1. Concept of Plant Life Management

A nuclear power plant is born after a lengthy, multi-year construction period, and ends its life decades later, having generated a vast amount of electricity. Its period of operation is, of course, far longer than its period of construction.

"Construction" is the process of using technology to create something of value -- a new nuclear power plant. "Operation" is the process of "raising the child" with care so that its potential can be realized to the fullest over the course of its life.

Ideally, optimal management of a plant would mean, over the course of its life, the maximum production of electricity for the minimum total investment.

To this end, from the view point of plant life management, it is appropriate to divide the life of a plant, into three stages -- "fostering," "mature" and "aging" -- and to manage them accordingly. It has become particularly important for Utility companies under the competitive power market, to manage aging plants effectively, beyond their depreciation periods, in order to extend their lives with a sustained high level of performance. Whether that is in fact possible depends, in turn, on how the plant was operated in the prior stages -- that is, on how it was "brought up."

2. Stages of Plant Life; Steps in Life Management

(1) "Fostering" Stage

Newly-constructed nuclear plants have tremendous potential. Generally, however, as the so-called "bathtub curve" of reliability shows, troubles at the beginning are to be expected. So, it goes without saying that sufficient "debugging" of a plant is necessary during its trial operations, in order to help it be born (start regular operations) as a "health baby." This is the first step in plant life management.

Most machinery requires a period of "breaking in," during which the interactions of components are smoothed and they become well fitted. Depending on the component and equipment, the time required varies. This start-up period, the period to the achievement of stable normal operations, is important because it is largely responsible for the physical "constitution" and "strength" of the plant thereafter. Thus, as with a new automobile, it is best not to impose excessive demands on the plant and to continue rated operation carefully during this period, which, depending on the plant, can range from a few to several years. We can refer to this as the "fostering" stage of the plant.
Through periodic inspections carried out during the fostering stage, it is necessary to identify the weaknesses of the plant as well as its strengths. At the same time, any peculiarities of the plant should be understood and reflected in operating methods and maintenance, by which a strong plant constitution can be developed. This is the second step in plant life management.

(2) "Mature" Stage

A plant nurtured with care will have acquired a strong physical constitution and be able, in its next -- "mature" -- stage, to meet high performance expectations (for example, operating cycles with extremely short inspection periods including refueling; longer operating cycles, 18 to 24 months; and increases in rated output).

The concepts of “risk-based maintenance” and “performance-based maintenance” become easier to apply when components and equipment operate stably in the mature stage; “maintenance during operation” on major components and equipment becomes similarly possible. Reduced outages for maintenance and improvements in capacity factor can thus be expected without impairing the plant's safety and reliability.

Having become a highly-reliable base source of supply, the plant must challenge to attempts to improve various performance factors and indicators and thus contribute to reducing power costs, become the plant at this stage is an important business asset for the Utility company, as well as being a reliable source to the power system network.

All the more because the plant is expected to be so valuable at this stage, precise care is required in its operation and maintenance so as not to impair its generating performance through trivial causes. For that reason, utmost efforts should be made to monitor the state of plants in operation and to detect any signs of abnormality as quickly as possible. Measures allowing repair during operation or with the shortest outages are similarly required, and it is essential that human errors be minimized during operation and maintenance, and during inspections.

It goes without saying that, in the management of technology, errors attributed to technology should not be made. At a nuclear power plant, not only nuclear, human involvement spans every stages from planning, designing and manufacturing, construction, to operation and maintenance, and at every stage, there is no need to repeatedly declare the importance of the "human factor” in preventing potentials of troubles during plant operation afterwards. So-called TQC (total quality control) or TQM (total quality management) through the whole stages is important. Even if trivial, human error in any stage will appear as trouble of the plant in operation. Therefore, it is legitimate to point out especially that when a plant has reached the mature stage -- technically stable and productive -- great care should be taken in preventing wasteful abnormalities stemming from human oversight or error.

Management of plants focusing on consideration to these points is the third step in plant life management.

(3) "Aging" Stage

Aging is inevitable, and a plant will eventually reach the "aging" stage despite every effort over the years to rejuvenate, improve, upgrade, renew, clean, decontaminate or replace its components and equipment. Given, nevertheless, the vast investment of capital and resources, including human resources, in a nuclear plant, it is important both for the company and for society that the value of the asset be maintained for as long as possible, which value has been increased as explained above.

Measures to extend the lives of aging plants -- "aging measures" or, I dare say, “life-extension measures” --
mark the final step in plant life management.

In Japan, nuclear power plants are regarded as becoming subject to aging measures some 30 years after commissioning. This will be explained in Section 4 in more detail.

3. General Significance of Plant Maintenance and Inspections

In this section, in the context of plant life management, the significance of maintenance and inspections commonly carried out at plants is considered.

In light of the progressing deregulation of power markets, it is essential that nuclear power generation be cost-competitive. This inevitably requires changes in the concepts of maintenance and inspections.

In Japan, periodic inspections Which are comprehensive inspections undertaken at scheduled intervals, requiring long outage period in operation of the plant, are general practice up to now.

- Statutorily, the operating cycle of a plant is a maximum of 13 months, and a periodic inspection is required before the start of the next cycle. Such inspections are basically "overall" inspections of the plant, and take about 90 days. This means a plant's annual capacity factor can be no more than about 75%.

- In principle, when plants are restarted after a periodic overall inspection, the "bathtub curve" -- the reliability curve -- applies again, which means the increase of the chances of troubles occurring. So sufficient attention must be given to prevent troubles at the beginning of each restart (the beginning of the next operating cycle). Periodic inspections should be strictly implemented to keep safe and stable operation of next cycle so that the plant will be accepted by the public; at the same time, however, the inspections themselves should not increase the chances of troubles occurring.

- Prior to deregulation, preventive maintenance was standard thinking; that is, endeavoring to avoid the occurrence of troubles, given the potential social seriousness if they did in fact occur, with less of an eye on reducing operation and maintenance costs. Parts and equipment were replaced at scheduled times, regardless of their actual condition, regardless of whether they are still sound or not. This is, so called, "time-based maintenance."

For these ten years in anticipation of deregulation, efforts have been made to reduce shutdown period, during periodic inspections, in order to improve plant capacity factors. Other efforts, too, to improve efficiency in working process control, including the improvement of working environments, have been made. In Western countries, "condition-based maintenance" is increasingly introduced. Under that concept, parts and equipment subject to maintenance are selectively chosen based on evaluations of trouble-occurring risk and the remaining life of each item, according to operational domestic and overseas experiences and other technical information. "Maintenance during operation" is carried out where possible, combined with the idea of "break-down maintenance" in the case of minor parts and equipment. By applying these maintenance approaches, periodic inspections in the range of 20 to 30 days have been realized one after another in Japan.

Such efforts are regarded as the process that the potential physical strength of the plant is extracted and realized to its maximum. Which is to say, plants with excellent constitutions may be able to cope with shorter maintenance outages and longer operating cycles. It may similarly be no exaggeration to say that such physical strength depends on how well the plant was made and how well it was brought up -- although such causal connections are difficult to substantiate quantitatively (as is, say, proving the relationship between education and
specific human outcomes).

4. Safe Operation of Nuclear Power Plants and Aging Measures to Extend Plant Life

Currently, 52 light-water reactors are in operation in Japan. Within the next five years, 13 of those units will have been operating for more than 30 years; within ten years, 23 of them, nearly half the total, and be subject to aging measures. As seen recently in the United States, it is clear that these existing, well-managed aging plants will be increasingly important for the utilities both as power sources and, in deregulated markets, in terms of cost. Extension of plant life, with continued safe, stable operation, is therefore an important issue.

The Japanese government and the utilities have been thinking together about the matter for more than ten years. Their basic thoughts are outlined next.

(1) Part 1 (Governmental Discussions)

In 1994, the government prepared and released a report titled "Basic Concepts on Aging." The objective was an evaluation of the soundness of major equipment on the assumption that plants could be operated 60 years, and to establish the concept of "aging measures." Key points are outlined below.

- Two BWR units and one PWR unit, all are approximately 30 years old, deemed representative of aging plants, were selected, and their major equipment, including pressure vessels, core internals, recirculation pumps, primary piping systems, containments and concrete structures, were evaluated technically. Results showed that plants can be operated safely by better periodic inspections and examinations, even over longer periods of time.
- For plants 30 or so years old, the contents of periodic inspections by the government, and maintenance requirements on the utilities, will be modified to keep and enhance safe and stable operations of the aged plants.
- Utilities will carry out detailed technical evaluations of each item of equipment at plants 30 years or so beyond commissioning, and issue concrete maintenance plans for them.
- Changes to structural standards taking account of, for example, the changing strength of materials with aging will be made, referring to U.S. standards.
- Development of inspection and repair technologies necessary to manage aging plants on a reliable basis will be continued, and data on materials and the operation of plants over time will be continuously compiled.

(2) Part 2 (Utility Discussions)

In response to the actions outlined in Part 1, the utilities decided to evaluate the long-term soundness of overall plant facilities, and issue plans for necessary maintenance to cope with aging. Key points are as follows:

- Evaluation Method
  - Equipment and structures subject to evaluation were: (a) facilities important to maintaining safety; (b) facilities particularly important to continuing operation, including power generation equipment; and (c) others. Facilities under (a) and (b) were categorized into fifteen types, including pumps, motors, heat exchangers, containers, piping, valves, electric facilities, instrument and control systems, cables, and concrete and steel-frame structures. Each type was further divided into groups according to structure and usage, etc., and equipment representative of each group was chosen for technical evaluation.
  - Any technically assumed changes that could occur at a nuclear power plant -- whether common changes in materials as a result of aging, or other changes that could be associated with aging based on past records and the latest knowledge -- were extracted. In addition, any changes to equipment or structures that
should be considered in light of structural, material and usage conditions or the environment for use were similarly identified.

- For equipment and structures representing each of the aforementioned groups, (a) evaluation of its soundness; (b) review of the current state of maintenance; and (c) a comprehensive evaluation based on both of the preceding two points (that is, an evaluation of appropriateness of the current maintenance, including whether the maintenance matches the changes caused by aging) were done. In addition, (d) maintenance points to be considered in the case of long-period operation, and necessary items for farther R & D, were identified.

- In terms of seismic safety, if there were any changes caused by aging that might affect the seismic reliability of equipment more than nominally, such effects were evaluated individually, and whether a maintenance item should be added or not, was considered.

? Results of Evaluations

- The long-term soundness of most equipment was judged to be ensured by current maintenance activities, while some items requiring additional attention, although not urgently, were identified. The latter items will be consolidated into “The long-term maintenance program,” to be systematically implemented during periodic inspections commencing 30 years after commissioning of a plant.

(3) Efforts Hereafter on Aging Measures

? Implementation of Long-Term Maintenance Programs

For plants not yet at the aging stage, soundness can be confirmed for the next operational cycle (until the next periodic inspection) at a current periodic inspection with reference to the history of periodic inspections carried out more or less every year. Periodic safety reviews, including consideration of aging measures, will be implemented at all domestic nuclear power plants before approximately their 30th year.

For plants passed their normal design lives of 30 years, 60 years of life is assumed which is considered technically reasonable looking from past operating experiences etc. During this extended period, in order to maintain an appropriate physical constitution of the plant, maintenance items are selected in the “Long-term maintenance program” in addition to the present daily maintenance and periodic inspection, and will be steadily implemented.

? Periodic Safety Reviews

Consideration of aging measures will be included in “Periodic safety reviews of plants”, which the utilities will implement every ten years or so as part of their voluntary activities to maintain safety. “Periodic safety reviews” incorporating consideration of aging measures will be implemented at all domestic nuclear plants before the plants have been operated 30 years. Such safety reviews were done at three plants. In June 2001, following the first three (the 2 BWRs and 1 PWR mentioned in (1) above), another 2 plants were reviewed and the results were reported to the Nuclear Safety Commission as incorporated in the “Periodic safety reviews” and released.

? Nuclear Power Plant Life Engineering Center

In April 2002, the Nuclear Power Plant Life Engineering Center (PLEC) was established within the Japan Power Engineering and Inspection Corporation, as a third-party organization to upgrade aging-related technological infrastructure and disseminate technical information. Its major activities include the following: (a) technological development; (b) accumulation of technological data and utilization of technological development results; (c) technological exchanges with domestic and overseas parties and organizations; and (d)
information dissemination.

5. Conclusion

Nuclear power plants are the technological product of dozens of years, huge investments, and efforts by many people. They represent technology meeting social demand. In all steps from planning, designing, and manufacturing, through construction, operation and maintenance, to dismantling following the end of operation, people are, by definition, intimately involved -- "helping" the plants to live up to their potential; carefully maintaining their soundness on the premise of securing safety throughout their lives; and, finally, putting a period to those lives. Plant life management should be based on this kind of understanding. In all steps, there should consistently be "kind consideration" to the plants, their equipment and facilities, and "morality" toward society on the part of those engaged with the technology as professionals.

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