

# **U.S., European and South Korean Efforts to Raise Nuclear Power Plant Utility factors**

## **-- What Japan Should Learn from These Efforts -- ♦**

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### **Executive Summary**

Japan has recently been urged to implement measures to increase utility factors for nuclear power plants in order to address energy security and greenhouse gas emission cuts. The average utility factor for Japan's nuclear power plants in 2009 rose from 58.0% in 2008 to 64.7%, still below levels in other major nuclear power generation countries including South Korea and the United States. Some major foreign nuclear power generation countries have kept their utility factors for nuclear plants at high levels at or above 90% since 1990, while others including the United States and South Korea have raised their respective factors since 2000 following the 1990s when their factors were close to the Japanese level. The latter group made ambitious efforts to raise these factors.

Specifically, the United States has shortened planned outage time for periodic maintenance and repairs of nuclear power plants year by year as the nuclear industry and the Nuclear Regulatory Commission have tried to take advantage of risk information for optimizing instrument-by-instrument inspection frequencies and for expanding the scope for preventive maintenance during operation (PMO). Unplanned outage time to solve nuclear plant instrument issue has also been shortened substantially thanks to the reduction of the trouble incidence rate and shorter repair and restart times. The United States has also tried to lengthen operational cycle periods, adopting 18-to-24-month cycles for many plants. In a bid to shorten plant outage time, South Korea has promoted not only the improvement of operational skills and the introduction of sophisticated instruments but also the enhancement of maintenance know-how including the reform of maintenance and repair processes and the improvement of inspection work steps.

Overseas cases for the restart of nuclear plant operations from an unplanned plant outage include those in multiple countries in which thorough investigations into minor troubles or measures for their future prevention were not necessarily required for restarting plants. As far as our analysis generally indicates, local governments are not authorized to examine nuclear plant safety in foreign countries. An apparent dominant view in foreign countries is that it would be reasonable to utilize infrastructure as much as possible once safety regulation authorities conclude that a plant restart would have no safety problems.

As existing nuclear power plants have been required to be effectively utilized under the top priority on safety, some countries have continuously achieved high utility factors for nuclear plants, between 85% and 95% over 10 to 20 years while meeting safety standards at the same level as in Japan. In considering specific measures to effectively utilize existing nuclear reactors, Japan should take full account of these overseas efforts and promote discussions on overall Japanese nuclear energy and safety approaches.

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## **1. Introduction**

### **1-1 Objective**

From the viewpoints of energy security and greenhouse gas emission cuts, nuclear power plants that emit no carbon during their electricity generation are positioned as quasi-domestic energy resources and great hopes are placed on their maximum utilization. But low utility factors for Japanese nuclear plants have recently been viewed as problematic. The average utility factor for nuclear plants in Japan in 2009 stood at 64.7%, rising from 58.0% in the previous year when the Niigata Chuetsu-oki Earthquake seriously affected nuclear power plant operations. But the 2009 factor in Japan was still lower than in major countries with excellent nuclear power generation performances, including South Korea with such factor at 93%, the United States with 91% and Finland with 93%, all in 2008. Meanwhile, the frequency of emergency plant shutdowns on troubles in Japan has been lower than other countries as Japan has continued the development of technologies for operations of light-water reactors since its introduction of commercial nuclear power plants.

Despite higher safety technologies and fewer troubles in Japan, its present utility factor is lower than other countries. In considering measures to improve the utility factor, we must first analyze reasons why the factor has been low. Therefore, we must analyze causes behind the slack utility factor by comparing and considering objective data of utility factors for nuclear plants in Japan and other countries. While comparing and considering the data, we must also consider the feasibility of measures contributing to raising the factor in Japan by analyzing overseas efforts and challenges.

Given the above, in order to contribute to the consideration of specific measures to effectively utilize nuclear power plants, this study collects overseas efforts, specific information on cases regarding causes behind slack utility factors, measures their improvements, analyzes problems with the effective utilization of existing reactors and recommends specific measures.

### **1-2 Scope of analysis**

This study focuses on:

- a) the United States and South Korea as representative countries that have had excellent technological capacity and experiences for nuclear energy and boasted excellent nuclear plant operations and very high utility factors,
- b) France and Germany as major nuclear power generation countries that feature less excellent plant operations than the United States and South Korea but more excellent operations than Japan and have continuously improved such operations, and
- c) Sweden that depends heavily on nuclear energy for electricity supply and has achieved relatively better plant operations.

Particularly, the United States and South Korea have promoted various efforts to improve utility factors, providing great implications for Japan's future efforts.

Specifically, this study analyzes operational cycle periods, plant outage time by cause, efforts to shorten periodic inspections and cases for restart of plant operations as elements affecting utility factors in these countries. The study then considers these causes in a bid to understand some implications about the present situation of Japanese nuclear plants and future measures to improve the utility factor.

## **2. Analysis and consideration**

This chapter compares changes in utility factors for nuclear plants, operational cycle periods, and preventive maintenance during operation (PMO) exerting great influences on plant outage time in these countries. Based on the comparison, outage time is reviewed by cause and cases where nuclear plants were restarted after unplanned outage in these countries. Furthermore, a deeper look is taken into the characteristics of the relevant efforts made by the United States and South Korea that have recently achieved high utility factors.

## 2-1 International comparison

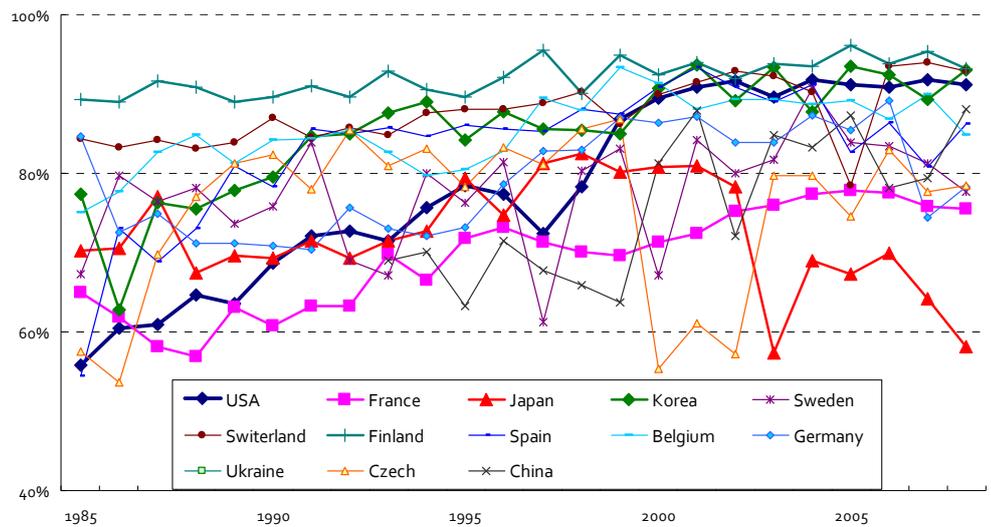
The following is a comparison of conditions of nuclear power plants in these countries. We compiled countrywide utility factors for nuclear plants and operational cycles in these countries as representative indicators for a comparative analysis and reviewed their safety regulations.

### 2-1-1 Changes in utility factors

Figure 2-1 indicates chronological changes in average utility factors for nuclear plants in major countries. Specifically, such utility factor changes from 1985 to the present are provided for the United States, France, Japan, South Korea, Sweden, Switzerland, Finland, Spain, Germany, Ukraine, the Czech Republic and China.

Japan's utility factor for nuclear plants continued on an upward trend until 2000, plunged around 2005, and has remained slack due to the Niigata Chuetsu-oki Earthquake and other incidents. Meanwhile, the United States and other countries with upward trends indicate the results of their various efforts to improve these factors. Countries that have kept utility factors at high levels feature not only excellent plant operation skills but also practices and organizational climates for the high factors. Some countries such as Sweden, China and the Czech Republic feature wild fluctuations in utility factors. They have their respective reasons for such fluctuations. One common reason for these countries other than Japan is that each of them has a limited number of plants. A long-term outage for one plant can reduce the average utility factor substantially. This is a major reason for unstable utility factors in these countries.

Figure 2-1 Chronological Changes in average utility factors in major countries



Source: Power Reactor Information System (PRIS), the International Atomic Energy Agency, 2009

Different from these countries, however, Japan has had as many as 54 nuclear plants (until 2009), therefore its slack utility factor in recent years is estimated to have emerged from a combination of some structural factors, rather than special factors for one or two plants. The following are apparently estimated as incidents where multiple plants were subjected to long outages:

- 2002-2003: Tokyo Electric Power Co. was forced to shut down all of its nuclear plants due to inappropriate plant operation reports and safety regulation violations.
- 2005: Tohoku Electric Power Co. shut down all plants at its Onagawa nuclear power station due to an earthquake.
- 2007-2009: Tokyo Electric Power shut down all plants at its Kashiwazaki-Kariwa nuclear power station due to an earthquake.

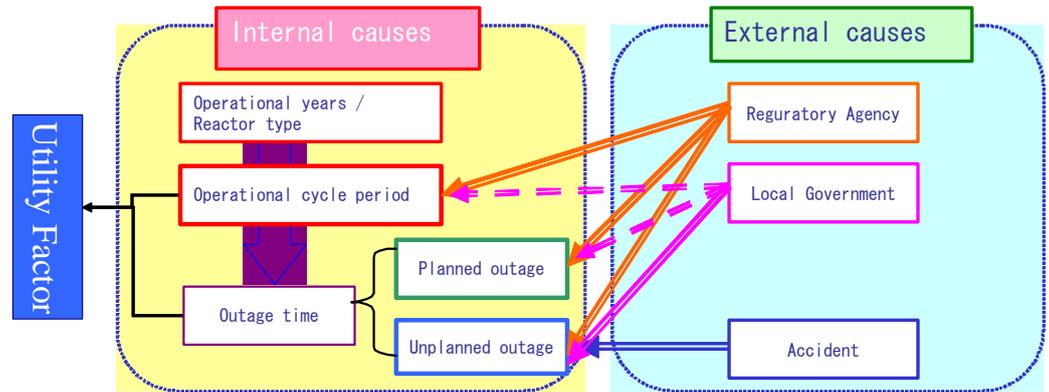
These incidents, however, cannot explain the long-term slackness of the utility factor for Japan's 54 nuclear plants with a total capacity of 47 GW (at the end of 2009). In addition to those shut downs on further reasons, several more have always been left out of operation for various reasons other than earthquakes or common safety problems. We must thus analyze factors that have led Japan to feature a remarkably lower utility factor for nuclear plants than other major countries with similar technological levels.

### 2-1-2 Elements affecting utility factors<sup>1</sup>

The nuclear plant utility factor depends on operational cycle periods and outage time. Outage time includes planned outage hours for periodic and other inspections and unplanned ones resulting from accidents, depending on the years of operation for specific plants and plant types. Cited as external causes affecting operational cycle periods and outage time that determine the utility factor are safety regulations, local governments and disasters including earthquakes. These elements also eventually affect the utility factor. The relationships between elements affecting the utility factor are illustrated below:

The following analyzes mainly “operational years and reactor types,” “the operational cycle period,” “planned outage time” and “unplanned outage time” that can be analyzed quantitatively and objectively among the elements affecting the utility factor. As national macro information, we first analyzed

Figure 2-2 Causes affecting to the utility factor



“operational years and reactor types,” “the operational cycle period,” and “preventive maintenance during operation (PMO)” as an element affecting planned outage time. Sections from 2-2 analyze “outage time by cause” and “cases for restart of plant operations from unplanned outage” as micro information regarding country-specific cases.

First, macro information analysis findings are given below:

### 2-1-3 Operational years, reactor types and the utility factor

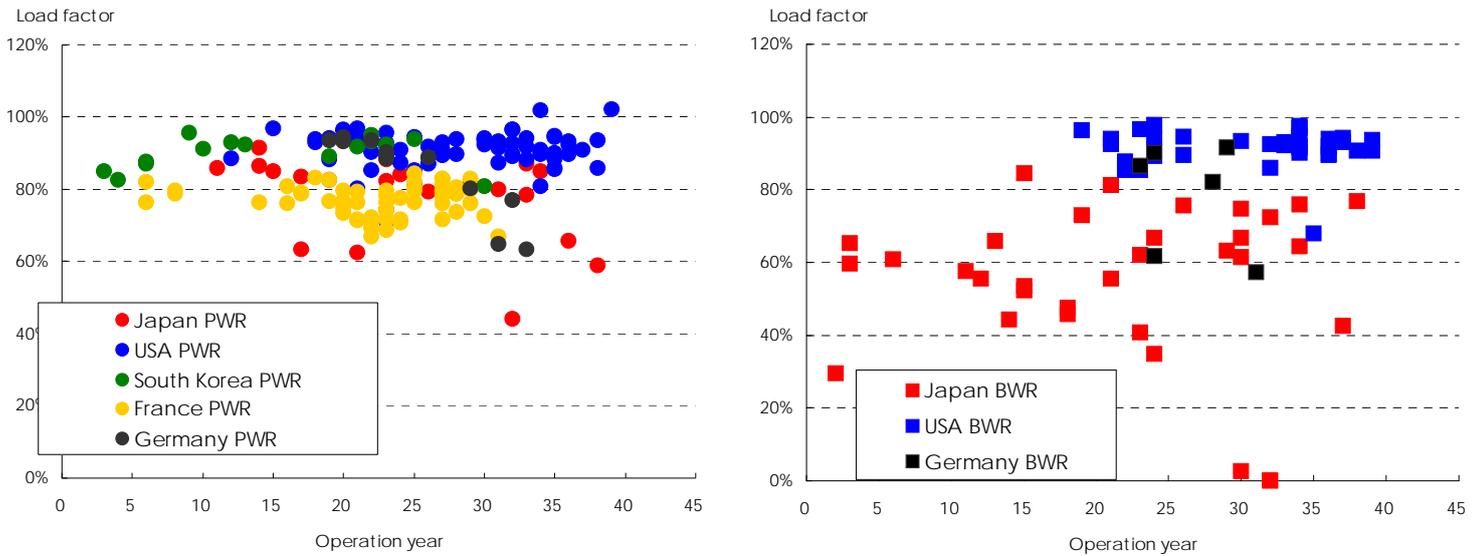
The impact of the number of operational years, among the causes illustrated in Figure 2-2 as affecting the utility factor, has been cited for a hypothesis explaining the low utility factor for nuclear power plants in Japan. This means that Japan introduced nuclear plants relatively earlier and now has relatively older plants, forcing periodic inspections to take more time. Another hypothesis is that Japan has two reactor types – the PWR (pressurized water reactor) and BWR (boiling water reactor) and features a lower utility factor than France that has introduced a single type of reactor.

The following examines the hypothesis about the relationship between the number of operational years and reactor types, and the utility factor based on the IAEA’s nuclear plant operation database:

Figure 2-3 indicates the relationships between the number of operational years and the utility factor on a plant-by-plant basis for nuclear plants in Japan, the United States, France, Germany and South Korea. A relationship in which the utility factor declines on aging of plants is not found in the United States or France. The PWR-BWR comparison does not indicate that the utility factor differs depending on reactor types. In Germany, there is little gap between the reactor types while the number of operational years has some correlation with the utility factor. This is because Germany intentionally suspends operations of older plants as its anti-nuclear law restricts total power generation output. In Japan, plants subjected to prolonged outage over recent years have been BWRs, resulting in a lower utility factor for BWRs rather than for PWRs. As for the hypothesis on the adoption of the two reactor types, the U.S. and German cases do not indicate that the presence of the two types has led to a slack utility factor.

<sup>1</sup> Strictly, outage time is used for defining the operation factor. The operation factor is defined as the ratio of the number of hours that the unit or plant was online to the annual total of 8,760 hours. The utility factor is defined as the ratio of the energy generation (net) during a given time period to the reference energy generation (net) during the same time period. Attention must be paid to the difference between the operation factor and the utility factor. But the gap is roughly limited to around 5%, allowing key points in this study to remain unaffected. Therefore, this study refrains from separating the two measures.

Figure 2-3 Operational years, reactor types and the utility factor (left:PWR. Right:BWR)



Source: Power Reactor Information System (PRIS), the International Atomic Energy Agency, 2009

Any simple conclusion is difficult to make about the relationship between the number of operational years and reactor types, and the utility factor as national conditions differ. As far as the above-cited hypothesis is concerned, however, there is not any clear relationship between the number of operational years and reactor types, and the utility factor. The hypothesis cannot satisfactorily explain why the utility factor for nuclear plants in Japan has been lower than in foreign countries.

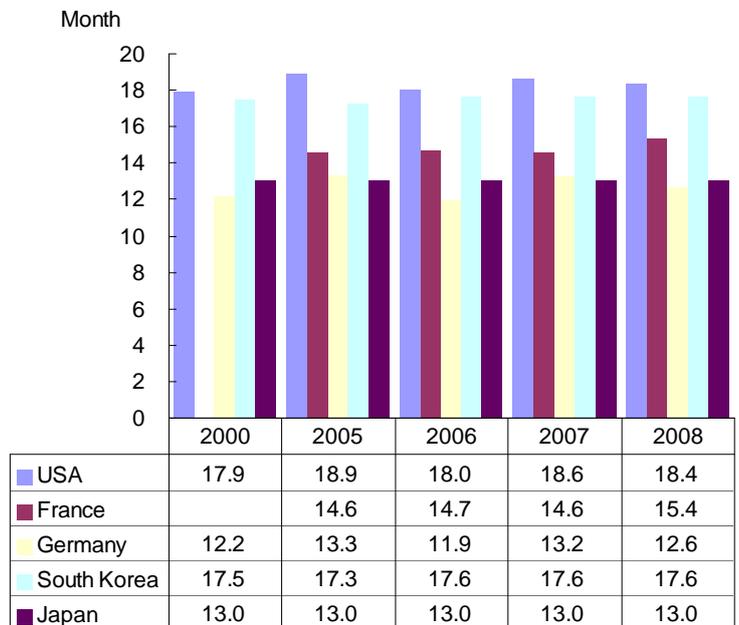
**2-1-4 Operational cycle period**

Figure 2-4 indicates average operational cycle periods for nuclear power plants in Japan, the United States, France, Germany and South Korea.

The figure shows that the average period stands at about 18 months for the United States, about 15 months for France, about 13 months for Germany, about 17.5 months for South Korea and about 13 months for Japan. National chronological trends indicate that operational cycle periods tend to be extended over a long term.

Against this operational cycle period data, the utility factor stood at about 91% in the United States in 2008, at about 76% in France, 78% in Germany, 93% in South Korea and 58% in Japan. As explained later, the operational cycle period is significantly proportionate to the utility factor.

Figure 2-4 Country-by-country average operational cycle period



Source: "World Nuclear Power Plants 2010", Japan Atomic Industrial Forum, Inc.

**2-1-5 Country-by-country policies on PMO**

As safety systems above certain levels must be online during plant operation, the inspection of maintenance on important safety systems is principally conducted during plant outages. If these systems are allowed to go offline for the maintenance during plant operation in a manner to meet safety requirements or keep from affecting safety, inspection steps during a plant outage may be reduced to improve the utility factor. This point has been discussed since the 1990s and such measures have been provided in each country’s safety regulations. Therefore, safety regulations are an element to determine planned outage time (mainly for inspection, repairs and refueling) that greatly influences the utility factor.

Particularly, regulations on the types and numbers of safety systems for inspection during plant outage or offline inspection during plant operation and their enforcement are directly linked to planned outage time. Therefore, differences between countries in such regulations are important. Here, we compare country-by-country measures in accordance with a report<sup>2</sup> compiled in August 2001 by the OECD NEA<sup>3</sup>. As some countries began to implement the PMO one after another, the NEA compared relevant regulations of such countries and made the report. Table 2-1 indicates a comparison of PMO<sup>4</sup> regulations and implementation policies, and present conditions.

**Table 2-1 Comparison of policies and status on PMO by country**

	Belgium	Czech Republic	Finland	France	Germany	Spain	Sweden	Switzerland	USA	Japan
National policy for inspection and maintenance during operation	In principle, PMO is not allowed.	Allowed if limits and conditions approved by regulatory body	Allowed only by a special permission of regulatory body. AOT is not allowed to be used in PMO.	No specific rule. Allowed to use AOT in the TS.	Regulatory authority gives a recommendation which allows PMO.	The maintenance rule allows the licensee to use AOT in the TS.	Allowed only in systems and components specified in TS.	No specific rule. Allowed to use AOT in the TS.	Licensee is permitted to perform PMO after a risk assessment.	Not allowed practicing periodical inspection during operation in principle. AOT is specified in the TS.
Licensee’s plan to further apply to maintenance during operation	None	None	Already extensively performed	Licensee provides a risk analysis.	Licensee performs PMO along the condition	Going to be carry out soon	Maybe in the long run.	Already taken in 4 trains in the NPP	Licensee will perform increasing amounts of PMO	Licensees are studying the application.
Safety Evaluation	None	Licensee evaluates and regulatory body approves	Licensee evaluates TS and regulatory body approves it.	Licensee evaluates TS and regulatory body approves it.	Licensee and Technical Inspection Agency evaluates TS and TUV approves it.	Licensee evaluates maintenance rules and regulatory body reviews it.	Licensee evaluates TS and regulatory body approves it.	Regulatory body evaluates the safety.	Licensee evaluates TS and regulatory body approves it.	Licensee evaluates TS and regulatory body approves it.
Maximum AOT	In the TS.	Defined in limits and conditions	Based on probabilistic analysis	In the TS	In the TS	In the TS	In the TS	None	In the TS	In the TS
Regulatory procedure	None	Regulatory inspection of periodical testing	No written regulatory procedure but internal guide in the regulatory body	None	Licensees keep TS based on the recommendation by regulatory body	Inspection manual	Inspection process	The existing rules and regulations are applied.	Reactor oversight program	None
Methods of verification for licensee’s performance	Inspection programme, including review of documents	Regular (daily) inspections by site inspector	Resident inspectors carry out weekly inspections	Periodic tests	Independent experts are on the site on behalf of the regulatory authority.	The regulatory body monitors maintenance activities by routine inspection and assesses the licensee’s report on PMO	Normal inspection process	Normal inspection process	Routine scrutiny by resident inspectors verify it.	Checking licensee’s performance by witness and document review

Source: "Inspection of Maintenance on Safety Systems During NPP Operations “ August 2001, OECD/NEA

Note: AOT: Allowed outage time, TS: Technical specifications

The table shows that Finland and Switzerland introduced the PMO before the comparison and analysis were conducted in 2000. While Belgium has not approved the PMO in principle, the others had plans to introduce the PMO under certain conditions, irrespective of whether the PMO was actually introduced in 2000. They were allowing the PMO to be implemented as far as it meets technical specifications or safety standards including safety regulation durations. In fact, when the report was compiled, the United States took advantage of risk information to expand the scope of safety systems subject to the PMO, contributing to shortening U.S. planned plant outage time.

<sup>2</sup> "Inspection of Maintenance on Safety Systems During NPP Operation,” Working Group on Inspection and Practices, Committee on Nuclear Regulatory Activities, Nuclear Energy Agency, August 2001

<sup>3</sup> The Nuclear Energy Agency (NEA) is an organization created within the OECD.

<sup>4</sup> The PMO may be considered similar to Online Maintenance (OLM) or In-Service Inspection (ISI) as seen in Japan and the United States.

The above indicates that the PMO is a leading contributor to improving the utility factor for nuclear power plants and allowing such countries as the United States and Finland to achieve higher utility factors. When the report was compiled, nuclear plant licensees and regulators in Japan were conducting preliminary research on the PMO. Then, Japan’s conditions for the PMO (including safety-securing methods and how to certificate licensees for the PMO) were basically similar to those in foreign countries. This means that Japan was fully aware of overseas information about the PMO idea and relevant conditions while failing to take steps to introduce the PMO. As of April 2010, Japan just began to consider introducing the PMO.

**2-2 Plant outage time by cause and cases for restart of plant operations from unplanned outage**

Differences between utility factors for nuclear power plants can be traced to plant by plant differences of outage time. Based on the IAEA’s annual “Operating Experience with Nuclear Power Stations in Member States,” this section classifies average outage time for nuclear plants by cause in each country. The IAEA divides unplanned outage, as given in Figure 2-2, into two groups – unplanned outage caused by external causes and other unplanned outage. The agency thus classifies causes for nuclear plant outage into the following three groups:

- Planned outage causes: Outage maintenance and repairs that are controllable within plant maintenance and repair plans (periodic inspection, etc.)
- Unplanned outage causes: Causes for unplanned outages that are controllable (system troubles, etc.)
- External causes: Outage causes out of control (earthquakes, etc.)

The following are nuclear plant outage time by cause and cases for restart of plant operations from unplanned outage<sup>5</sup>.

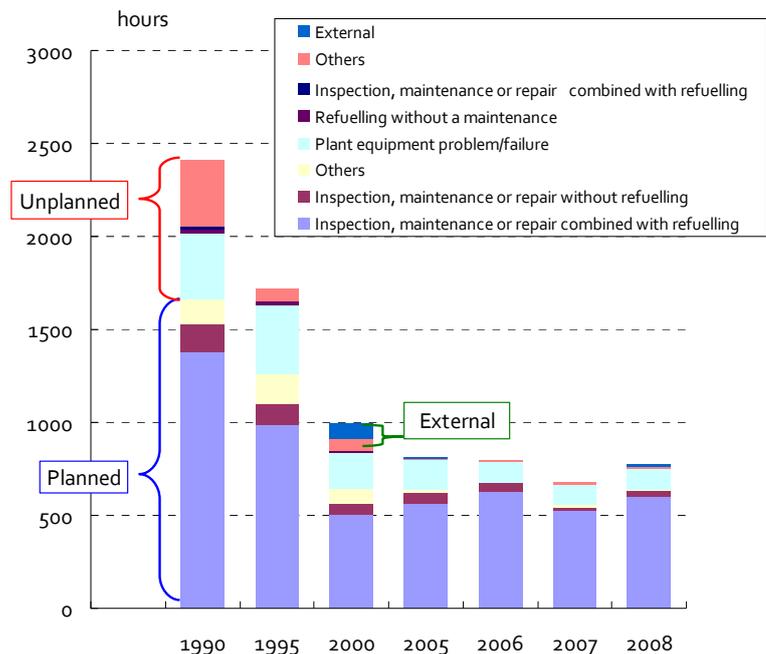
**2-2-1 U.S.**

**(a) Outage time by cause**

Annual nuclear plant outage hours have persistently declined after peaking at 2,417 hours in 1990 as shown in Figure 2-5. Continuous efforts of the NRC and other relevant organizations might have contributed much to the decline.

Both planned and unplanned outages time decreased. This indicates that improvements for efficient operations of existing nuclear power plants have made progress in all areas through the reduction of periodic inspection hours, of frequencies for various troubles and of hours for restart from troubles. As noted later, the risk information-based rationalization of

Figure 2-5 Average outage time by cause in the US



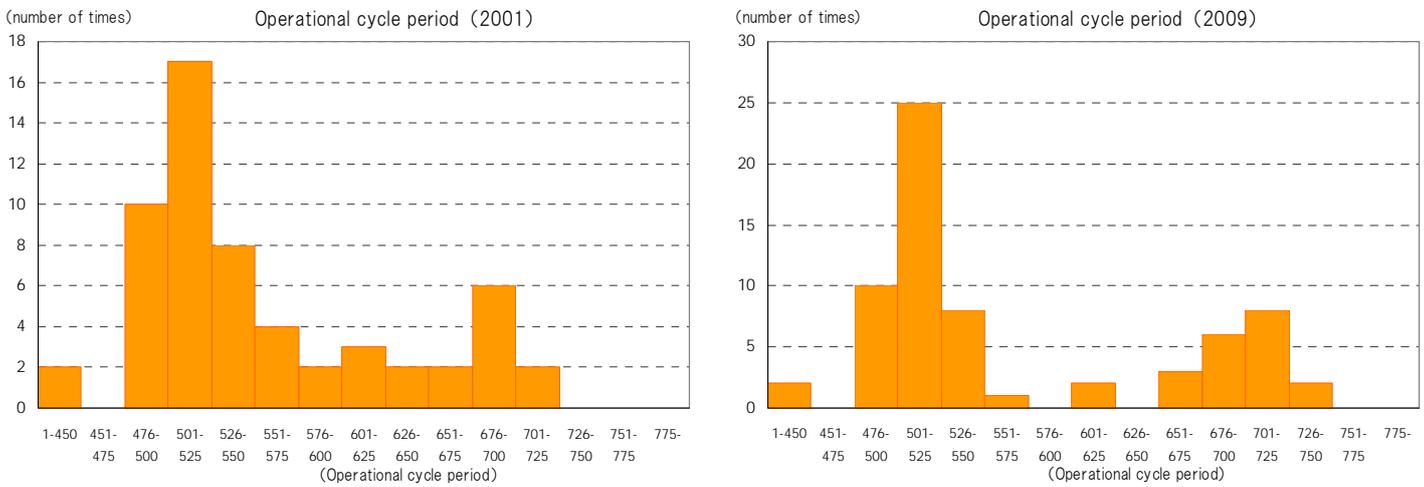
inspection frequencies for each system, the expansion of the online maintenance or PMO scope and the extension of operational cycle periods have reduced annual outage hours for periodic maintenance and repairs, boosting the overall utility factor for nuclear power plants. Annual unplanned outages triggered by external factors including troubles of systems in plants and grid voltage drops have been reduced substantially, indicating that the trouble frequency has been falling along with plant maintenance, repair and restart hours. Thanks to the substantial decline in plant outage hours, the utility factor for U.S. nuclear power plants rose from the same level as the Japanese one in the 1990s to one of the highest in the world in 2008.

<sup>5</sup> Data include those gained through interviews for this study.

**(b) Operational cycle period**

This section computes and compiles actual operational cycle periods and outage time for U.S. nuclear plants, based on NRC-published data<sup>6</sup>. Figure 2-6 indicates changes in actual operational cycle periods for U.S. nuclear plants.

Figure 2-6 Changes in estimated operational cycle periods in 2001 and in 2009

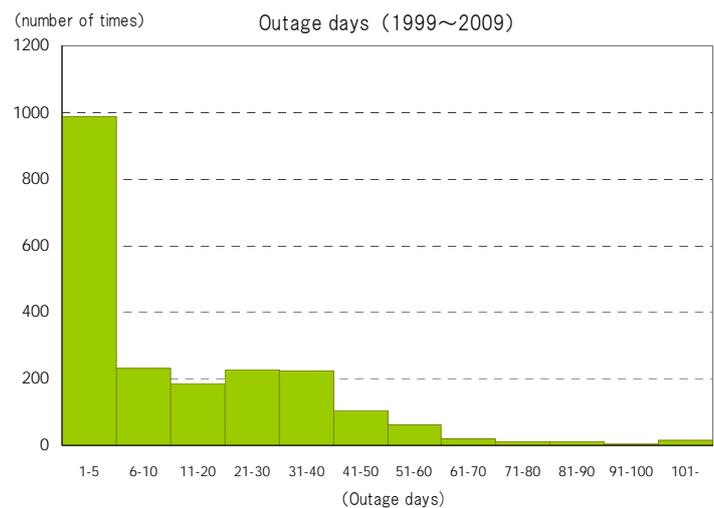


In 2001, the most frequent operational cycle period was 501-525 days (about 17 months), followed by 676-700 days (about 23 months). Operation controls then might have been based mainly on an 18-month cycle. Nuclear plants might have been operated for a cycle of 18 or 24 months. In 2009, the most frequent operational cycle period was 501-525 days (about 17 months), followed by 701-725 days (about 24 months). From 2001, cycle durations between 18 and 24 months declined and 650-day or longer durations increased. This indicates longer planned operational cycles.

The actual operational cycle period exceeding 726 days was seen in 2009. This is worthy of attention. Among nuclear plants that ended operational cycles in the year, the Brownsferry-2 achieved the longest operational cycle period at 740 days from April 17, 2007, to April 25, 2009, exceeding two years. During the cycle duration, the plant posted four outages totaling 16 days – one three-day outage, two four-day outages and one five-day outage, achieving very good performance.

Figure 2-7 indicates the numbers of outage days between 1999 and 2009. Outages were dominantly limited to the one-to-five-day range. Most of the other outages were limited to 60 or fewer days. The numbers of days of outages, including those for planned and unplanned repairs as well as periodic inspections and refueling, were mostly limited to two months or less. Few cases existed for longer outages. This may be because nuclear plant operators have focused on the repair and replacement procedures regarding only the specified problems cited as causes for unplanned outages, and have restarted plants promptly after the elimination of such causes, as explained later in the section for “cases for restart of plant operations from unplanned outage.”

Figure 2-7 Frequency of outage days between 1999 and 2009



An analysis of actual U.S. nuclear plant operations as given above indicates the following three points:

- Longer operational cycles were implemented from 2001 to 2009 (extension of operational cycle periods)

<sup>6</sup> <http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/>

- Among outages including those for periodic inspections, few outages lasted for 70 or more days (reduction of periodic inspection periods)
- Plants are restarted in less than five days after small troubles (reduction of outages before restart of operations)

**(c) Conditions for restarting and cases for restart from unplanned outage**

In the United States, nuclear plant licensees voluntarily take countermeasures for minor troubles that end swiftly and are basically responsible for deciding whether to restart plants after trouble-caused outage (responsible for decisions on operability and countermeasures). These responses of licensees remain under observation by resident inspectors through their daily inspection. If problems are significant and complicated or if plant performance declines including repeated problems, the NRC confirms licensees’ countermeasures and issues confirmatory action letters (CALs) to licensees. The CALs specify the NRC’s agreements with relevant plant operators. Through inspection, the NRC confirms plant operators’ completion of measures specified in the CALs. At such level, operators voluntarily shut down plants in most cases. The completion of CAL-specified measures may thus become a condition for restarting plants in most cases.

If a licensee’s performances decline remarkably and a special oversight is required, or if a plant operator’s performances decline to intolerable levels and the NRC issues a plant shutdown order, an oversight may be conducted under the IMC 0350<sup>7</sup> “Oversight of Reactor Facilities in a Shutdown Condition due to Significant Performance and/or Operational Concerns.” In such case, an NRC oversight panel prepares a restart checklist and oversees progress in corrective measures by a licensee. If the panel concludes the plant in question as prepared for restarting under the restart checklist, the restart may be implemented upon approval by the Office of Nuclear Reactor Regulation (NRR) director and the regional administrator.

As restarting originates mostly from safety problems as noted above, the NRC as the only U.S. organization responsible for nuclear plant safety is designed to inspect and oversee licensees toward restarting. No other organizations intervene in the process in principle.

The Perry-1 case (2009)<sup>8</sup> is given below as a restarting case in accordance with the above plant restart procedures after an unplanned outage:

The Perry-1 was manually shut down due to an emergency service water pump trip on October 15, 2009. This was because the plant had to be shut down for inspection due to the expected repair time exceeding the time required in the Technical Specification (TS). Later, inspection was conducted with alternative systems prepared. On October 21, the sixth day after the shutdown, the pump’s repair was completed. The plant was restarted on November 2 and achieved its full power operation on November 7. The NRC then concluded that the trip was caused by a defect in the manufacturing process for the power supply cable of the pump. Table 2-2 outlines steps and output between the shutdown and restart of the nuclear plant, based on the NRC event report.

Table 2-2 Chronology of the restarting process at Perry-1 in 2009

2009	October	15	The emergency service water pump B tripped and the plant shutdown was commenced
		16	Plant shutdown was completed by manual actuation
		19	The plant remained in Mode 3 until 4:29 and entered Mode 4
		21	Alternative method of decay heat removal was established
	November	28	Repairs and testing are over and declared operable at 13:58
		2	Restarting procedures got started
		7	The plant reached to full power

Source: NRC licensee event report, L-09-331

<sup>7</sup> The IMC-0350 means the NRC Inspection Manual’s Chapter 0350.

<sup>8</sup> Licensee Event Report from NRC website at <https://nrcoe.inel.gov/secure/lerssearch/index.cfm?fuseaction=SearchResults.showLER&doc=4402009003R00.pdf>

In the case of Peach Bottom-3<sup>9</sup> in 2009, the plant also restarted within a week after an unplanned shutdown. In every case of these, the safety systems remained undamaged, requiring no repair for the reactors and other key systems and that might have enabled a quick restart after their respective shutdowns.

In many cases in the US, they concentrate on specific problems for minor unplanned shutdowns, refer to the similar past cases, promptly implement repair steps, conclude that the plants in question would not have to remain in outage any more, and restart these plants within a short period.

**(d) Efforts to improve the utility factor**

As explained above, the United States has implemented “the extension of plant operation cycle period,” “the reduction of plant outage time for refueling” and “the curtailment of unplanned outage time” to improve the utility factor. As a result, the country has gradually achieved improvement of the plant equipment reliability and the utility factor. The NRC’s aggressive efforts to improve costs and efficiency amid the deregulation trend have also been cited as a factor behind the successful improvement<sup>10</sup>.

Another important factor is a combination of industrial and governmental efforts including the industry sector’s unified messages from Nuclear Energy Institute (NEI) and NEI’s coordination with NRC. And also nuclear plant licensees have sought to shorten outage time through extension of AOT (allowed outage time) and the adoption of PMO taking advantage of the risk information, while the Institute of Nuclear Power Operations (INPO) has promoted analyses, evaluation and sharing of nuclear plant operation performance and relevant technical support.

The regulators also have promoted an inspection system reform reflecting results of audit by the Office of Inspector General (OIG), the dissemination of scientific and rational safety regulations incorporating probabilistic risk assessment, the improvement of operation and maintenance left to the private sector’s voluntary efforts, and the development of specific standards and other efforts that have been consistent with the industry sector trends. For example, the NRC has gradually expanded the scope of PMO through the development of risk-reduction methods. In line with revisions in 2000 to the 10CFR50.65 “Requirement for monitoring the effectiveness of maintenance on nuclear power plants (maintenance regulations),” NRC has obliged plant licensees to evaluate safety before the maintenance activity and enabled them effectively to conduct online maintenance on multiple systems<sup>11</sup>.

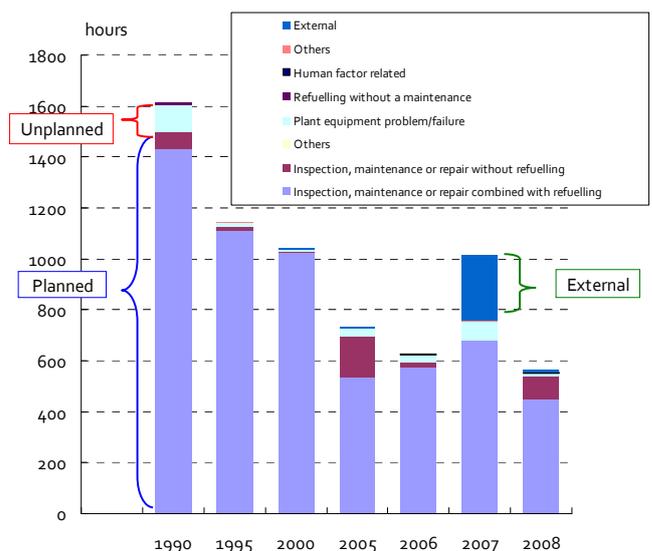
In this way, the United States has spearheaded efforts to continuously and gradually improve the utility factor for nuclear power plants. The present high performances of nuclear power plants are comprehensive results of the past pioneering efforts.

**2-2-2 South Korea**

**(a) Outage time by cause**

The average outage time in South Korea has been substantially shortened, roughly halved from 1990 to 2006. In 2007, Kori-1 was shut down for a long term due to a policy debate over whether the plant should be scrapped, affecting the average outage time for South Korean nuclear plants. Generally, however, the average outage time for South Korean nuclear plants has been

Figure 2-8 Average outage time by cause in South Korea



<sup>9</sup> The plant’s output declined on trouble with a main transformer on January 19, 2009. In response, the plant was shut down on January 19 for the replacement of the transformer and put into operation again on January 30.

<sup>10</sup> Eiji Yamada et al., “Reviving U.S. Nuclear Industry – Improvement toward Regulations based on Scientific Reasonability,” Kiho Energy Sogo Kogaku (Applied Energy Quarterly) Vol. 129, No. 2 (2006)

<sup>11</sup> Second meeting of the Working Group on Operation Management, Nuclear Reactor Safety Subcommittee, Nuclear and Industrial Safety Subcommittee, Advisory Committee for Natural Resources and Energy, July 24, 2009

shorter. Particularly, planned outage time has been shorter and there has been little unplanned outage. Periodic inspections have been completed quickly without troubles, bringing about very high nuclear plant operation performances.

South Korea has set the goal of “one cycle trouble free (OCTF)” operations for higher efficiency and achieved 67 OCTF runs by the end of 2008. Details are available on the website of Korea Hydro & Nuclear Power (KHNP) <sup>12</sup>. The following discusses details of efforts to shorten planned outage time and cases for restart from unplanned outage, extracting and assessing causes behind the high utility factor for South Korean nuclear plants.

**(b) Efforts to shorten outage time<sup>13</sup>**

South Korea has continuously tried to improve the utility factor for nuclear plants, achieving a shorter average outage time than Europe and the United States. Causes behind the shorter outage include “the improvement of maintenance and operation know-how,” “the improvement of systems,” and “the development of the outage management process.” Table 2-3 indicates the shortest outage records in South Korea and at the world’s representative nuclear plants. In a bid to further improve the utility factor for nuclear plants, KHNP has analyzed actual performances of nuclear plants with the shortest outage records and fed analysis findings back into its business operations.

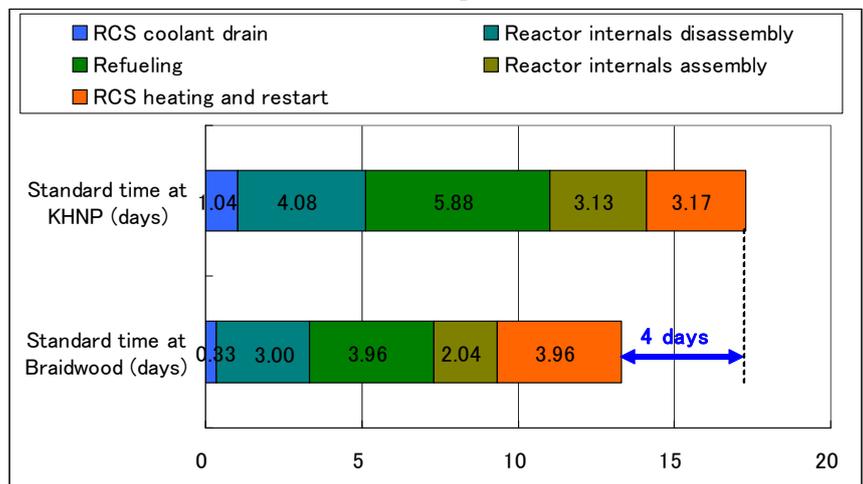
Table 2-3 The shortest record in South Korean plant outage time and in the world

Country	Year	Plant	Reactor type/Capacity	Days
Korea	2009	Ulsan unit 3	OPR1000/1000MW	24.9
Korea	2008	Kore 1nit1	PWR(other)/580MW	19.6
Korea	2003	Wolsong unit 4	CANDU/700MW	18.7
Belgium	2001	Doel unit 2	PWR/412MW	15.1
USA	2003	Braidwood unit 2	PWR/1258MW	15.3
USA	2002	Turkey Point unit 4	PWR/726MW	15.6

Source: “Learning from high utility factor for South Korean nuclear power plants – from Korea Hydro & Nuclear Power report at Japan-South Korea nuclear industry seminar,” Japan Atomic Industrial Forum

In South Korea, plant operation teams basically use standard templates to display the standard time for each process based on the shortest past records in working out plant outage schedules. These templates are regularly updated, allowing these teams to compare the past records with their achievements for each process. Particularly, the time for checking reactor cooling and water drain systems has been reduced substantially. Eventually, the total time for procedures during outage has been cut by about 30 hours. KHNP has used the templates to compare its plants with the U.S. Braidwood nuclear power station (with two 1.2 million kW reactors), finding that there is still a four-day gap between the United States and South Korea and that a further cut in the time for procedures during outage would be feasible.

Figure 2-9 Differential analyses of planned outage time using standard templates



Source: “Learning from high utility factor for South Korean nuclear power plants – from Korea Hydro & Nuclear Power report at Japan-South Korea nuclear industry seminar,” Japan Atomic Industrial Forum

<sup>12</sup> <http://www.khnp.co.kr/en/030003>

<sup>13</sup> See “Learning from high utility factor for South Korean nuclear power plants – from Korea Hydro & Nuclear Power report at Japan-South Korea nuclear industry seminar,” Japan Atomic Industrial Forum

For the future, South Korea is promoting the so-called "9402" target to further shorten nuclear plant outage time<sup>14</sup>. The target means that South Korea will seek to achieve the utility factor of 94% and a shutdown frequency of 0.2 times per unit for its standard OPR1000 reactor in 2014 while securing safety and reliability. Specific measures to that end include the extension of the OLM and AOT, the improvement of refueling processes, the application of the preventive maintenance template (PMT), the improvement of reactor upper heads, the expansion of cooling capacity at spent nuclear fuel pools and the review of additional outage optimization feasibility. KHNP estimates the average outage time for refueling to decline to 21 days through these measures.

Furthermore, South Korea plans to optimize long-term maintenance plans every 10 years<sup>15</sup>. Specifically, it plans seven outages over 10 years for refueling, vessel/material surveillance and repair and seeks to optimize the pattern. South Korea works out long-term plans in line with the optimized process and manages progress in procedures while implementing them to facilitate overall procedures. For example, KHNP's relevant divisions (machinery, electricity, instrumentation and control, etc.) coordinate procedures at workplaces where multiple contractors are present. At the same time, an "outage control center" integrates process controls by a "schedule control group (including workers from outside contractors)," and "tamper prevention," "work area control," "industrial safety" and "operation support" teams to achieve the optimum work pattern.

As explained above, South Korea has considered model cases in major countries including the United States, compared these cases with its own cases and studied improvements. In addition, South Korea has tried to further improve efficiency by working out its own long-term plans. As a result, the country has achieved one of the world's highest utility factors over recent years. As far as the above efforts are sustained, South Korea is expected to continuously make excellent achievements.

**(c) A case for restart of plant operations from unplanned outage**

In South Korea, unplanned outage time as well as planned outage time is short. This section extracts and assesses key points from Kori-3 case in June 2008 that represents a swift restart from an unplanned outage.

Approximately 21:17 on June 6 (Friday), 2008, there was a water leak from a welded line of a drain valve for a water chamber at Steam Generator B during normal operation. The plant licensee manually shut down the reactor to solve the problem. The Korea Institute of Nuclear Safety conducted an onsite inspection of the reactor in line with reporting and disclosure regulations and provided technical considerations for pre-restart safety verification, concluding that the event amounted to an important safety-related event as provided in Section 1 of Article 3.2 (measures after nuclear reactor shutdown) in Part 3 (nuclear reactor facility operation management) of an operational and technical guideline for Kori-3 and -4 units.

Table 2-4 Chronology of Kori-3 unplanned shutdown

2008	May	31	2 : 20	Completion of the 18 <sup>th</sup> periodic preventive maintenance and reactor attained criticality
			4 : 06	Parallel in
	June	2	18 : 10	Full power operation
		6	12 : 10	Detected a leak from reactor coolant system (RCS) by recognition of unusual water level in the chemical volume control (CVCS) tank
			14 : 37-	Inspections conducted 3 times for specification of the accurate leak point
			21 : 17	Specified the leak point with the welding line in the draining valve on the drain pipe from the water chamber of steam generator B
		7	22 : 00	According to 3.4.13, Operation Technical Guideline, determined to shut down
		1 : 27	The reactor shut down manually	

<sup>14</sup> Information from KHNP's director of maintenance planning and engineering at the 30th Japan-South Korea nuclear industry seminar (October 26-27, 2009)

<sup>15</sup> Information from KHNP's director of maintenance planning and engineering at the 30th Japan-South Korea nuclear industry seminar (October 26-27, 2009)

The onsite inspection team compiled a restart checklist for pre-restart safety verification and asked the licensee to submit reports on voluntary checks and assessment based on the checklist. Table 2-5 indicates the restart checklist.

Table 2-5 A restart checklist for pre-restart safety verification

Items	Contents
1	Appropriate actions taken by the operators in case of the event
2	Appropriate analyses and evaluations of the penetrating cracks on the welding line
3	Integrity of safety related systems including similar points (welding lines on small pipes)
4	Appropriate analyses on the impact of the event - Coolant inventory leaked out of the primary loop - Radioactive releases within the unit and to the environment - Potential dose exposed to the workers
5	Appropriate provisions to prevent relapses

The inspection team conducted safety verification in line with the checklist and announced the verification results and assessment in three days. In response to the assessment, the reactor restarted on June 12, 2008, to launch a process toward the restart of normal operations.

Even though the event represented a primary system coolant leak from a pipe for a steam generator water chamber, normal operations were restored a week after the event. During the week, the licensee carried out integrity verification at not only the event point but also tens of similar points. The levels of promptness and compactness of the verification were considerably high. In South Korea, the licensee (KHNP) is permitted to decide to restart a plant after outage on condition that the plant’s safety is ensured. Even without investigations into any root cause of an accident and the completion of measures to prevent similar accidents, the licensee can decide to restart the plant. The rational approach that separates the secured safety of the plant in question from long-term maintenance operations is similar to European and U.S. approaches and might be taken into consideration in Japan.

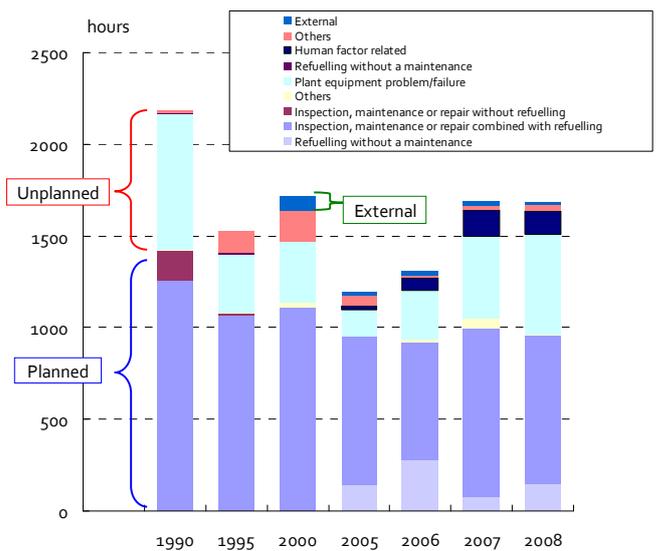
**2-2-3 France**

**(a) Outage time by cause**

France substantially shortened the average outage time from 1990 to 1995 and further shortened from 2000 to 2005. This may be because Électricité de France (EDF) implemented a program<sup>16</sup> to rationally shorten outage time from 1999 to 2006.

Since 2007, however, outage time including unplanned outage has tended to increase on system troubles and workers' walkouts. Outage time in 2008 rose back to the 2000 level. In response, EDF and other licensees are considering introduction of the U.S.-adopted risk informed operation positively to shorten planned outage time. Expecting that sufficient risk information and facility performance data would be required for risk informed operation, they are now discussing the matter with plant vendors and with safety regulatory authorities.

Figure 2-10 Average outage time by cause in France



<sup>16</sup> EDF made long-term repair plans including the replacement of large components for a planned nuclear plant service life of 60 years and conducted preventive maintenance and other operations.

**(b) A Case for restart from unplanned outage**

The following is a chronological explanation of the Tricastan-2 trouble case in 2008:

In September 2008, two fuel assemblies were found in abnormal positions when preparations for taking out fuel were underway at the 955 MW Tricastan-2 PWR that was in outage. The preparations were suspended then.

Table 2-6 Chronology of the restart from an unplanned shutdown on Tricastan-2

2008	September	8	The event revealed
		17	The safety authority (ASN) conducted a spot inspection at the plant
		22	EDF began to investigate the event
		26	Started preparation for the restore, conducted safety analyses and concluded “no problem for the restart”
		29	Discussed possible methods to recover the suspended fuel assemblies
		30	Recovering methods of the assemblies determined
	October	17	A full-scale test was conducted at the PWR test facility and the procedure was confirmed to be appropriate
	November	3&12	Discussed on the prevention of relapses
	December	8	Discussed on the prevention of relapses
		-	ASN permitted EDF to restart the reactor <sup>17</sup>

Source: EDF press releases, “Overseas safety and regulatory information” (JNES), “Activities regulated by ASN” Chap.12, PP.341 “Blockage of two fuel assemblies during core unloading of the Tricastan 2 reactor, “ and interviews

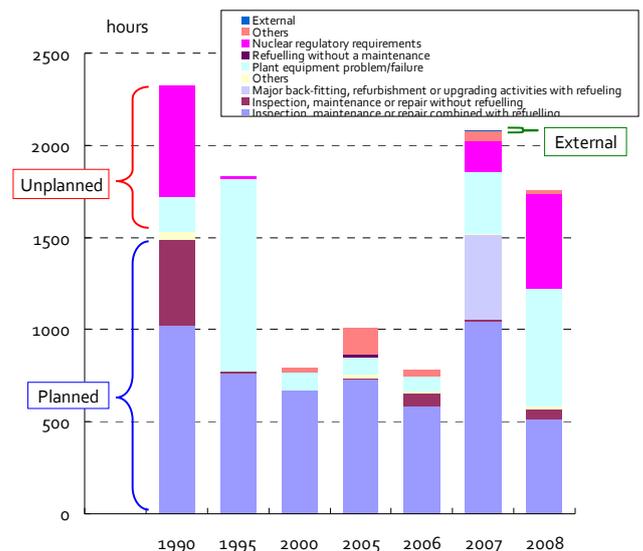
Since the event, the division of duties among relevant parties has been specified. The licensee (EDF) persistently makes independent decisions on specific responses. Regulators examine these responses. Based on plans submitted by the licensee, tests are conducted in the presence of inspectors from safety regulatory authorities. Regulators finally decide whether to restart a plant and how to prevent similar troubles. The event was categorized as INES-1<sup>18</sup> under the international safety standards. Though it was a minor trouble from the viewpoint of nuclear reactor safety and radioactive effects on the vicinity of the reactor, EDF and the Nuclear Safety Authority (ASN) collected and analyzed detailed information on the event, provided findings to other nuclear plants and worked out measures to prevent similar troubles. As soon as safety was verified, the plant was restarted. EDF and the Atomic Energy Commission (CEA) said their approach was that “as power stations are important infrastructure, their rational utilization serves national interests.”<sup>19</sup>

**2-2-4 Germany**

**(a) Outage time by cause**

The average outage time in 2006 declined to about one-third of the 1990 level. In the recent past

Figure 2-11 Average outage time by cause in Germany



<sup>17</sup> Though the accurate restarting date is unknown, the unplanned outage time of Tricastan-2 in 2008 is 1,924 hours according to IAEA, and the event happened on September 8, therefore the plant has been supposed to be restarted by the end of the year.

<sup>18</sup> INES stands for International Nuclear Event Scale. The INES safety standards are based on the presence or absence of radioactive substances, the destruction of multiple protection systems, workers’ exposure to radiation, etc. INES-3 and lower-ranked troubles are called “event.” INES-4 and higher-ranked troubles are named “accident.”

<sup>19</sup> From an interview with CEA officials

excluding 2007 and 2008, the outage time has followed a steady downward trend.

In 2007 and 2008, however, outage time increased substantially. The Krummel and Brunsbittel nuclear power stations were in outage over a long term due to troubles. Their outage was prolonged even after the completion of repairs to avoid their closure under the anti-nuclear law. In this way, the German nuclear phase-out law has greatly affected the utility factor of nuclear plants. This situation is peculiar to Germany.

**(b) A case for restart from unplanned outage**

The following is the Biblis-B case in October 2006.

On October 16, 2006, a defective anchor bolt<sup>20</sup> installation was found at Biblis-B, a 1.3 GW PWR made by Siemens, forcing the reactor to be shut down for repair. The anchor bolt repair was then scheduled for the Biblis-A of the same type during its next periodic inspection. Each work step was implemented, based on the plant operator’s coordination with regulatory authorities and a technical assessment organization. In addition to the relevant bolt installation repair, a random inspection was conducted for anchor bolts made by other firms than the one that produced the bolt in question. As a result of such horizontal development, a total of about 15,000 anchor bolts at the Biblis-A and -B units were reinstalled.

On November 30, 2007, the safety regulatory agency of Hessen State, where the unit was located, permitted the reactor to be restarted<sup>21</sup>. The conditions for the restart were the refurbishment regarding the anchor bolt problem and the completion of all inspections. At the power station, measurement and preparations for the restart were implemented over several days after the completion of the repair and inspections.

The above developments have been officially published. The reactor’s outage time might have included a political outage reflecting the nuclear phase-out law. The political outage is part of planned outage for major back-fitting, refurbishment or upgrading activities with refueling, as specified in the IAEA database.

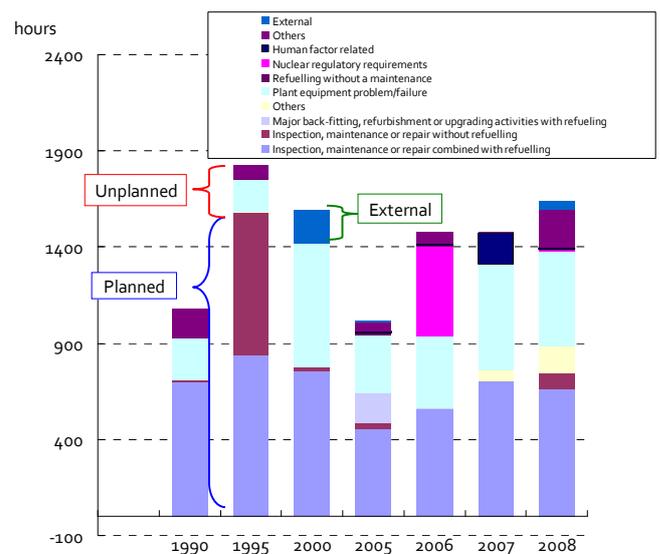
Such intentional outage extension for political reasons is difficult to find in officially published data and should be taken into account in the evaluation of German nuclear plant performances. Even taking the point into consideration, the total outage time for the reactor came to a little more than one year, including the political outage. This time length may be considered reasonable, given the graveness of the event regarding safety standards. In this sense, the Biblis-B case could be one of remarkable references for Japan.

**2-2-5 Sweden**

**(a) Outage time by cause**

The average outage time increased in 1995 due to a long refurbishment of the Oskarshamn-1 reactor that took three years from 1993. In 2000, an increase in outage time was attributable to a prolonged unplanned outage of the Ringhals-1 reactor over a trouble regarding the core spray system. Since the number of reactors in Sweden is limited to 10 (from 2005, 12 until 1999), a prolonged outage of one reactor in a year can greatly affect the average outage time for the year. This should be taken into account. Despite these extraordinary events, planned outage time declined smoothly from 1995 to 2005. As a factor behind the shortened outage time, electric utilities, safety regulatory authorizes and maintenance service

Figure 2-12 Average outage time by cause in Sweden



<sup>20</sup> The anchor bolt is used to fix the reactor container-supporting pedestal to the container. Several thousands of anchor bolts are used for each reactor.  
<sup>21</sup> No federal government permit is required.

entities cited the adoption of three work shifts around the clock for critical paths<sup>22</sup>.

In recent years from 2006 to 2008, however, the plant outage time increased incrementally. This is because Sweden intermittently shut down some reactors for inspections as they failed to achieve designed performances after their uprating and upgrading. Since the 1990s, Sweden has been uprating and upgrading existing nuclear reactors.

The utility factor slipped below 70% for the Forsmark-3 and Ringhals-3 reactors in 2007 as their unplanned outages on system failures were prolonged. In 2008, multiple control rods were found broken at Oskarshamn-3 and Forsmark-3 as discussed below, affecting the year's overall average outage time.

Planned nuclear plant outages have generally been short in Sweden while unplanned outages have been frequently prolonged over the past years. Although its average planned outage time is not so different from the U.S. and South Korean levels, its overall utility factor has failed to increase. Nevertheless, Sweden restored nuclear plant operations from unplanned outage in a very prompt manner frequently, as indicated by the following cases:

**(b) Outage-shortening efforts as indicated by cases for restart from unplanned outage**

The following are the Oskarshamn-3 and Forsmark-3 cases in October 2008.

On October 5, 2008, cracks were found in one of 169 control rods at Oskarshamn-3 in outage for planned repairs. This control rod had been in use since 2003. A survey on the vicinity of the rod indicated various cracks in some 25% of all control rods. As checks on similar reactors were implemented, similar cracks were found in many control rods at Fosmark-3. The cracks were attributed to thermal fatigue originating from temperature gaps between cool water and high-temperature coolant. The Swedish Radiation Safety Authority (SSM) classified these findings as Category 1 events<sup>23</sup> and ordered plant licensees to suspend commercial operation of the two reactors.

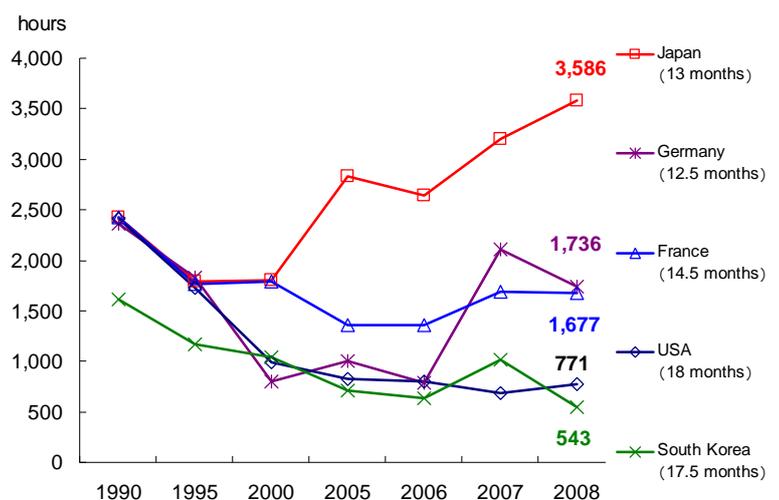
SSM, Oskarshamn power station operator OKG and Swedish engineering firm Studsvik cooperated in looking into the cause of the thermal fatigue. SSM conducted an analysis, based on these plants' next outage planned to come in about seven months. As a result, SSM concluded that additional troubles were unlikely to occur in the coming seven months and that no safety problem was expected with continued operation until the next planned outage. Oskarshamn-3 restarted on December 31, 2008 and Forsmark-3 did so on January 2, 2009. They were permitted to restart on a tentative basis. Oskarshamn-3 was allowed to remain in operation until March 1 and Forsmark-3 until July 31. During the respective planned outages in 2009, control rods were replaced.

The above cases represent a typical common European case in which regulators separate temporary safety-securing measures from long-term performance-improving measures and allow reactors to be operated if safety conditions are met even before root cause analyses are entirely figured out.

**2-2-6 Generalization of foreign cases and their comparison with Japanese cases**

Foreign nuclear power generation countries roughly posted 2,000 hours in average outage time in the 1990s before shortening such time. Japan alone has seen an upward trend in the average outage time. In 2008, Japan's average outage time was about seven times longer than South Korea's record that was the shortest in the figure. Given cases in

Figure 2-13 Comparison of average outage time and the operational cycle periods



Source: IAEA, "Operating Experience with nuclear power stations in member states"

<sup>22</sup> Sweden and many other Western countries have adopted three work shifts around the clock for the critical path for periodic inspections. In Japan, some electric utilities have adopted such work shifts. But such work shifts in Japan have not disseminated as much as in Western countries.

<sup>23</sup> Category 1 amounts to INES-1.

Germany and France where operational cycle periods are close to Japanese periods, Japan may be expected to halve its average outage time to some 1,500 hours<sup>24</sup>.

As explained above, major nuclear power generation countries have attempted to improve and actually have improved utility factors for nuclear plants. As for 2007 and 2008, there were attention-attracting efforts to raise utility factors, including dramatic improvements in the U.S. utility factor, South Korea's extremely high utility factor, preventive maintenance during operation, and three work shifts around the clock, while nation-by-nation developments regarding troubles and legal matters may have to be taken into account. French and Swedish cases for restart from an unplanned outage indicate that both countries promptly investigate troubles and restart nuclear plants soon after safety verification, while making separate efforts to improve long-term plant performances. Behind such swift actions is an approach that nuclear power plants should be utilized as much as possible under reasonable decisions. This is an important point.

**2-3 Implications for Japan's future efforts**

In this section, we identify differences between overseas efforts as discussed above and Japanese measures and discuss what steps Japan could make in the future.

**2-3-1 Comparison of Japanese and U.S. nuclear outage times by cause**

Chronological changes in Japan's average nuclear plant outage time since 1990 indicate that the time has followed an upward trend following the bottom of 1,795 hours in 1995. In 2008, the time doubled from the bottom to 3,586 hours. A cause-by-cause breakdown of nuclear plant outage indicates that planned outage for repairs and refueling under periodic inspections has grown longer<sup>25</sup>. In addition, unplanned outages stemming from system troubles have increased. Institutional revisions regarding inspections in October 2003 worked to lengthen periodic inspections. In 2007, the Niigata Chuetsu-oki Earthquake as an external factor contributed to increasing nuclear plant outage. The average outage time thus exceeded 3,500 hours in 2008. Measures taken to adapt nuclear plants to a new earthquake-proof guideline since 2006 have also worked to increase planned outage time. At present, the outage time has been thus prolonged and Japan is urgently required to identify factors behind the prolonged outage and take some countermeasures.

Figure 2-14 Comparison of average outage time by cause in Japan and the U.S.

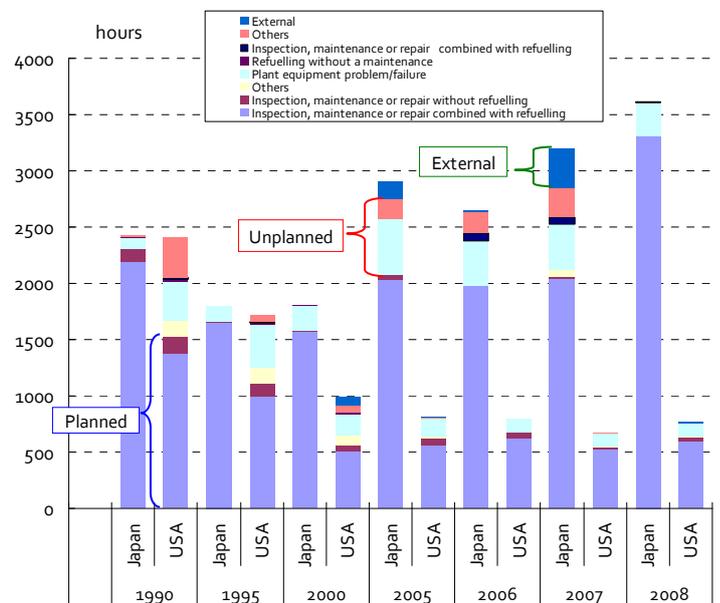


Table 2-7 Comparison of performances between the U.S. and Japan concerning the utility factor

	Data	Number of plants	Average operational cycle period	Unplanned shutdown	Unplanned shutdown per year	Outage days per unplanned shutdown	Average inspection period	Load factor (%)
Japan	Operation period and Inspection period	53	13 months	31	0.54	34 days	140 days	70%
USA		103	19 months	188	1.2	4.7 days	38 days	92%

Source: The 22<sup>nd</sup> meeting, Nuclear Power Committee, METI on March 5, 2010

<sup>24</sup> In 1995 and 2000, Japan's nuclear plant performances were similar to those in Germany and France.

<sup>25</sup> Outages on troubles and seismic reinforcement during periodic inspections are classified as repair and refueling outages in some cases.

Table 2-7 indicates a comparison of Japanese and U.S. nuclear plant performances. The gap is about six months in the average operational cycle period, about 100 days in the number of periodic inspection days and about 30 days in the number of outage days, resulting in a difference of about 20 percentage points in the utility factor. Based on the table, the U.S. and Japanese utility factors can be approximately indicated by the following formulas.

$$\text{Utility factor}^{26} = \frac{\text{Operational cycle period}}{\text{operational cycle period} + \text{unplanned outage days} + \text{periodic inspection days}}$$

(U.S.) 
$$\frac{570 \text{ days}}{(570 \text{ days} + 4.7 \text{ days} \times 1.2 \text{ times} + 38 \text{ days})} = 92.8\%$$

(Japan) 
$$\frac{390 \text{ days}}{(390 \text{ days} + 34 \text{ days} \times 0.54 \text{ times} + 140 \text{ days})} = 71.1\%$$

The three gaps' effects on the utility factor are broken down by factor as follows:

- 1) If Japan achieves a U.S.-level average number of periodic inspection days (at 38 days):

$$\frac{390 \text{ days}}{(390 \text{ days} + 34 \text{ days} \times 0.54 \text{ times} + 38 \text{ days})} = 87.3\%, \text{ up } 16.3 \text{ points from the present}$$

- 2) If Japan achieves a U.S.-level operational cycle period (at 19 months):

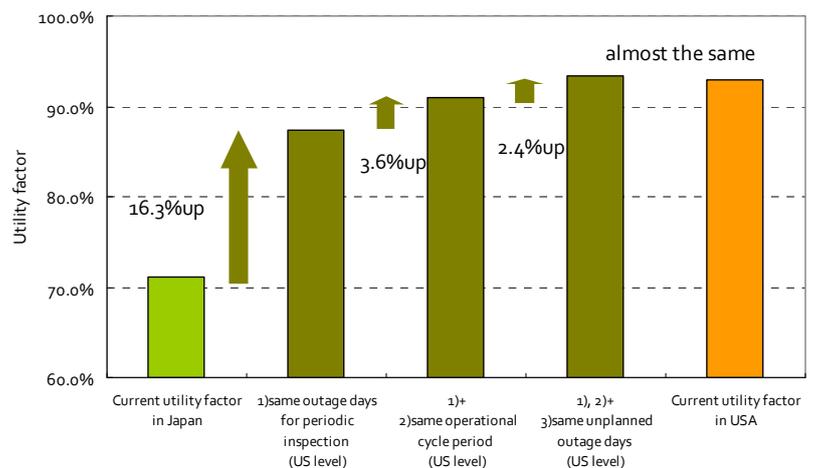
$$\frac{570 \text{ days}}{(570 \text{ days} + 34 \text{ days} \times 0.54 \text{ times} + 140 \text{ days})} = 78.3\%, \text{ up } 7.1 \text{ points from the present}$$

- 3) If Japan achieves a U.S.-level number of unplanned outage days (4.7 days):

$$\frac{390 \text{ days}}{(390 \text{ days} + 4.7 \text{ days} \times 0.54 \text{ times} + 140 \text{ days})} = 73.2\%, \text{ up } 2.1 \text{ points from the present}$$

The above means that reduction in the number of periodic inspection days contributes to improving the utility factor most. By reducing the number of periodic inspection days to the U.S. level, Japan could achieve a utility factor of 87.3% exceeding the past record. The second largest contributor is the extension of the operational cycle period. By extending the period to the U.S. level, Japan could increase the utility factor to 78.3%. By reducing the number of unplanned outage days, Japan could raise the utility factor to 73.2%. By combining the three measures, Japan could attain the U.S.-level utility factor<sup>27</sup>. The above factor

Figure 2-15 Approaches to raise the utility factor to the level same as the U.S.



<sup>26</sup> Strictly, this definition indicates the operation factor. As noted earlier, however, we consider the operation factor as approximately similar to the utility factor in this report.

<sup>27</sup> Since the unplanned outage frequency (the annual number of outages divided by the number of reactors) in Japan is less than in the United States,

analysis is indicated in Figure 2-15.

A summary of the above discussions indicates that Japan should implement the reduction of periodic inspection days, the extension of operational cycle periods, and the reduction of unplanned outage days in order to improve the utility factor. Japan should seek to restore an earlier-achieved level of about 80% first and then raise the factor to a higher level. In this process, Japan should take various measures while learning from measures implemented by the United States and other foreign countries that boast excellent performance of nuclear plants.

In the following, we discuss an analysis and implications for each means.

### **2-3-2 Reduction of periodic inspection days**

As indicated by Figure 2-2, older ages of nuclear reactors in operation or different types of reactors in operation may not be of any decisive factor behind the increased number of periodic inspection days.

Effective measures that can be taken immediately include the utilization and dissemination of preventive maintenance during operation (PMO) for the contraction of each periodic inspection step and extension of the allowed outage time (AOT) during which safety systems are allowed to remain offline unless safety is damaged. At present, experts are discussing the PMO and the extended AOT, based on U.S. and other efforts. In February 2010, the fundamental policy panel of the Nuclear and Industrial Safety Subcommittee at the Advisory Committee for Natural Resources and Energy compiled a report listing future challenges, based on recent changes in the environment surrounding safety regulations<sup>28</sup>. Based on changes in economic and international conditions regarding the utilization of new experiences and knowledge in safety regulations (including the consideration of measures to utilize risk information), maintenance during operation, safety evaluation related to the extension of operation, the improvement of nuclear reactor output, etc., the report called for local governments, residents, the industrial world and other nuclear plant stakeholders to increase communications and build mutual confidence. The operation control working group of the Nuclear Reactor Safety Subcommittee at the Advisory Committee for Natural Resources and Energy is considering the safety of nuclear facilities and regulations regarding the implementation of maintenance during operation.

The point-by-point verification of Japanese and foreign periodic inspection programs and analyses on their differences are useful for making it easier to compare effects of the introduction of new systems in Japan and other countries. Electric utilities might have conducted such analyses in making operation programs for each nuclear power stations, however, these analyses are not published and kept prudently confidential. Considering global marketing of Japanese nuclear industries, Japan may have to make national efforts to raise the nuclear plant utility factor. In this sense, electric utilities should share operation program templates as much as possible to make the domestic comparison easier. Toward the future, it is desirable for electric utilities to strictly report work hours for major regulation inspection steps in line with common templates and easily compare the data.

The template-based compilation of risk information may be useful for collecting risk information thoroughly and for disseminating such information horizontally as far as possible to secure effective uses of such information. Regulations should be reformed and implemented efficiently for Japan's introduction of risk information-utilizing analysis methods that have been adopted in the United States and considered in other foreign countries.

Some foreign countries including the United States and South Korea have made excellent achievements in reducing periodic inspection periods and accumulated relevant know-how steadily. Given that the three shifts around the clock for periodic inspections, which are widespread in Europe and the United States, have been introduced and implemented smoothly at some facilities in Japan, we do not believe that Japan's technological levels are inferior. Japan could achieve the reduction of periodic inspection periods and the high utility factor that have been attained in these foreign countries. Meanwhile, large

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Japan could achieve a utility factor of 93.4%, a little above the U.S. level, by upgrading the other parameters to the U.S. levels.

<sup>28</sup> "Challenges Regarding Nuclear Safety Regulations," Nuclear and Industrial Safety Subcommittee, Advisory Committee for Natural Resources and Energy, February 2010

long-term maintenance projects that are implemented over several months in Japan are very few in the United States. Japan will have to consider increasing inspection efficiency and look into what steps are taken in foreign countries.

In implementing various measures, Japan should accumulate risk information and experiences of nuclear plant operators and modify regulations as necessary while giving sufficient considerations to safety. Since massive procedures are expected to become necessary for reforming systems, Japan should not spend much time on various preparations. In this sense, Japan should take advantage of overseas lessons and information for efficient preparations and promote technical analyses and efforts to get the understanding of the people, particularly residents close to nuclear facilities, regarding nuclear energy.

### **2-3-3 Reduction of unplanned outage days**

Supported by Japan's excellent technological capacity and safety, the unplanned outage frequency for nuclear power stations in Japan has been relatively lower than in other countries such as the United States. Meanwhile, the time between the shutdown and restart is estimated at several times as long as in the United States. Given that nuclear plants have been operated without problems in the United States and South Korea, we believe that a rapid restart of plant operations from an unplanned outage would not be technically impossible. Particularly, the United States, South Korea, France and other foreign nuclear power generation countries have adopted a roughly common approach that nuclear plant operators should restart reactors after verifying the absence of safety problems and later conduct detailed research into root causes in a bid to prevent their relapses. This approach is far different from those of Japan. Based on this fact, Japan should first compare technical inspection work hours in Japan and other major nuclear power generation countries to increase the technical work efficiency. Analyses of non-technical work hours and problems should be the next step.

### **2-3-4 Extension of operational cycle periods**

Operational cycle periods for nuclear power stations in Japan are shorter than in the United States and South Korea. In this respect, regulations have allowed operational cycle periods to be extended up to 24 months since April 2010. The scope for the extension is expected to expand. In order to smoothly shift to longer-term operation, plant operators are expected to take advantage of information on common systems, fuel characteristics changes during longer operation and other details at plants subjected to longer operation.

Nuclear plant operators should consider not only single cycles between periodic inspections but also long-term operation plans covering multiple cycles. Japanese electric utilities have already considered such long-term operation plans. Based on the South Korean case, Japan should consider 10-year or multiple-cycle operation plans optimized to include inspection work preparations and measures for aging reactors in advance. Furthermore, Japan should build on Swedish efforts to manage operation cycle periods and maintenance plans on a nationwide basis to grasp the nationwide distribution of engineers and other workers and realize the optimum distribution of limited human resources. Regarding unplanned troubles at one plant, other plants are sometimes required to undergo checks for similar troubles. Therefore, long-term operation plans should be flexibly adapted to Japan's unique conditions while based on foreign practices. As skilled engineers are required on aging of nuclear plants, Japan should seek to optimize all nuclear plants over a long term. This is an important point for the Japanese nuclear industry holding 54 reactors.

Measures for the reduction of periodic inspection periods, the reduction of unplanned outage days and the extension of operational cycle periods include many tasks that Japan is technically able to implement soon. Japan should give top priority to the prompt, steady implementation of such measures. Meanwhile, nuclear power generation characteristically has more cultural and social problems that cannot be solved with technologies alone than other power sources. In order to solve these problems, residents close to nuclear facilities, the people in general, nuclear plant licensees and the central government should specify points at issue and work closely together. The promotion of mutual understanding is expected to contribute to efficient operations of nuclear power stations in Japan.

### 3. Conclusion

The utility factor for nuclear power plants in Japan had been almost equal to European and U.S. levels in the 1990s but has become far lower in recent years. Regrettably, continuous efforts to secure safe, efficient nuclear plant operations have failed to make sufficient achievements. In fact, foreign countries including the United States and South Korea have implemented various measures and improved utility factors steadily. Based on these foreign efforts, Japan should consider and promote its own efforts. Specifically, Japan should further promote and steadily implement measures for the three key purposes – the reduction of periodic inspection periods, the reduction of unplanned outage days, and the extension of operational cycle periods.

A conclusion based on the review and analyses in this report is that Japan should specify and give full considerations to technical causes behind the slack utility factor and gradually implement measures as far as possible to improve the factor. Based on this approach, nuclear plant licensees and regulatory authorities should proceed with detailed discussions. Specifically, nuclear plant licensees should utilize common templates as discussed in the 2-3-2 section to finely shorten work hours for each periodic inspection step. Regulatory authorities should repeal or modify unnecessary or excessive regulations while securing safety.

For this research, we had opportunities to hear opinions from foreign experts. We found foreign countries' common approach that "nuclear power plants should be utilized as much as possible under reasonable decisions." If based on the view that nuclear power plants are not only facilities containing potential dangers but also useful infrastructure for society, this may be a very reasonable approach and should be recognized in Japan. Views about nuclear safety and security and about central governments in charge of safety regulations in foreign countries are different from those in Japan. In this sense, nuclear energy discussions are greatly social while being purely technical.

Finally, we would like to specify roles that the central and local governments should play.

The central government should positively take the initiative in promoting the above measures and directly promote national understanding about nuclear energy and be ultimately responsible for regulatory matters. Local governments should promote local residents' sufficient understanding about nuclear energy and serve as a communications bridge for them. In order to allow relevant parties to steadily implement various measures to improve the utility factor for existing nuclear plants, Japan should overcome disputes between nuclear proponents and opponents, distrust in administration and excessive worries about safety, should consider how to take advantage of existing facilities and should secure the people's sufficient understanding. Without such efforts, even ongoing efforts could face obstacles and cause unnecessary delay. As a result, Japan could fail to achieve levels that are viewed as technically achievable at present. We should take full note of such possibility.

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