IMPROVEMENT OF NUCLEAR POWER PLANT OPERATION AND MAINTENANCE IN JAPAN

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ABSTRACT

Following the inauguration of commercial nuclear power generation in Japan in 1966, capacity factors were held in the relatively low level until around 1975 due to initial-period troubles.

With subsequent improvement, however, capacity factors have climbed steadily and recently been sustaining more than 70%.

To obtain this successful result, a various kind of improvement have been made not only for the operation management area but also for the maintenance management area in conjunction with the successive effort to reflect the operating experiences to the early stage design.

Nowadays nuclear generation has assumed increasing importance for Japan's electrical power needs, and is making a great contribution to stabilizing power supply costs.

PREFACE

The commercial nuclear power generation in Japan was inaugurated in 1966, with the start of operation of the Tokai Reactor, which is a gas cooled reactor, introduced from the United Kingdom. After this unit, however, the type of nuclear power plants adopted in Japan have all been light water reactors (LWR), such as those put to practical use firstly in the United States, and the start of LWRs in our country, began with Tsuruga Unit #1 (BWR) and Mihama Unit #1 (PWR), which commenced operation in 1970.

In the initial stage when the LWRs were first introduced into our country, technical problems particular to the LWRs experienced such as stress corrosion crackings in the stainless steel pipes in the primary system of the BWR, and leaks in the steam generator tubes of the PWR. The countermeasure against these technical problems required lengthy periods of the plant shutdown, resulting in low plant annual availability factors of 40 - 50%.

Upon encountering such experiences as foregoing, the utility companies, the nuclear steam supply system equipment manufacturers and the government cooperationaly proceeded studies to resolve such technical problems and at the same time reviewed countermeasures to prevent recurrences. Hence, for the new power plants, the results of the studies were fully reflected into the designing, and at the same time necessary equipment modifications were made on the existing power plants.

Meanwhile, for the operation and the maintenance of the nuclear power plants, the substantial education and training of the plant operators, and improvements to the technologies in operations management were conducted. Also with the object of preventing troubles, the thorough inspection and maintenance practices have been enforced, and furthermore, efforts for the betterment of maintenance management technologies have been continued by utilizing experiences of accidents and troubles that occurred in Japan and other countries.

Also, since 1975, with the aim at improving plant reliability, rationalizing of annual periodic inspections, and reducing of radiation exposure dose during working periods, a program has been promoted as an independent technology of Japan for the improved design standardization of the LWRs.

Consequently, presently at the end of fiscal year 1986 period, there are 33 units of nuclear power plants in operation with generation capacity of 25,681 MWe. Also the nuclear power plant efficiency has continued to improve steadily showing a high annual plant

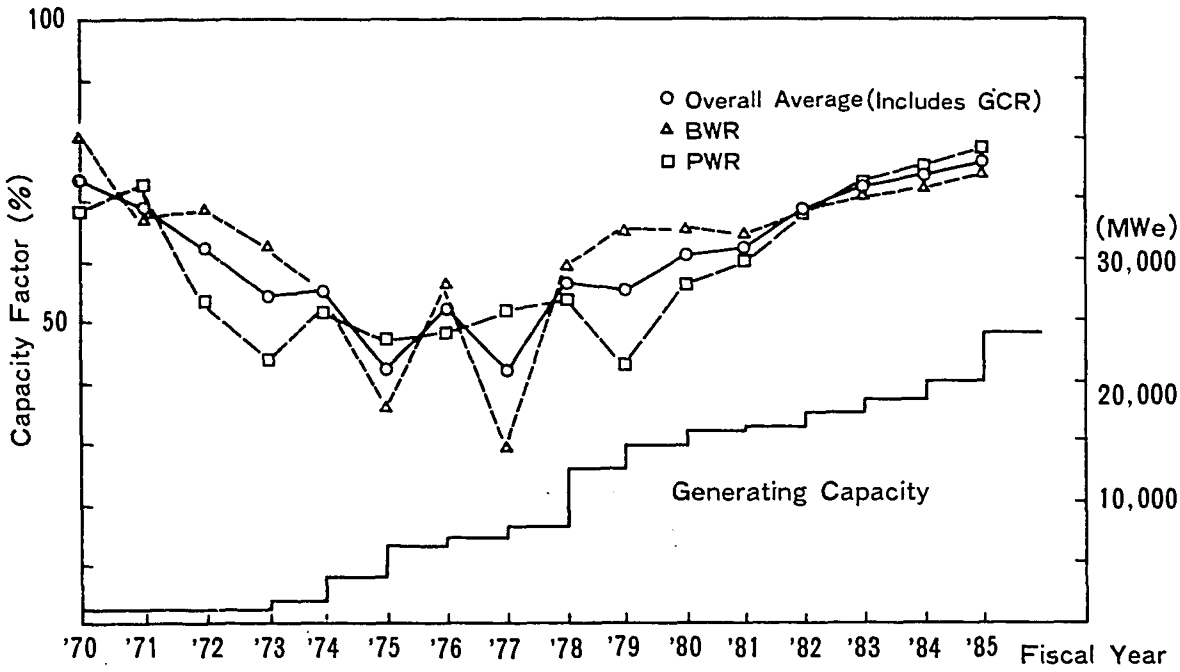

Fig. 1 Historical Trend of Capacity Factors

availability factor of over 70% continuously since 1983. In the 1985 period, this factor has risen to 76%, indicating that the nuclear power plant as a major source of energy supply in Japan have entered the stable stage(Fig. 1).

IMPROVEMENTS IN OPERATION AND MAINTENANCE

Described below are the summary of the improvements achieved in operation and maintenance of nuclear power plants in Japan.

I Elevation of operation management technology—Education and training of plant operation personnel

On executing the operation management of nuclear power plants, the rearing and training of high quality operators possessing necessary knowledge and expertise in the design and operational performance of the total plant, as well as with high moral sense, are indispensable.

The utility companies of Japan, select from new recruits that are employed by the company in April every year, those that are considered as being appropriate for operation personnel of nuclear power plants, and are given a lengthy and continuous in-house education, centering on on-the-job-training (OJT) at a power station until they become a skilled operator. In addition, the operators are dispatched occasionally to the operators training facilities outside of the company to maintain and elevate their high quality. The training facilities for operators are the Nuclear Power Plant Operators Training Center (NTC) for PWR plants and the BWR Operators Training Center (BTC) for BWR plants which were both established in 1974. These facilities accept and train the nuclear power plant operators coming from the various utility companies, in accordance with the capability of the individuals. The training is not conducted only on individuals, but also importance is placed on the family training in which the operation shift groups are given group seminars.

Although it is a happy situation that there is a reduction in the number of SCRAMs recently (Fig. 2) and is in the trend of scarcity in dealing with troubles in Japanese nuclear power plants, the necessity of measures for replenishing the qualities of the operators are being pointed out.

For this purpose, the utility companies are conducting specific programs for elevating the contents level of their respective OJT training. And recently there is a move among the utility companies to install compact type simulators for their own education and training.

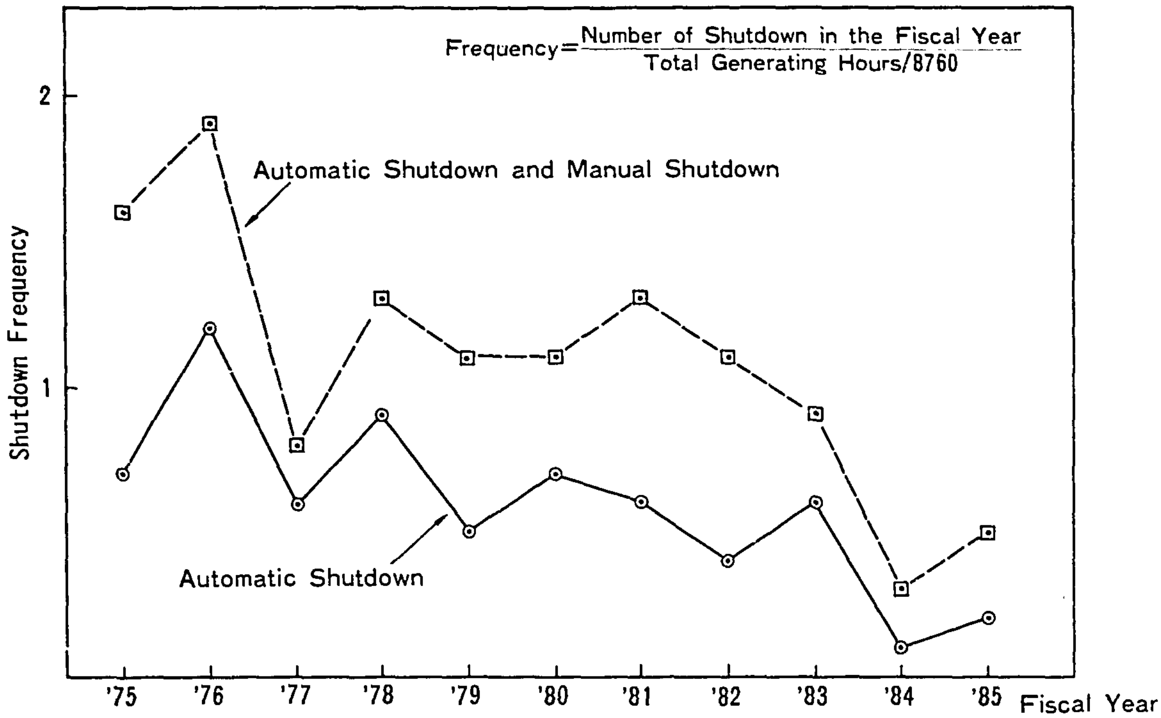

Fig. 2 Trend of Shutdown Frequency due to trouble in Operation

As one of the characteristics of in-house training of the utility companies, it can be said that, in relation, also, with the social background of the lifetime employment system particular to Japan, a strong sense of group consciousness has been built up within the shift crew of the operators which contributes to the efficient on-the-job-training.

In other words, accidents occurring within Japan or in other countries, are reviewed within the operator shift groups and efforts are made to prevent similar occurrences, or attempts are made to strengthen their mutual cooperation conducts by performing drills on simulated accidents.

II Improvements to maintenance management technology

One of the reasons that the nuclear power plants operating efficiency has risen steadily in the recent years is due to improvements in maintenance management technologies as described below.

(1) Application of periodic inspections

It is required by the regulation in Japan, to shut down the plant approximately once a year and execute periodic plant equipment inspections.

The contents of the inspections, have the aim of preventive maintenance, and the respective apparatus and components are dismantled and inspected at stipulated intervals, with emphasis given on ensuring the high level of quality assurance management by centering on severe checkings upon completion of the inspections and repairs made as necessary.

Also, by utilizing the informations regarding accidents and troubles occurring in nuclear power plants within or offshore of Japan, preventive measures are executed against recurrences of similar problems.

In the past, periodic plant inspections required more than 100 days, with total plant shutdown, but with the decrease of troubles due to design improvements of equipment and components, and increase in efficiency of time scheduling for dismantling and inspection tasks, the periodic inspection time has been reduced recently to approximately 60 - 80 days, which reflects favorably on the annual plant availability factor(Fig. 3).

(2) Preventive measures against typical LWR troubles

The typical troubles related to the LWR, or namely the Intergranular Stress Corrosion

Cracking (IGSCC) of the BWRs, and the steam generator tube damages of the PWRs, have been counter treated as described below.

i) IGSCC of BWR

The fundamental countermeasure against IGSCC is in selection of the material, hence for the existing plants the middle and small diameter stainless steel pipes have been gradually replaced with those containing low carbon contents stainless steel. For stainless steel pipes of large diameters the IHSI (Induction Heating Stress Improvement) method was developed and applied. The foregoing countermeasures have been completed on most of the BWR plants, so as the present, there are no more troubles with IGSCC occurrences.

ii) Steam generator tube damages of PWR

As the countermeasures against the typical troubles occurring in the steam generators of the PWR plants (e.g. tube corrosion of tube sheet crevice, thinning of tubes at locations of tube support plate, etc.), improvements to water quality control was executed, including replacement of sodium phosphate which was initially used, with hydrazine. Also, measures were taken against the tube by full depth expansioning. With such countermeasures as foregoing the occurrence of tube failure have steadily decreased.

For the new PWR plants that were built, the actions taken for strengthening the tube damage countermeasure include, improvement of steam generator tube material, change of the material for tube support plate and installation of demineralizers for improving water quality of feed water to be supplied to steam generators, as well as the measures against IGA which is being recognized recently, by intensifying the surveillance of existing free Na^+ content in the feedwater.

By thorough actions for strengthening the water quality management, it is greatly anticipated that the plant operations, henceforth, will be favorably affected by countermeasure as afore-mentioned.

(3) Improvements to measures against troubles

In case of troubles occurring in which the plant must be shutdown, the respective utility company will immediately report its situation to MITI (Japanese regulatory body) and the local governing authorities.

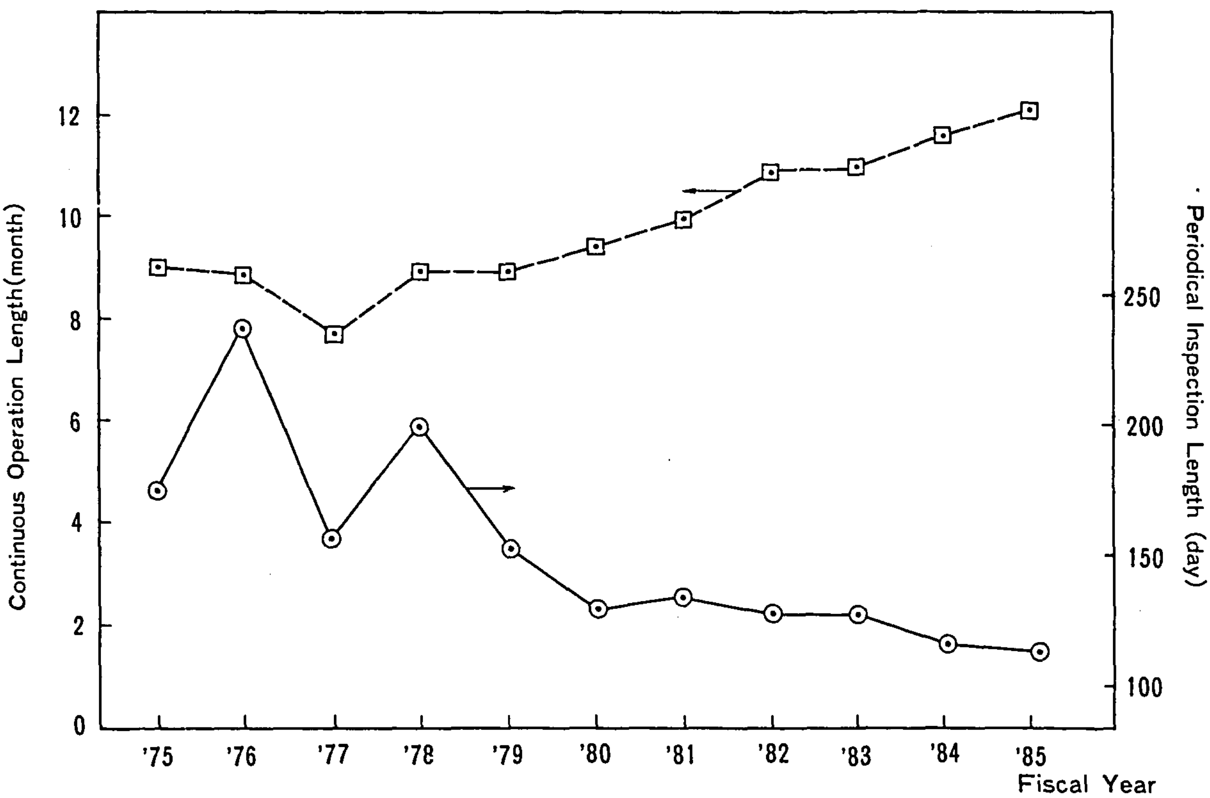

Fig. 3 Trend of Continuous Operation Length and Periodical Inspection Length

In such a case, the investigation of the source of the trouble, and appropriate countermeasures must be executed. Upon resolving the problem it is desirable to restart the operation of the plant, subject to MITI approval, as soon as possible, especially in consideration of its importance from the view point of public acceptance.

In Japan, the major nuclear equipment and component suppliers are on constant standby, and when trouble notification are received, they immediately dispatch engineers to the power plant site and offer technical aid to the utility company. This system has greatly contributed to resolving of troubles in the past.

(4) Improvement of contract maintenance work

For doing maintenance and other necessary tasks, such as during periodic inspections, the vendors execute all of the work under contract agreements with the utility companies. In general, for the annual maintenance work, about a half of the total volume of work is contracted by the major vendors (equipment and component suppliers), and the remaining half by the small and medium sized vendors operating in the locality of the respective power plant site. An important problem for the utility companies is in elevating the maintenance work technologies, especially of the small and medium vendors. For example, some of the measures being taken by the utility companies are, the level-up of the technical capability of the vendor individuals, the offering of positive advises as the vendors become regulars to the plant, as well as, the standardizing as much as possible, the dismantle and inspection work during annual periodic inspections.

III Improvement in designs of plant system and components

Since 1975, the utility companies and the vendors have jointly continued the cooperative work of improved standardization design for constructing light water reactors that possess high safety and reliability, by effectively reflecting the results of accumulated past experiences in operations and maintenances. The new power plants that were constructed and that began operation within the past one year, has been designed under the so called The 2nd Phase Improved Standardization Design, and contains features as follows:

For the BWR:

i) Improvement of maintenance workability inside the containment vessel.

ii) Adoption of anti-stress corrosion cracking (low carbon stainless steel) materials.

iii) Measures against crud formation and its removal.

iv) Expansion of areas for automation in in-service inspections (ISI).

For the PWR:

i) Improvement of the steam generator structure and automation of steam generator tube inspections.

ii) Improvement of fuel and refueling equipment.

iii) Automation of water analysis apparatus.

IV Improvement to water quality control

Generally speaking, the rise in radiation dose from the pipings of the nuclear reactor primary system is considered as the main reason for increase in the radiation exposure dose of the workers in the nuclear power plants, and actually this is caused by the adherence to the inner surface of pipings of distributed corrosion products (crud) of the primary system which had been activated in the reactor. And especially in the BWRs constructed at earlier period, the affect from crud being conveyed into the reactor through the reactor feedwater system were large.

In order to reduce the volume of crud being conveyed into the reactor system, the countermeasures applied to existing plants are described below, and are showing good results.

i) In the feedwater system, an appropriate quantity of oxygen is continuously injected which strengthens the oxidized film of the feedwater system piping (carbon steel) surface and restricts the detachment of corrosion products.

ii) A forward filter is installed in the condensate demineralizer which reduces inflow of crud from the condensate into the feedwater system.

iii) At the time of long shut down of the plant, such as during the annual periodic inspections, the feedwater system is drained as soon as the plant operation stops, and duration of the shut down the pipes are kept dry which prevents corrosion progress of the pipe surfaces.

iv) Prior to the startup of the nuclear reactor after a long shut down, the main condenser is made vacuum and deaeration operation is conducted by recirculation of the feedwater via the main condenser, which restricts corrosion products introduction to the reactor system at the time of nuclear reactor startup.

Also for the newly sited BWR plants, along with the actions as afore-mentioned, the measures in addition are such as using low cobalt materials for piping, and so the accumulated radiation exposure dose of the workers during annual periodic inspections have already shown an extreme decrease.

V Improvements to fuel design

It can be said that the BWR fuel of the early stages was poor in quality control regarding hygroscopic moisture in the process of the fuel pellets loading into the cladding tube during manufacturing, hence many fuel damages caused by hydrogen embrittlement inside the tube claddings were experienced during plant operations. However, with the improvement of quality control during manufacturing this has been practically resolved.

However, when the increase in the power generation of the nuclear reactor was executed and, consequently, sudden changes were imposed on the fuel rods, damages were experienced caused by the pellet-clad interaction, so in order to avoid sudden changes in power output, the interium operating management which restricts power raising rate was adopted.

And yet, due to the foregoing improved methods, although the damages to the fuel rods had decreased, it resulted in greatly limiting the reactor power increasing rate upon startup or when raising the power from lower level.

The countermeasure for this problem was to make fuel bundles that would withstand the sharp rise in power generation. Hence, a fuel with zirconium lining on the inner surface of the cladding was developed, and its use to practical application has already started.

Due to such improvements of fuel performance as mentioned above, the restrictions to plant operations are being eased, and in addition it is anticipated that load following operations can be sufficiently executed in the future.

Meanwhile, for the PWR fuels, in the early stages the fuel damages due to inadequate quality control of hygroscopic moisture within the fuel rods were experienced as the same as the BWR fuels. Also the collapse of fuel cladding due to high pressure in the PWR primary system was experienced.

Later, the collapse problem was solved by pressure enclosing helium (30 - 35 kg/cm^2) inside the fuel rods.

Furthermore, it was found that some damages occurred due to fretting caused by water vibrations to the fuel rods, by jet stream created inside the reactor from the seams of the baffle boards in the reactor core. This problem is also being solved by design revisions, from the original design of downward flow to the upward flow of the cooling water that flow the exterior of reactor core - baffle boards.

As the results of foregoing countermeasures, the fuel failure rate is on the decrease trend.

It is thought that there are some fuel damages caused by pellet-clad interaction, hence restrictions are enforced in the operation method at the time of increase in power generation, as the same as the BWR afore-mentioned.

Other experiences are, bending of fuel rods and damages to the grids caused by rubbing among fuel grids during the fuel exchanges. The problem of fuel rod bending was solved by increasing the number of grids (8 layers to 9 layers), and the improvement of the grid design.

VI Decrease in radiation exposure dose of the workers

During the early stages of the light water reactor operations, due to the accumulation of radioactive crud which were contained in the primary system coolants, the radiation dose of the primary equipments became high, and so the radiation exposure dose of the workers in relation to maintenance works reached, for the BWRs about 1,500 man·rem per year, and for the PWRs about 500 - 600 man·rem per year (Fig. 4).

As the immediate countermeasure by enforcing water quality control, the oxidized film of feed water quality control, the oxidized film of feed water system piping inner surface was strengthened and formation of crud was supressed, which resulted in the successful control against the trend of the radiation dose increase in the primary system. Also, the reduction of work radiation dose was executed by development of maintenance facilities using robotic technologies, such as, for the BWR, automatic control rods exchange apparatus, and for the PWR, automatic inspection and repair apparatus for steam generator tubes.

Furthermore, for the new plants, in addition to afore-mentioned technologies, low cobalt materials and appropriate shielding designs were adopted. As the result, the light water reactors that were built under The 2nd Phase Improved Standardization Design, and which started operation recently, achieved an extremely low radiation exposure dose of the workers less than 50 man·rem per year (Fig. 5).

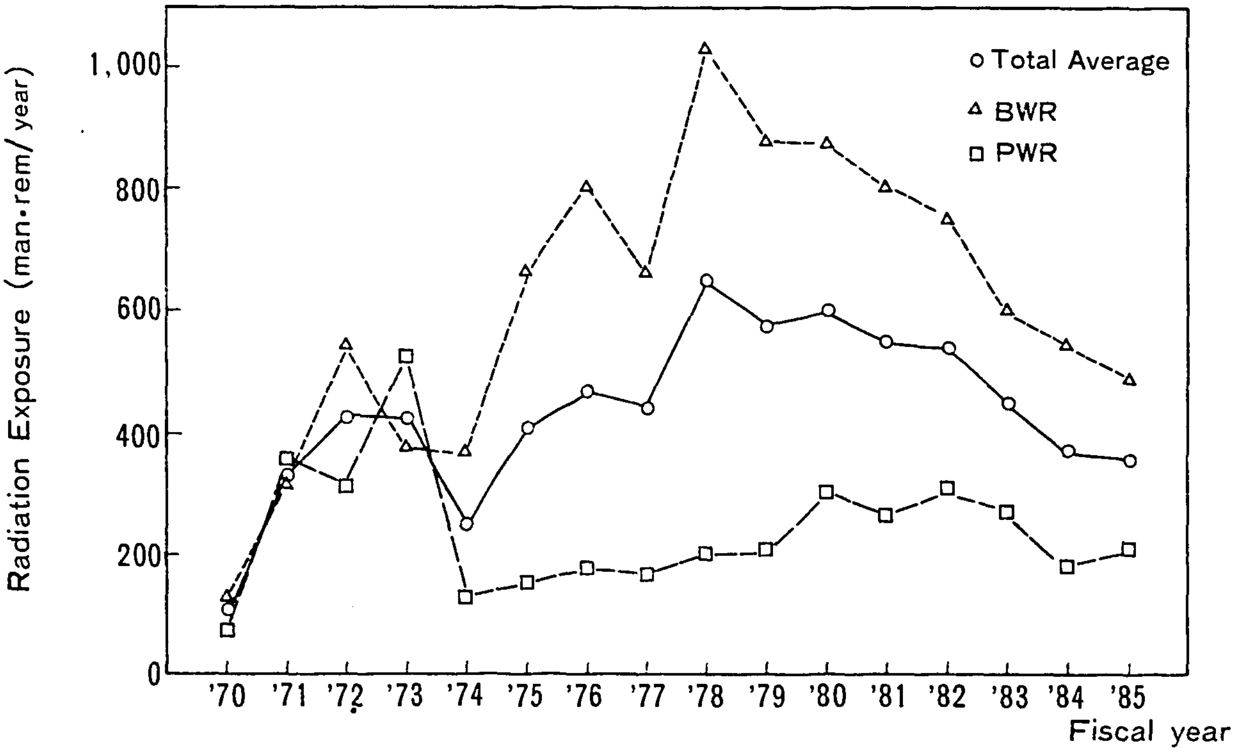

Fig. 4 Trend of Radiation Exposure per Unit

VII Improvement in radioactive waste treatment technologies

Regarding the liquid waste from the BWR plant, in order to restrict disposal to its environment, all drainage water produced from the plant had been given recycle treatment, thus the activity discharged to the environment has remarkably decreased. But on the other hand, with the increase in volumes of foregoing treatments, it began showing a trend in increase in the quantities of solid wastes, such as, the sludges of used filter aids and cement solidified drums containing concentrated liquid waste.

In order to improve such situations, measures conceived were in using filters that did not require filter aid materials, or by adopting methods of bitumen or plastic solidifications for the concentrated liquid waste, which resulted in large reduction in the volume of solid wastes created.

Furthermore, by adopting the dry cleaning apparatus for disposal of laundry liquid waste, the yearly disposal volume of liquid waste from the light water reactors have been reduced to less than 1 mCi per respective unit (Fig. 6).

Other measures adopted are, installing incineraters to dispose of combustible solid waste, which contributes greatly to reducing the volume of solid waste accumulation.

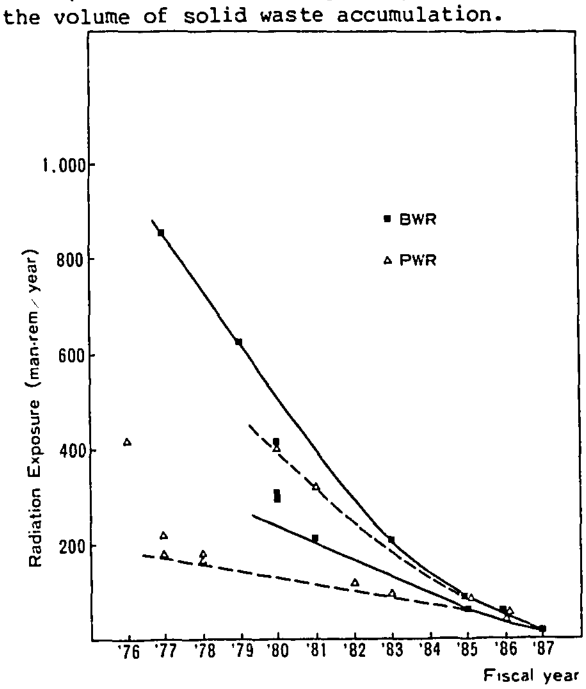

Fig. 5 Trend of Radiation Exposure of the First Annual Periodic Inspection Outage

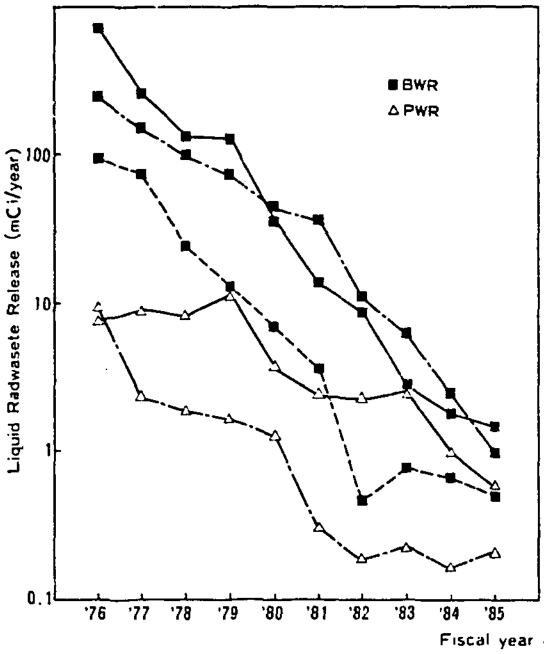

Fig. 6 Trend of Liquid Radwaste Release per Year

CONCLUSION

As the result of continuous efforts on imporvements to the facilities design and management technologies on operation and maintenance, based on past experiences, steady improvements have been realized, not only in the plant availability factor, but also in reliability of operation and maintenance, radiation exposure control, and radwaste management.

Even since the Chernobyl nuclear power plant accident, the necessity for considerations of the human factor problems in the operation of nuclear power plants have become strongly stressed. In Japan, currently, these problems are being taken care of by information exchanges and joint studies among the utility companies, and further effort is being exerted aimed at securing the more safe, reliable and economic nuclear power generation in the future.