARI-3	PWR	866	HEPCO	MHI	2009/12		
42 TSURUGA-2	PWR	1108	JAPCO	MHI	1987/02		

Source：*"Nuclear Power Reactors in the World",* IAEA, 2017 Edition and the Agency for Natural Resources and Energy of the METI

Note: Data for restart of reactors and renewed license reactors are as of July 2017

Table 2 REACTORS UNDER CONSTRUCTION (31 DEC. 2016)

	Reactor Name	Type	Capacity (MW)	Operator	NSSS Supplier	Construction Start	Commercial operation
1	OHMA	BWR (ABWR)	1328	EPDC	H/G	2010/05	N/A
2	SHIMANE-3	BWR (ABWR)	1325	CHUGOKU	HITACHI	2007/10	N/A

Source： *"Nuclear Power Reactors in the World", IAEA, 2017 Edition*

NSSS: Nuclear Steam Supply System

H/G＝Hitachi GE

Table 3 REACTORS PLANNED FOR CONSTRUCTION AS KNOWN ON 31 DEC. 2016

	Reactor Name	Type	Capacity (MW)	Operator	NSSS Supplier	Expected Construciton Start
1	HAMAOKA-6	BWR (ABWR)	1350	CHUBU		N/A
2	HIGASHI DORI-1	BWR (ABWR)	1343	TEPCO	H/G	N/A
3	HIGASHI DORI-1	BWR (ABWR)	1343	TEPCO		N/A
4	HIGASHI DORI-2	BWR (ABWR)	1067	TOHOKU		N/A
5	KAMINOSEKI-1	BWR (ABWR)	1325	CHUGOKU		N/A
6	KAMINOSEKI-2	BWR (ABWR)	1325	CHUGOKU		N/A
7	SENDAI-3	BWR (ABWR)	1590	KYUSHU		N/A
8	TSURUGA-3	BWR (ABWR)	1538	JAPCO	MHI	N/A
9	TSURUGA-4	BWR (ABWR)	1538	JAPCO	MHI	N/A

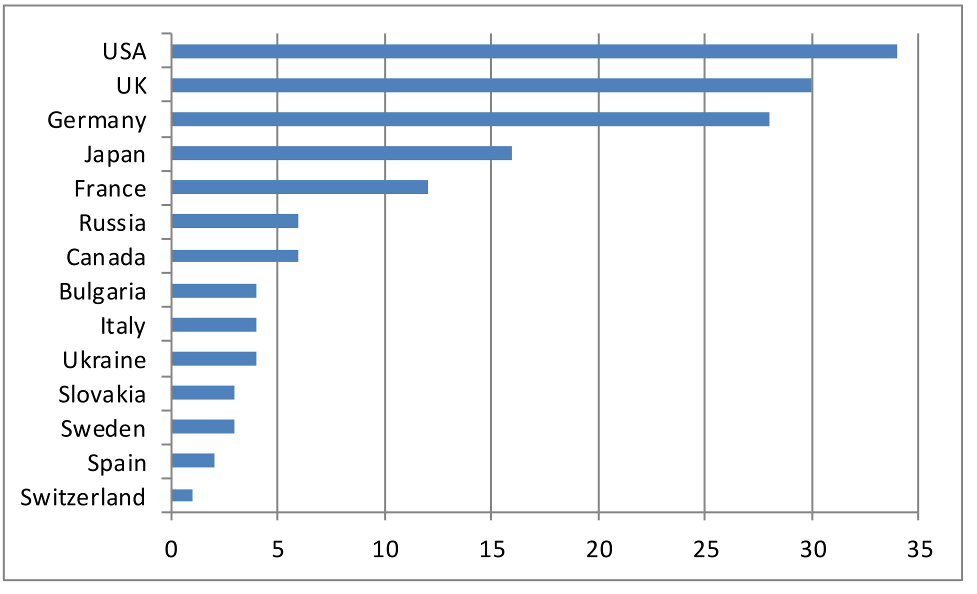
Source： *"Nuclear Power Reactors in the World"*, IAEA, 2017 Edition

MHI=Mitsubishi Heavy Industries、GE＝General Electric、WH＝Westinghouse

Decommissioning a Nuclear Power Plant

Decommissioning or Extending the Lifespan of NPPs

Figure 2 REACTORS PERMANENTLY SHUT DOWN BY COUNTRIES



Source： "Nuclear Power Reactors in the World", IAEA, 2017 Edition

A relatively new NPP is designed with a lifespan of 60 years. However, most old NPPs were engineered with an expected forty-year service life and must be decommissioned within this shorter lifespan. According to the IAEA, 446 reactors are operating around the world as of December 2016. An increasing number of NPPs in advanced countries are scheduled to or have already ceased operations (Figure 2). In Japan, 17 NPP units are scheduled to be decommissioned (Table 4). Germany decided to shut down all of its NPPs by 2022 in the aftermath of the Fukushima disaster, as mentioned above. The French Ecology Minister announced that EDF is likely to shut as many as 17 NPP units to fulfill the government's plans to reduce the share of nuclear energy from 72 percent to 50 percent by 2025.

Table 4 **REACTORS PERMANENTLY SHUT DOWN (31 DEC. 2016)**

Reactor Name	Type	Capacity (MW)	Operator	NSSS Supplier	Commercial Operation	Shut down
1 FUGEN ATR	HWLWR	148	JAEA	HITACHI	1979/03	2003/03
2 FUKUSHIMA-DAIICHI-1	BWR	439	TEPCO	GE/GETSC	1971/03	2011/05
3 FUKUSHIMA-DAIICHI-2	BWR	760	TEPCO	GE/T	1974/07	2011/05
4 FUKUSHIMA-DAIICHI-3	BWR	760	TEPCO	TOSHIBA	1976/03	2011/05
5 FUKUSHIMA-DAIICHI-4	BWR	760	TEPCO	HITACHI	1978/10	2011/05
6 FUKUSHIMA-DAIICHI-5	BWR	760	TEPCO	TOSHIBA	1978/04	2013/12
7 FUKUSHIMA-DAIICHI-6	BWR	1067	TEPCO	GE/T	1979/10	2013/12
8 GENKAI-1	PWR	529	KYUSHU	MHI	1975/10	2015/04
9 HAMAOKA-1	BWR	515	CHUBU	TOSHIBA	1976/03	2009/01
10 HAMAOKA-2	BWR	806	CHUBU	TOSHIBA	1978/11	2009/01
11 IKATA-1	PWR	538	SHIKOKU	MHI	1977/09	2016/05
12 JPDR	BWR	12	JAEA	GE	1965/03	1976/03
13 MIHAMA-1	PWR	320	KEPCO	WH	1970/11	2015/04
14 MIHAMA-2	PWR	470	KEPCO	MHI	1972/07	2015/04
15 SHIMANE-1	BWR	439	CHUGOKU	HITACHI	1974/03	2015/04
16 TOKAI-1	GCR	137	JAPCO	GEC	1966/07	1998/03
17 TSURUGA-1	BWR	340	JAPCO	GE	1970/03	2015/04

Source : *"Nuclear Power Reactors in the World", IAEA, 2017 Edition*

Plant operators have another option besides shutdown: to extend the lifespan of aging NPPs. EDF faces a 55 billion euro price tag to maintain aging plants and extend their lifespans. In Japan, the 2012 amended rules limit the lifespan of NPPs to 40 years, though the NRA can renew licenses for an additional 20 years at a time. Takahama Unit 1 and 2 and Mihama Unit 3 of Kansai Electric have been granted license renewals that extend their operating lives from the original 40 years to 60 years.

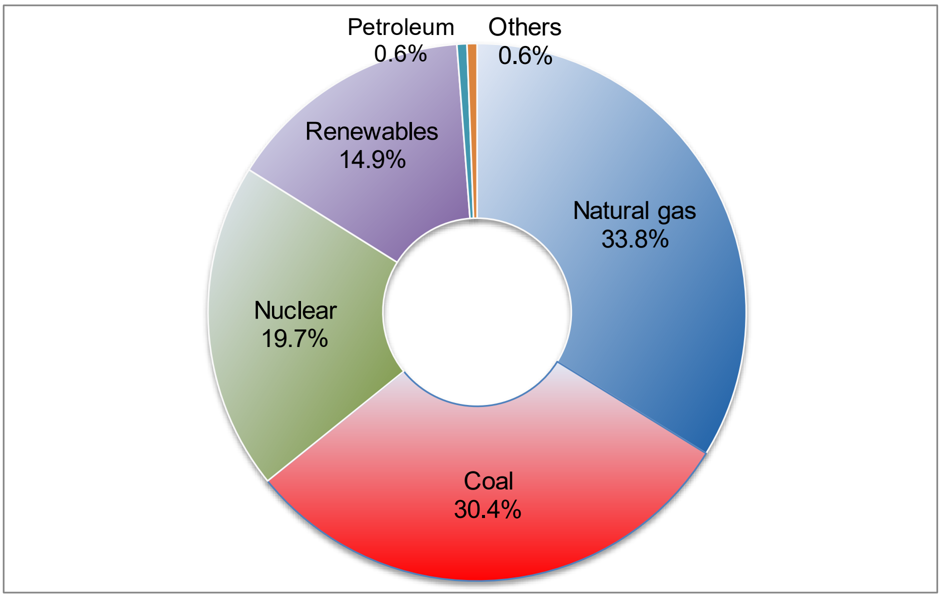
The Ministry of Economy, Trade and Industry (METI) cites the US NRC's reactor license renewal as justification for this extension.[6] The NRC issues licenses for commercial power reactors to operate for up to 40 years and bases its decisions to extend the lifespan of aging nuclear plants on decades of research. The license renewal process provides continued assurance that the same licensing standards for safety will be satisfied for the duration of the extended operation.

By the end of 2016, the NRC extended the licenses of 87 out of 99 reactors.

[6] "40-year rule of NPP lifespan and its issues", the METI, October 2016

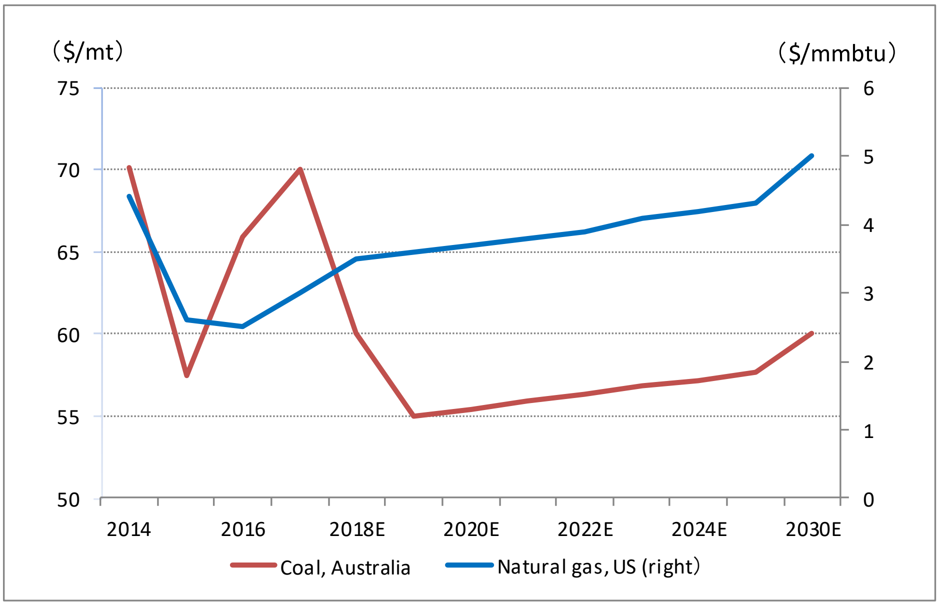
Davis-Besse Unit 1 extended its license from 2015 to 2037, requiring an investment of

Figure 3 ELECTRICITY GENERATION BY ENERGY SOURCE（US）



Source：US Energy Information Administration

Figure 4 WORLD BANK COMMODITIES PRICE FORECAST



Source：World Bank　E=World Bank estimates

almost US$1 billion from the plant owners. The NRC requires four to six years to review the case and approve the license renewal. NPP operators are under financial strain due to the increasing costs of maintaining and renewing NPPs. In the US, the main source of electricity is thermal power plants, relying primarily on natural gas. NPP management may decide to prolong the lifespan of aging plants or to shut them down, depending on the comparison between NPP production costs and the prospects of natural gas prices (Figure 4).

Decommissioning

Most of Japan's NPPs were built in the 1970s. Even if license renewals for these NPPs were granted, the plants are slated for decommissioning during the next three decades. In the US and UK, decommissioning starts as with an early design stage. It takes a long time to decommission fully: 20 years at the shortest and 60 years at the longest. In the US, before a nuclear power plant begins operations, the plant operator must provide a financial mechanism—for example, a guarantee from its parent company—to ensure there will be sufficient funding for the ultimate decommissioning of the facility. Each NPP operator must report to the NRC every two years on the status of its decommissioning funding for each reactor.[7]

Decommissioning Methods

NPP operators may choose from three decommissioning strategies: DECON (immediate cleanup), SAFSTOR (deferred dismantling), or ENTOMB. Under SAFSTOR, a nuclear facility is monitored and maintained in a condition that allows the radioactivity to decay while the property remains decontaminated. Meanwhile, SAFSTOR offers plant operators extra time to increase their decommissioning funds. The operator may also choose to adopt a combination of the first two choices, dismantling or decontaminating some parts of the facility in DECON while other parts are left in SAFSTOR. The decision may be based on factors, such as availability of waste disposal sites, that consider more than radioactive decay. In any case, decommissioning must be completed within 60 years. Under ENTOMB, radioactive contaminants are permanently encased on site in structurally sound materials such as concrete. ENTOMB is widely known as the method at the Chernobyl plant. To date, no NRC-licensed facility has requested this option.

---

[7] "Backgrounder on Decommissioning Nuclear Power Plants", US NRC

Decommissioning Costs

Actual decommissioning costs vary depending on the reactor type, the plant's size and design, and the decommissioning methods. In the US, the costs range from US$300 million to US$820 million per unit if DECON (immediate cleanup) is adopted, but on average run at US$500 million per unit. The costs can exceed expectations if the plant is more contaminated than previously thought. The extension of decommissioning schedules incurs additional costs for power utilities. Japanese power companies plan to decommission their plants in the next three decades. In the meantime, nuclear waste storage sites need to be finalized. Japan currently lacks sustainable nuclear waste solutions. Nuclear waste held in surface level storage poses great risks, leaving it to more exposed to floods, terrorism, earthquakes, climate change, and human error.

Future Outlook

Wave of Innovation

The development of Small Modular Reactors (SMRs) is increasingly competitive in the most nuclear-reliant countries. SMRs are defined as nuclear reactors with a 300 megawatt equivalent or less. The term “modular” refers to the fabrication of major components of the nuclear steam supply system (NSSS) in a factory environment, from which they are shipped to the point of use. Even though current, tailor-made NPPs incorporate factory-fabricated components (or modules) into their designs, a substantial amount of field work is still required to assemble components into an operational power plant.

Small modular reactors (SMRs) simplify the design. SMRs are designed with modular technology using module factory fabrication, pursuing the economies of series production and short construction times. SMRs are envisioned to require limited onsite preparation and substantially reduce the lengthy construction times that are typical of the larger units. Compared to larger NPPs, SMRs provide enhanced safety features alongside the economics and quality afforded by factory production. Modular components and factory fabrication can reduce construction costs and duration. Small units seem to be a more manageable investment than are larger units. Reactor units can be sub-grade (underground or underwater), providing more protection from natural (*e.g.* seismic or tsunami) or man-made (*e.g.* aircraft impact) hazards. In the US, many coal-fired units are expected to retire by 2025. SMRs are more adaptable to the brownfield sites of decommissioned coal-fired plants.

There is intense competition among the US, Russia, France, and China to develop SMRs. A 2009 assessment by the IAEA concluded that there could be ninety-six SMRs in operation around the world by 2030. Private companies and the US Department of Energy (DOE) have invested over US$1 billion in the development of SMRs, and more investment is expected through public-private partnerships to ensure that SMRs are a viable option by the mid-2020s. It seems that there is a flood of innovations to make nuclear reactors and facilities faster, better, and cheaper (FBC).

Safeguard the Lives and Safety of Citizens

As the worst nuclear accident since the Chernobyl disaster, the Fukushima accident shook the world and will never be forgotten. In the aftermath, no country continued to embrace the illusion that nuclear electricity generation is safe. Instead, regulatory bodies in the US and Europe reviewed emergency planning and training at NPPs to become more thoroughly prepared for an immediate response to a nuclear accident.

The cost competitiveness of each NPP needs to be examined in the context of the expense of decommissioning and/or extending its lifespan. At the dawn of NPPs, advanced countries including Japan emphasized building nuclear power plants to curb emissions of carbon dioxide and benefit from competitive production costs compared with thermal power plants. More than half a century later, many of the NPPs are now coming to the end of their operating lifespans. Decommissioning after an NPP’s service life ends is a hurdle for NPP operators. Nuclear regulatory bodies in the US and Europe demand an operator to incorporate decommissioning in the early design phase of new NPP plans. Additionally, these countries face the difficulty of finding a permanent nuclear waste disposal site, prompting a strong opposition from local residents. It is time for Japan to reconsider its vision for the future of its energy policy in light of the movement of other nuclear-reliant countries.

References

- 「最終報告書」東京電力福島原子力発電所における事故調査・検証委員会（内閣府） 2012 年 7 月 23 日
- “The Fukushima Daiichi Accident”, IAEA, 2015
- 「福島第一原発事故と 4 つの事故調査委員会」経済産業省調査室　2012 年 8 月 23 日
- 「オフサイトセンターが機能せず」NHK，2011 年 6 月 6 日
- 「新規性基準について」原子力規制委委員会
- 「原発の 40 年ルールとその課題」経済産業省　2016 年 10 月
- 「我が国における原子力発電所の現状」経済産業省・資源エネルギー庁
- “Nuclear Power in the USA” The World Nuclear Association, June 14, 2017
- “EDF FARN (Fast Action Force in case of Nuclear Accident) — Focus on Radiation Protection of Workers”, IAEA
- “Backgrounder on Emergency Preparedness at Nuclear Power Plants”, U. S. NRC
- “Backgrounder on Decommissioning Nuclear Power Plants”, U.S. NRC
- “Backgrounder on Reactor License Renewal”, U.S. NRC
- “Status of the Decommissioning of Nuclear Facilities around the World”, IAEA, 2004
- “Costs of Decommissioning Nuclear Power Plants”, OECD, 2016
- "Nuclear Power Reactors in the World", IAEA, 2017 Edition
- “Electricity generation by energy source”, U.S. Energy Information Administration
- “World Bank Commodities Price Forecast”, released April 2017
- “Benefits of Small Modular Reactors (SMRs)”, Office of Nuclear Energy, US Department of Energy
- “Small Nuclear Power Reactors”, World Nuclear Organization, updated July 2017
- “Advances in Small Modular Reactor Technology Developments”, IAEA ARIS, September 2014