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EFFORTS TO REDUCE EXPOSURE AT JAPANESE PWRs: CVCS IMPROVEMENT

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ABSTRACT

Many reports have been focused on the reduction of radiation sources and related occupational exposures. The radiation sources mainly consist of corrosion products. Radiation dose rate is determined by the amount of the activated corrosion products on the surface of the primary loop components of Pressurized Water Reactor (PWR) plants. Therefore, reducing the amount of the corrosion product will contribute to the reduction of occupational exposures. In order to reduce the corrosion products, Chemical and Volume Control System (CVCS) has been improved in Japanese PWRs as follows :

a. Cation Bed Demineralizer Flowrate Control
b. Hydrogen Peroxide Injection System
c. Purification Flowrate During Plant Shutdown
d. Fine Mesh Filters Upstream of Mixed Bed Demineralizers

INTRODUCTION

In most nuclear power plants, annual inspection has been a major contributor to the occupational exposures. If operating plants have extra works such as maintenance without scheduled shutdown, their extra occupational exposures tend to increase. Mitsubishi and Japanese PWR utilities have been successful in reducing the occupational exposures, despite the numerous inspections of the PWR primary loop pipes and components. Figure 1 shows a trend of the collective exposures at the Japanese PWRs for the past two decades.

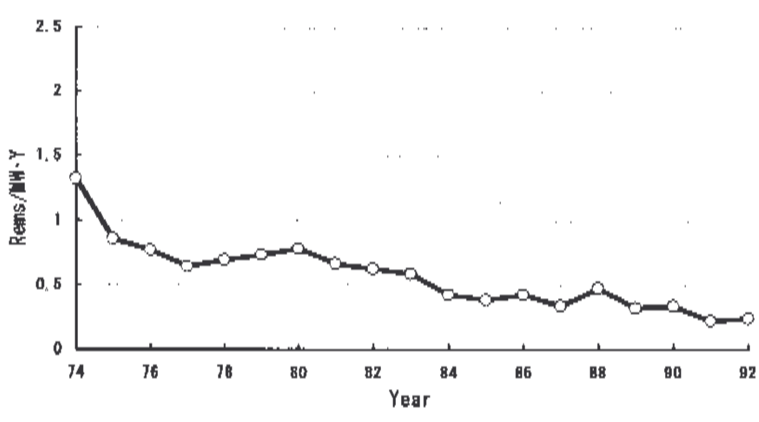


Figure 1. Radiation exposure : Japanese PWR plants

In 1974, 1.3 person–rem was incurred for each MW–year of electric power generated; in 1992, 0.24 person–rem was incurred. Then, there has been a fivefold reduction in person–rem per MW–year.
Because of the plan to replace steam generators (SG) in the near future, the need for extra works will increase. Therefore, the Japanese PWR utilities have intensive requirements to reduce both the collective and individual doses. In the early 1980s, Mitsubishi worked out a strategy for the exposure reduction and began to study the way how to reduce the exposures. The occupational exposures are composed of the time spent in the radiation field and the radiation level. The former depends on the amount, the difficulty, and the efficiency of work to be done. The latter is affected by the radiation sources, namely the amount of radioactive nuclides, especially cobalt, to exist on the surface of the primary loop components. The key elements associated with controlling the radiation source are summarized in figure 2. In the current paper, Mitsubishi introduces the outline of our works in this field.

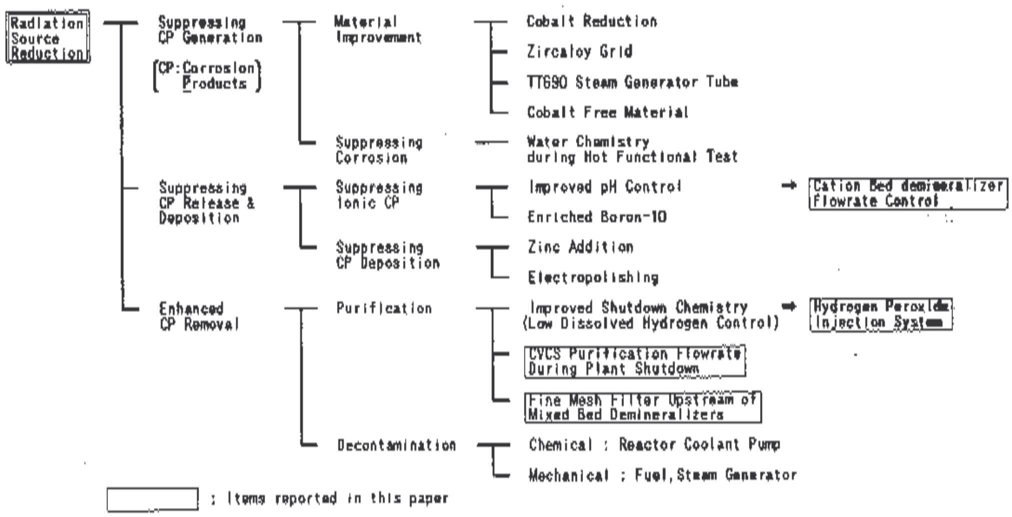


Figure 2. Key elements to control radiation sources

CVCS IMPROVEMENT

General System Feature

Figure 3 shows a simplified flow diagram of the CVCS. This shows a typical arrangement for a conventional 4-loop plant but all plants are basically similar. This system, which is usually referred to as the "CVCS" system, is one of the most important parts of PWR. It performs several functions when the plant is operating. Some of the functions are to purify the primary coolant water continuously and to adjust the primary water chemistry. Filters and demineralizers are provided for these purposes.

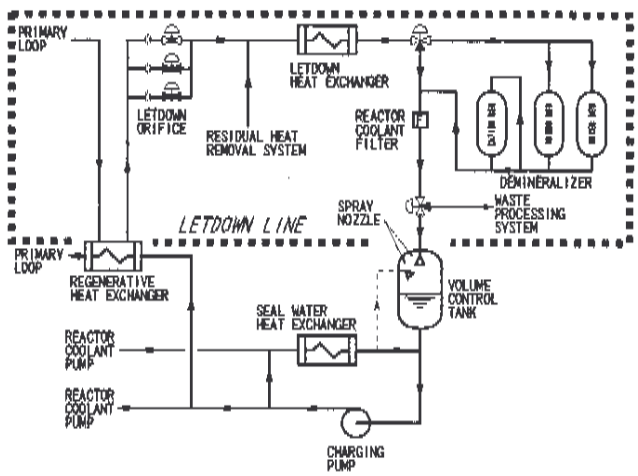


Figure 3. CVCS flow diagram

Figure 3 shows also what is called the letdown path. During a normal operation, water comes from one of the primary loops at a pressure of approximately 157 kg/cm^2 and is first cooled by the Regenerative Heat Exchanger. The letdown flow passes one of Letdown Orifices which reduces the pressure. The flow is then cooled further by the Letdown Heat Exchanger. The flow is cool enough to pass through the demineralizers for the purification downstream of the Letdown Heat Exchanger. The demineralizers remove ionic fission products and corrosion products. Filters are provided to ensure filtration of particles.

A further purification feature is provided for use during a shutdown operation. It is called the Low Pressure Letdown path. The Low Pressure Letdown flow bypasses the Regenerative Heat Exchanger and the Letdown Orifices, and passes into the letdown line upstream of the Letdown Heat Exchanger from Residual Heat Removal System.

System Improvements

Cation Bed Demineralizer Flowrate Control

The chemical control reagent employed for pH control is Lithium Hydroxide (LiOH) in PWRs. Li-7 is produced in the reactor core region due to irradiation of dissolved boron. The Li concentration is maintained within a certain control band. If the Li concentration exceed the control band, the Cation Bed Demineralizer is employed in the letdown in series operation with the Mixed Bed Demineralizer. Optimum control of the water chemistry is recognized to suppress the transport and activation of corrosion products. Mitsubishi has thought that the pH of 7.3 (@ 285° C) is appropriate to reduce the radiation source, which is based on our experiments and foreign information. Maximum Li is still 2.2 ppm, because we do not have enough data of the effect on Inconel yet. Mitsubishi has proposed to the Japanese PWR utilities that the Li is held at 1.8 to 2.2 ppm until a pH of 7.3 ± 0.1 (@ 285° C) is reached and then the Li is controlled to maintain the pH of 7.3 ± 0.1 (@ 285° C) until the end of the core cycle. This Li band is shown in figure 4.

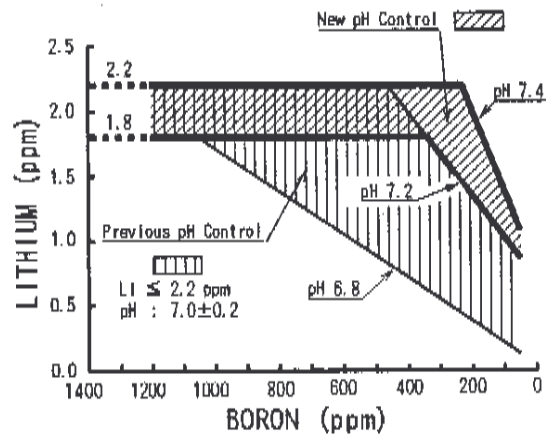


Figure 4. Lithium control band proposed by Mitsubishi

The Cation Bed Demineralizer flowrate is usually equivalent to the normal letdown flowrate. When it is necessary to remove some excess Li, the letdown flow passes through the demineralizer. In most operating plants, the operator numerously has to divert the flow path around the demineralizer, especially in the beginning of the core cycle (Figure 5).

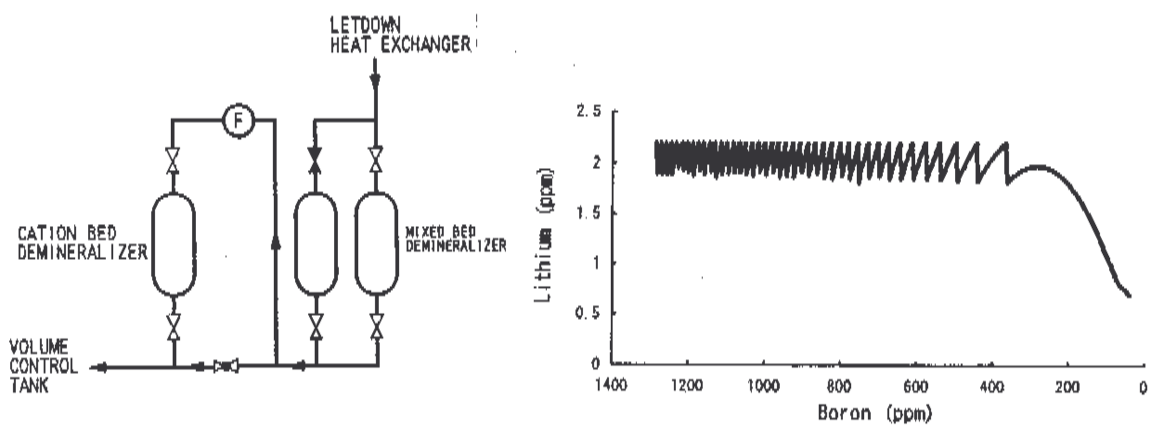


Figure 5. Manual control system and Lithium variation

Such numerous diversions would load on the operator. Therefore, the Japanese PWR utilities have preferred an automatic Cation Bed Demineralizer flowrate control system to lighten the operator's work. Mitsubishi has improved the cation bed demineralizer flowrate control system to control a low flowrate about 0.5 m^3/hr (nearly 2 gpm) continuously and remotely. Figure 6 shows the above improved system that will decrease significantly the frequency of the flow path diversion.

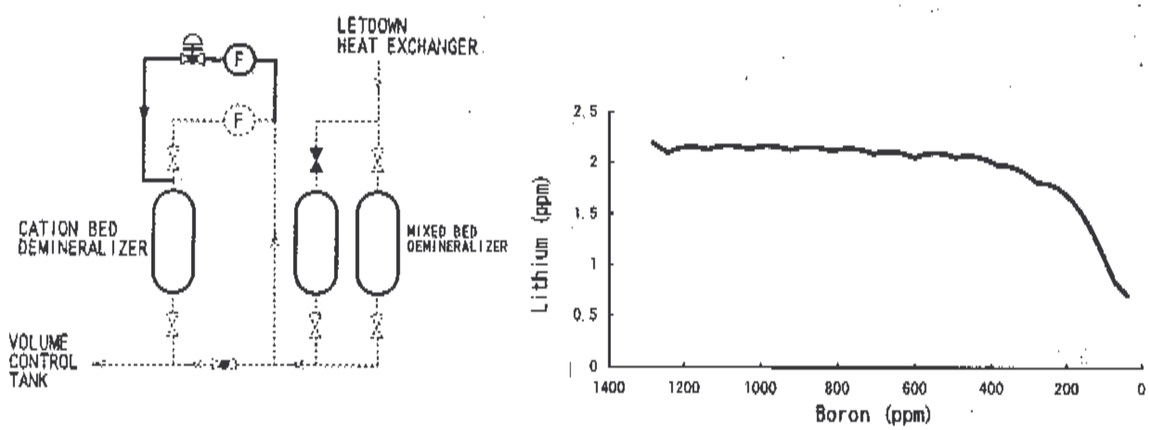


Figure 6. Continuous & remote control system and Lithium variation

Figure 7 presents our future plan of a full-automatic control system with a Boron meter and a Li meter, which would be controlled by a computer.

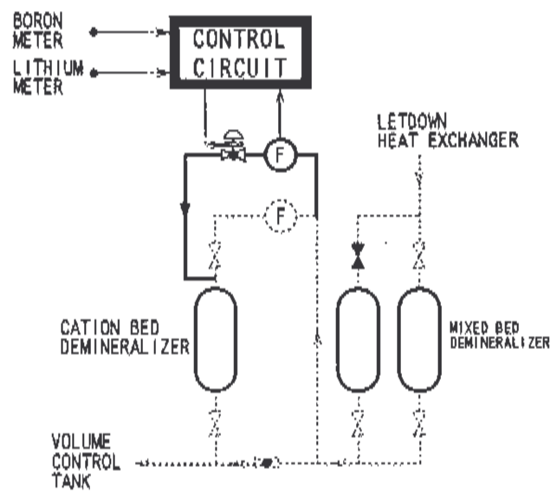
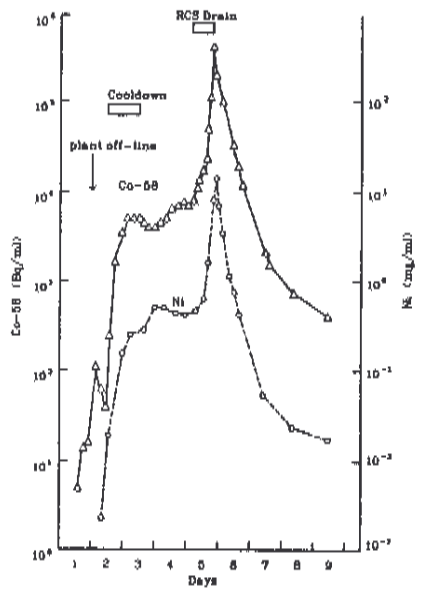


Figure 7. Full-automatic control system

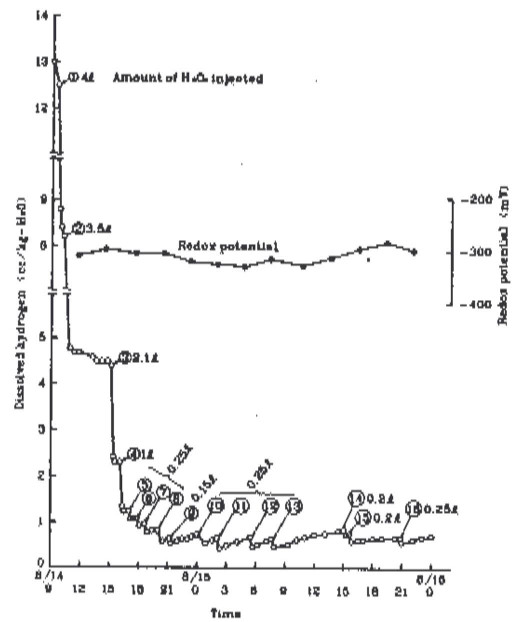
Hydrogen Peroxide Injection System

It is well-known that the soluble corrosion products reach an extremely high level after a plant hot shutdown, because the temperature and the chemical condition of the primary coolant vary to a great extent. Figure 8 shows an example of cobalt and nickel concentration during the shutdown operation. The concentration was observed to be 1000 or 10000 times higher than that during the power operation.



Co-58 and Ni concentration changes during the plant shutdown process (Genkai nuclear plant unit 2 6th annual inspection)

Figure 8. Co and Ni concentration during plant shutdown[1]



Changes of dissolved hydrogen concentration and redox potential by hydrogen peroxide injections (30% H_2O_2)

Figure 9. Dissolved hydrogen concentration with Hydrogen Peroxide addition[2]

Thus, the removal of the corrosion products during the shutdown operation is effective in reducing the radiation sources. In order to promote the corrosion product removal, Mitsubishi studied "Low Dissolved Hydrogen Control" with the Japanese PWR utilities. A low dissolved hydrogen concentration of approximately 0.5 cc/kg-H_2O was obtained to be optimum during the shutdown operation, promoting the corrosion product removal. Hydrogen Peroxide (H_2O_2) is injected to the primary coolant circuit after the cooldown operation to accomplish the chemistry condition.

The chemical reagent can be added by pouring them into the Chemical Mixing Tank which is connected with the Charging Pump suction line. Figure 9 shows a result of the dissolved hydrogen concentration with the Hydrogen Peroxide addition in an operating plant. The dissolved hydrogen was revealed to decrease rapidly. However, a lot of Hydrogen Peroxide addition was necessary to reach and maintain the low dissolved hydrogen.

Since the study, Mitsubishi developed the "Hydrogen Peroxide Injection System" to add the hydrogen peroxide semi–automatically (Figure 10). This system is composed of one tank, one positive displacement pump and several valves. The Hydrogen Peroxide is poured to the tank in advance. As a operator starts the system, an adequate quantity of the Hydrogen Peroxide is injected to the Charging Pump suction line. Then, an equipped timer terminates the injection. The flowrate is controlled by the pump stroke and/or the pump rotation.

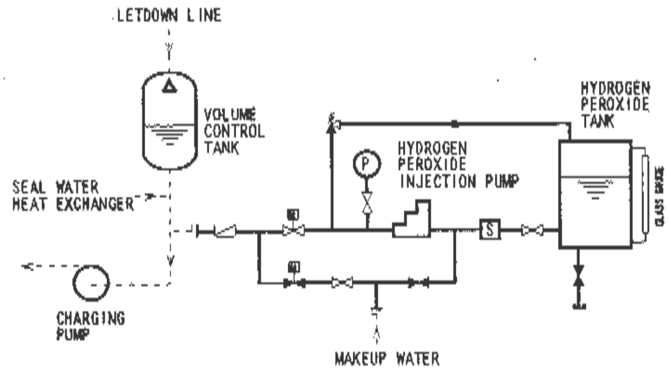


Figure 10. Hydrogen Peroxide injection system

Purification Flowrate During Plant Shutdown

The CVCS is used to purify the primary coolant water continuously and demineralizers are provided for this purpose. During the shutdown, concentration of cobalt and nickel is observed to be 1000 or 10000 times higher than that during the power operation (Figure 8). Therefore, the corrosion products can be removed effectively during the plant shutdown. With increasing the purification flowrate, the corrosion products would be removed more effectively. The CVCS purification flowrate is applied to two periods, such as the power operation and the shutdown operation. Increasing the flowrate during the power operation would increase the plant construction cost and on the other hand, would increase the plant heat loss. However, increasing the flowrate during the shutdown does not cause much increase in the plant construction cost nor the increase in the plant heat loss. Mitsubishi assessed the purification flowrate during the shutdown at approximately 60 m^3/hr (260 gpm) for conventional 4–loop PWR plants. If the purification flowrate during the shutdown would be increased for aging plants, the following improvements are required (Figure 11).

- Shift of the piping diameter to larger size, in the Low Pressure Letdown line.
- Increasing the capacity of filters, both upstream and downstream of the Mixed Bed Demineralizers.
- Additional installation of piping and valve, in order to use the Auxiliary Spray Nozzle of the Volume Control Tank together with the normal nozzle.

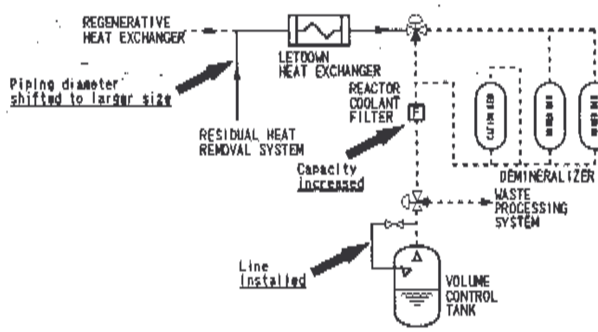


Figure 11. Improvement for increasing purification flowrate during shutdown

Fine Mesh Filters Upstream of Mixed Bed Demineralizers

In the letdown line of the conventional plant, only the Reactor Coolant Filter is provided downstream of the Mixed Bed Demineralizers, in order to collect the resin fines and particulate matter larger than 25 micron. The particles in the fluid would accumulate in the Mixed Bed Demineralizers. The accumulated particles would return to the primary circuit as released from the demineralizers. Diverting the demineralizer's effluent to the waste processing system would prevent the particles from returning to the primary circuit. This operation would load on the operator. By installing a fine mesh filter upstream of the Mixed Bed Demineralizers, the particulate corrosion products could be removed and the surplus operation should not be necessary. The diameter of the filter porosity is lower than one micron. The fine mesh filter would result in the radiation source reduction.

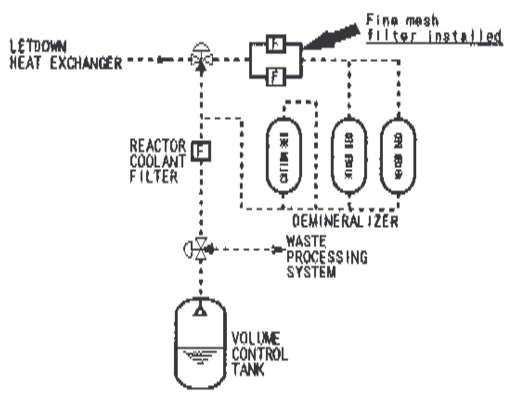


Figure 12. Installation of fine mesh filters

CONCLUSIONS

This paper introduces four CVCS improvements in Japanese PWRs. Mitsubishi has endeavored to reduce the occupational exposure by improving the system design and water chemistry. However, the efforts for further reduction of the exposure are still continuing.

REFERENCES

1&2 Tawaki, S., Koyasu, T., Katayama, Y., Yokota, T., Hisamune, K. and Saigusa, M., "Improvement of Shutdown Chemistry for Outer Oxide Layer Removal," in *1991 JAIF International Conference on Water chemistry in Nuclear Power Plants*, pp. 168-173, Japan Atomic Industrial Forum, Inc., Fukui City, Japan, April 1991.

Author Biography

Ryosuke Terada is a Senior Engineer with the Water Reactor Division of Mitsubishi Atomic Power Industries, Inc. in Japan. Mr. Terada has worked on designing the Nuclear Steam Supply System of commercial Japanese PWRs, that involved "Chemical and Volume Control System," "Emergency Core Cooling System," "Residual Heat Removal System," and other safety-related systems. Recently, he became a member of the Dose Reduction Program in Mitsubishi Group. Previously, he was engaged in the start-up test and operation at Takahama unit 4 of Kansai Electric Power Company, Inc., Japan. He holds an M.A. Sci. in Nuclear Engineering from Osaka University in Japan.

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DISCUSSION

Khan: I have two questions. The first question is about your automatic pH control system. Is it exclusively designed for Mitsubishi-designed reactors, or can it also be installed in other types of PWRs?

Terada: No, it isn't. We can apply it to any plants. This automatic system is for operating plants have decided to install and we have another option. It is manual needle valve system to control the low flow rate. So in this case about ten or thirteen plants have decided to install.

Khan: My other question relates to when you increase the purification flow during shutdown. Typically, I think, in PWRs you take a few percent. By how much do you increase the purification flow?

Terada: We increase the purification flow during shutdown up to 60 m^3/h for the conventional plants.

Helman: Did you backfit these or are these all a part of new construction? Did you add these systems to existing plants, or are these new construction ideas?

Terada: Yes, we did. The system has been added to existing plants.

Helman: I know that you added a couple of new fine filters, and usually when you add filters to systems you also increase your rad waste and increase your maintenance exposure to change those out. Did you see any of that?

Terada: Yes. Waste disposal will increase, but the fine mesh filter is mainly for preventing accumulated matter from returning to the primary circuits. Additionally the filter is effective to radiation exposure reduction.

Khan: I just want to add the point about the filters. Several years ago John Baum visited the Obrigheim Nuclear Power Plant in Germany and they strongly recommended the use of these ultra-fine pore filters. They suggested that you gradually transition to them, using intermediate pore sizes. In that case, your rad waste problems and exposures are much reduced. You lower the particulate activity gradually, and eventually you end up with the very fine mesh filters that you have been talking about.