CONSOLIDATION AND CONDITIONING SYSTEM

FOR SPENT BURNABLE POISON ROD ASSEMBLY

H. Yamada, Y. Komatsu, M. Taguchi
Kobe Steel, Ltd.
Nuclear Engineering and Equipment Division
Tokyo, Japan

Y. Yamamoto
Transnuclear, Ltd.
Tokyo, Japan

ABSTRACT

New consolidation and conditioning process for spent burnable poison rod assembly have been proposed and summarized in accordance with the existing options on spent fuel and waste management. A consolidation system utilizing sequence control robot operated under water has been applied to actual spent burnable poison rod assembly at PWR sites. The volume of burnable poison assembly was reduced safety and securely by a factor 7 to 14 for burnable poison rods and by 22 for hold down portions. An advanced type of consolidation system as well as conditioning system for dry storage and disposal has been clarified and proposed. Basic safety analysis method in connection with tritium release has been carried out based upon PIE and diffusion model.

INTRODUCTION

In pressurized water reactors (PWRs), burnable poison rod assemblies (BPRAs) are used for supplementary control of excess core reactivity. With a current trend of core management toward 18-month extended fuel cycles[1], the number of BPRA used is increasing. Spent BPRA is generally stored in a spent fuel pool at reactor site even in the countries adopting the reprocessing option because many reprocessing plants do not receive BPRA at present. The space for spent BPRA in a spent fuel pool will not be enough in the near future. On the other hand, in countries not adopting the fuel reprocessing option, such as the United States, the spent fuel pools are filling up and an increase in the storage capacity on site as well as away from reactor site will be needed in the near future. Fuel rod consolidation is considered to be one of the most feasible processes for economical high density storage of spent fuel and spent BPRA could not be stored in spent fuel assemblies in this case. So consolidation system for BPRA to realize higher density storage in a spent fuel pool as well as conditioning system for dry storage and/or disposal will have to be completed. The purpose of this paper is to propose a new management systems for spent BPRA with actual application experience and to evaluate some management alternatives.

Here management systems for BPRA, consolidation and conditioning are summarized in accordance with the existing options on spent fuel and waste management policy. A consolidation system for BPRA by means of a specially designed sequence control robot, which is operated under water, is.introduced, by which hundreds of BPRA have been consolidated in Japan.

A conditioning system, packing BPRA in a storage and/or disposal container after cutting BPRA into pieces, is also proposed. Behavior of tritium, which is produced in spent BP rod by nuclear reaction of boron and neutron in a reactor core, is evaluated from the results of PIE.

MANAGEMENT OF SPENT BURNABLE POISON ASSEMBLY

The conventional Westinghouse-type burntable poison (BP) rod[2] consists of annular borosilicate glass tubing enclosed in a sheath of stainless steel. A small diameter stainless steel tube is inserted inside the glass tubing for support, and the rod is sealed by welding plugs at both ends. The rod is suspended from the BPRA, as shown in Fig. 1.

Spent BPRA contains much of tritium as the product of nuclear reactions of boron and neutron and release of tritium from BPRA should be clarified when the storage or disposal be discussed. There are two treatment concepts classified and characterized as the following. Consolidation and conditioning system for spent BPRA or the combination of them will have to be evaluated in details according to the spent fuel and waste management policy in each country as well as the ristriction of each PWR site.

Consolidation

Consolidation for spent BPRA is here defined as to pack BPRA into basket for high density storage after dismantling just like fuel rod consolidation. The consolidation process would be effective in the case where storage or disposal container with the length more than 4 meters could be acceptable or where the spent fuel pool would be large enough to store the consolidated BPRAs. A consolidation process has been completed and has practically been applied to Japanese PWRs, which is described below.

Conditioning

Conditioning for spent BPRA is here defined as to pack BPRA into container with or without matrix after dismantling and cutting into pieces for dry storage and/or disposal. The conditioning process would be effective in the case where storage or disposal containers would be designed in accordance with various ristrictions. As can be seen in Japan where waste disposal could not be realized in the near future and large scale dry storage containers would not be compatible with the existing waste storage building at reactor site, the conditioning system would be effective.

Conditioning system would also be needed when the homogenuity of the waste for disposal would be required. As for the solidifying matrix of the cut BPRP for disposal, cement is considered to be most feasible evaluating of the high induced activity of stainless steel and of the release of tritium.

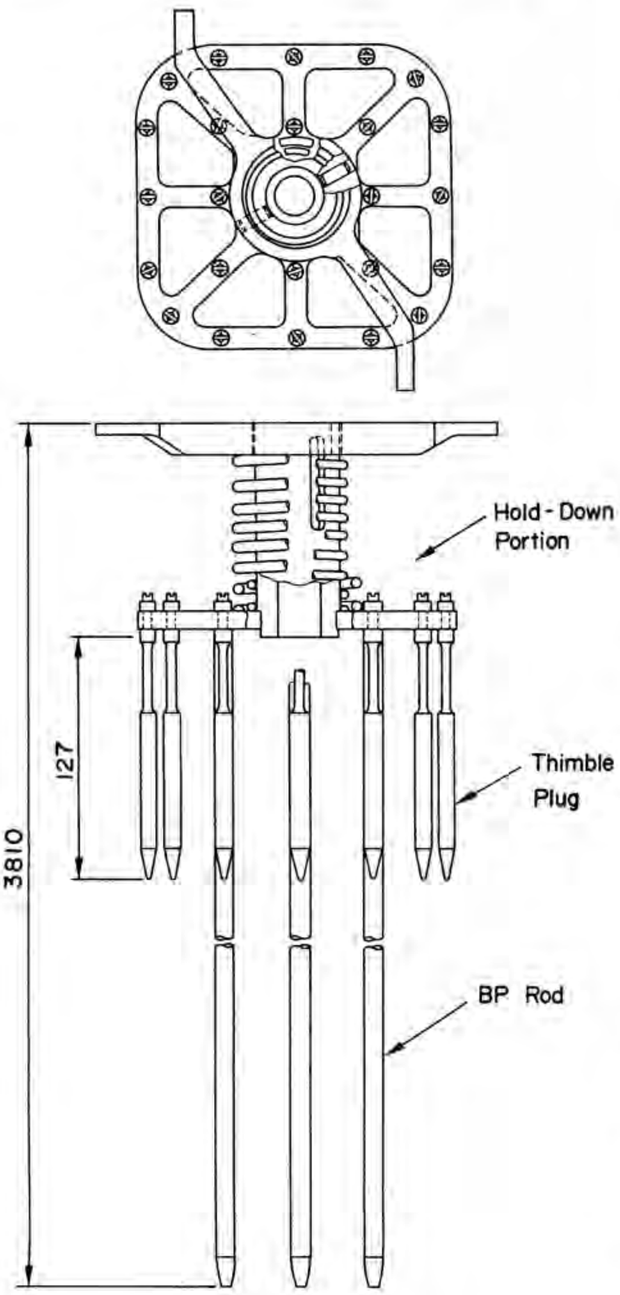

Fig. 1. Burnable Poison Rod Assembly.

CONSOLIDATION SYSTEM FOR SPENT BPRA

System Description

The consolidation system is composed mainly of arraying holder, sequence control robot, BP basket, hold-down basket, and handling tool. The sequence control robot[3] is shown in Fig. 2. The cutting, packing, and positioning mechanisms, stands for the BP rod basket, hold-down basket and for the arraying holder are attached to the frame. The hold-down portion of the BPRA is gripped and positioned by the clamp, which is located on the upper part of the cutter. Two sets of cutters made of special tool steel are fitted on the turntable and precisely positioned according to the configuration of the BP rods. The blades of the cutters are closed by means of a hydraulic cylinder, and the part of the end plug is cut without doing any damage to the rods.

The BP rods in the arraying holder are packed into the BP basket by the packing mechanism. The BP rods are introduced into the guide tubes of the BP basket, which holds 144 BP rods, by the driving and free rollers. The pressure on the rods by the rollers is controlled so as not to cause permanent deformation of the BP rods. The arraying holder and basket for BP rods are set at the desired position by the positioners, which are driven by air cylinders. The hold-down basket is set in the stand attached to the upper part of the frame. The cutting mechanism, positioning mechanism, and upper parts of the frame can be remotely dismantled, and any part of the BPRA can be separated from the robot if there are equipment problems during treatment. A specially designed handling tool for remote dismantling can be operated from floor level.

Each part of the robot is moved by an air cylinder, except the cutting blade, which is powered by the hydraulic cylinder as described previously. All movements of the robot are detected by magnetic sensors and are indicated on the control panel. The robot is automatically operated by means of a sequence controller, based on the sensor signals.

Operating Flow

The arraying holder and BP basket are set on the positioning mechanism, and the hold-down basket is set on the stand. At the top of the arraying holder guide tubes are arranged according to the BP rod configuration, and guide tubes are set in a line at the bottom. Shutters, which open and close the bottom, are attached to the arraying holder.

The BPRA is inserted into the arraying holder and is moved to the center of the equipment. The BPRA in the arraying holder is elevated and the hold-down portion is clamped. Cutters are positioned at the BP rods, and the end plugs are cut and separated from the hold-down portion. After all of the BP rods are cut, the hold-down portion is unclamped and packed into the hold-down basket, in which 22 hold-down are stacked up, by means of the multipurpose handling tool. The arraying holder containing BP rods is transferred and set on its stand, which is located in the upper part of the packing mechanism, by means of the positioning mechanism and multipurpose handling tool. The BP basket is set at the desired position to connect the guide tubes of the arraying holder and the BP basket. The shutter of the arraying holder is opened and the

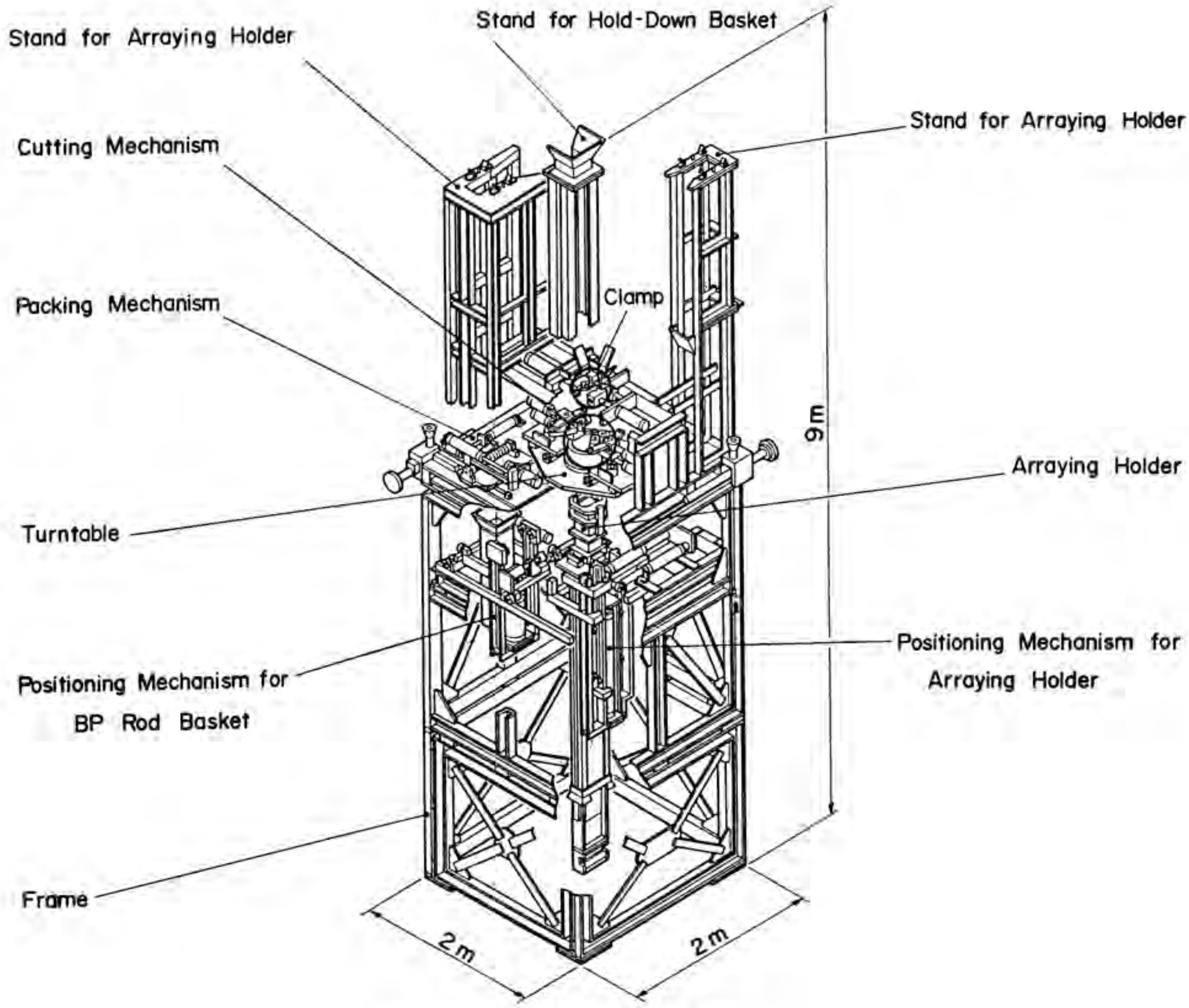

Fig. 2. Sequence Control Robot.

BP rods are packed into the guide tubes of the BP basket by the packing mechanism. The baskets filled with BP rods or hold-down portions are transferred to the desired storage rack by the multipurpose handling tool.

Consolidation Experience

Several hundreds of BPRA have been consolidated at Japanese PWRs. The performance of the robot was observed by three sets of underwater television cameras. Observation showed that the end-plug portions of the BP rods were cleanly cut and each of the movement was reliable. The volume reduction factor for BP rods is 14 to 7 and that for the hold down portion is 22. It took about 40 to 50 minutes to consolidate a BPRA. The collective application of the system was proved and confirmed by the operation at PWR sites.

Advanced Type of Consolidation Equipment

Advanced type of consolidation equipment has been developed and is shown in Fig. 3., which has the same function as the sequence control robot and handling tool as described above. The dimension and weight of the advanced type is much smaller as compared with the conventional type and the volume reduction factor as well as consolidation speed has been improved. The demonstration test for the advanced type of equipment has been performed.

It was also proved that the advanced consolidation system is collectively feasible.

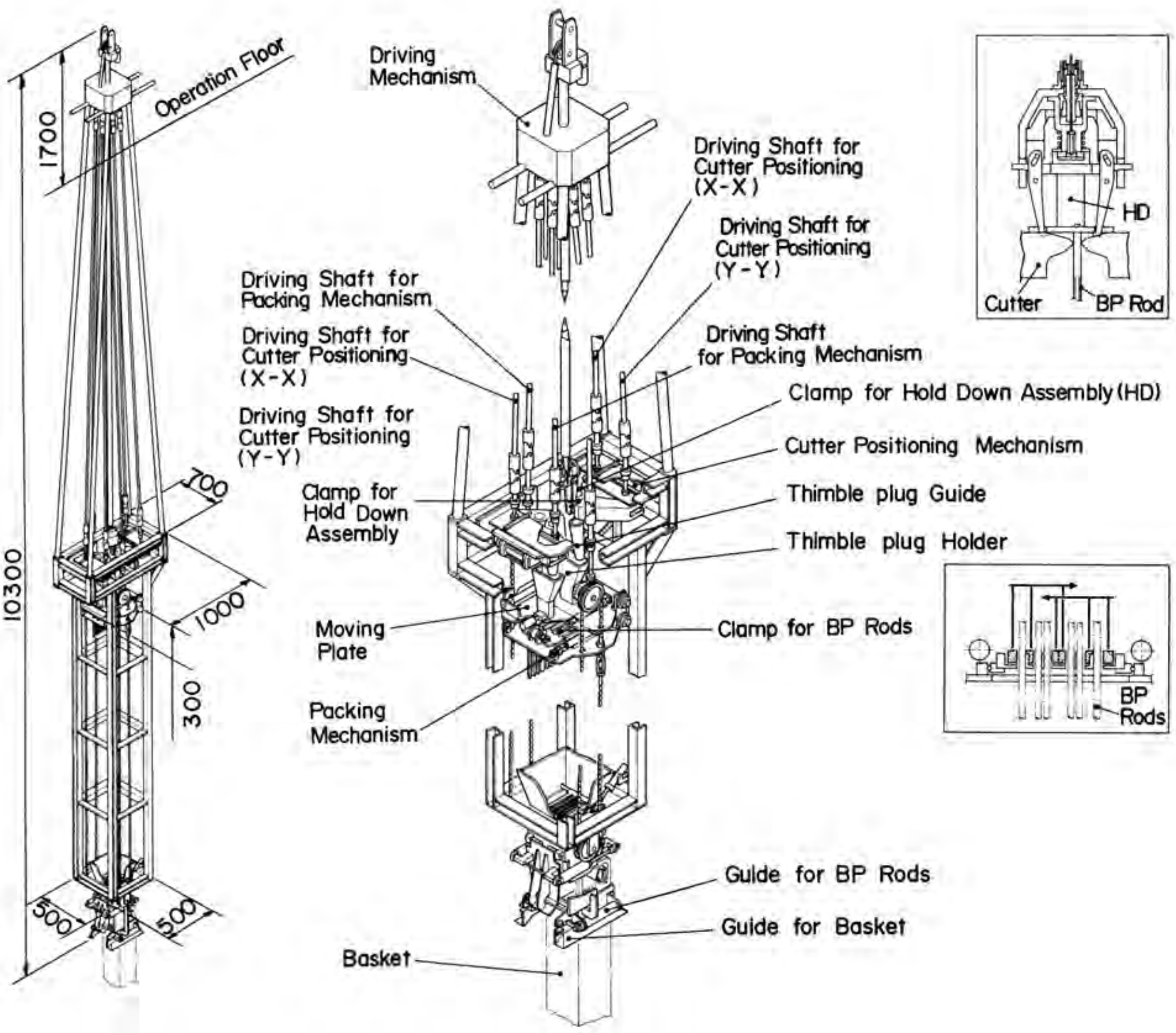

Fig. 3. Consolidation Equipment for Spent BPRA (Advanced Type).

CONDITIONING SYSTEM FOR SPENT BPRA

Conditioning system for spent BPRAs has been designed and the concept of the system is shown in Fig. 4. Spent BPRA is clamped in spent fuel pool by a specially designed handling tool with shielded wall and is transferred to cutting and packing equipment. The handling tool is connected to the equipment with tritium recovery unit and the inside of them is sealed off. The BPRA is descended to the shredder and cut into pieces, which are packed into the shielded container. The lid of the container is set in the equipment and the container comes out of the equipment after monitoring of tritium activity in the equipment.

The lid of the container is welded and sent to storage or disposal place. The tritium contained in the container is considered to be immobilized in borosilicate glass matrix in the form of hydro-oxyle group[3]. So release of tritium from the container can be evaluated very small. Solidification unit with in-drum-mixer can be attached to the cutting and packing equipment in the case where cement matrix would be needed. Anyway conditioning system as described above has been basically completed and safety evaluation including the behavior of tritium can be performed based upon the information as shown in the next section. However, the system will have to be optimized in accordance with the conditions and ristrictions of each reactor site as well as of disposal site.

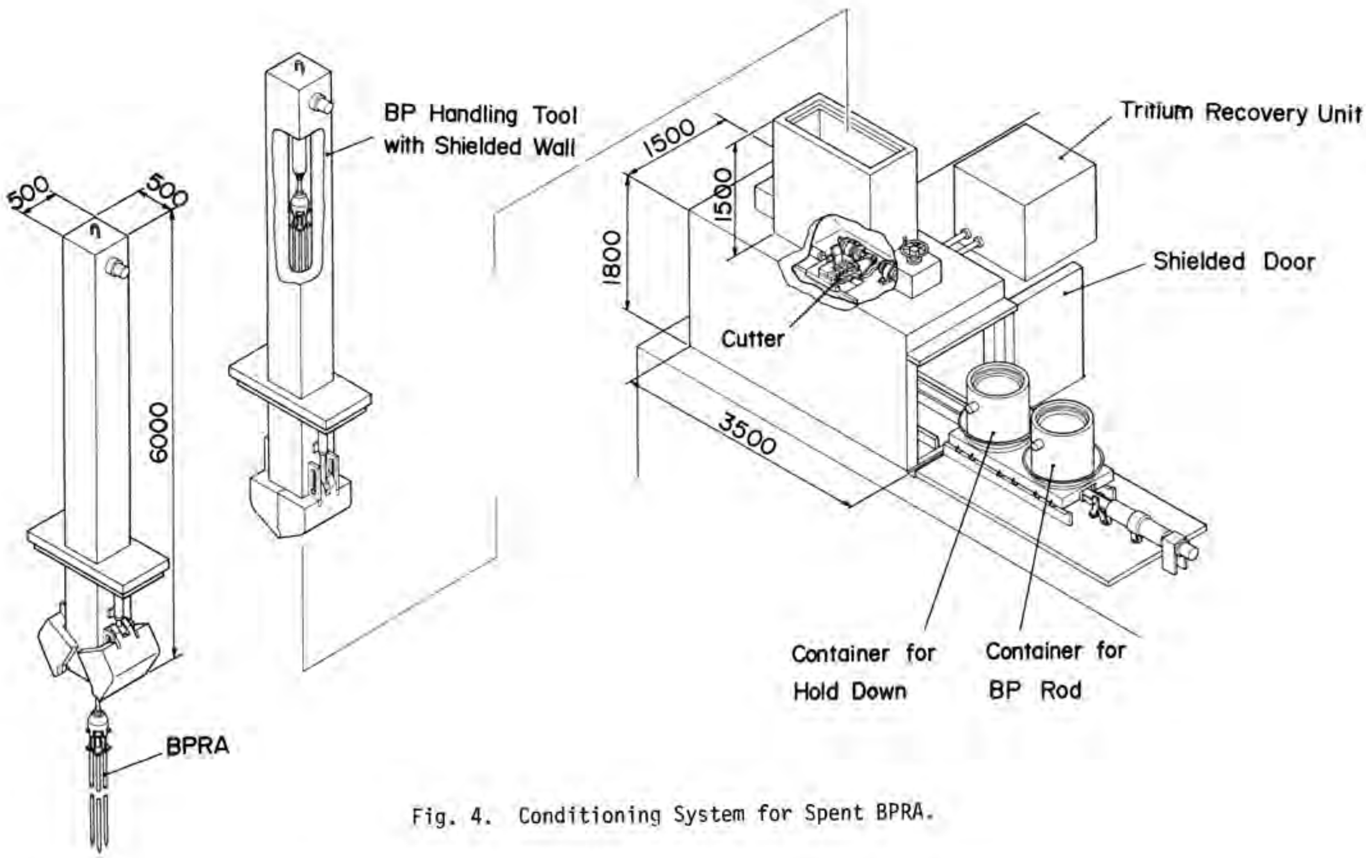

Fig. 4. Conditioning System for Spent BPRA.

SAFETY ANALYSIS

The behavior of tritium in BP rod is analyzed to evaluate the amount of tritium released in consolidation or conditioning system as well as during storage or disposal. The radioactivity of tritium in a BP rod is estimated to be about a curie, which is calculated by the ORIGEN code for 3 years of irradiation in a conventional PWR core. Tritium is produced by the major nuclear reactions of neutron and boron as follows:

$$10_B\ (n,\alpha)^7Li(n,n\alpha)^3T, \qquad (1)$$

$$10_B\ (n,\alpha)^7Li(n,2n)^6Li(n\alpha)^3T, \qquad (2)$$

and

$$10_B\ (n,2\alpha)^3T, \qquad (3)$$

It has been reported[4] that tritium produced in borosilicate glass would react with oxygen to form OT and diffuse out by a similar mechanism, as in the molecular diffusion of water in glasses. The chemical form of tritium released from neutron-irradiated borosilicate glass is tritiated water, and the amount released is determined by the diffusion of tritium in borosilicate glass. When tritium is released from borosilicate glass, it remains in the cladding, for the permeability of tritiated water in stainless steel is minimal. The amount of tritiated water existing in the free space in BP rods depends mainly on the irradiation period, influenced by the temperature in the reactor core and that in the storage pool.

The diffusion equation in a cylindrical system is expressed as follows:

$$D\left(\frac{\partial^2 C}{\partial r^2} + \frac{1}{r}\cdot\frac{C}{r} + \frac{\partial^2 C}{\partial Z^2}\right) + S = \frac{\partial C}{\partial t} \qquad (4)$$

where

- D = diffusion coefficient of tritium in borosilicate glass
- C = concentration of tritium at position (r,Z) in
- t = time
- S = tritium production rate.

Equation (4) is solved under the conditions described below. Initial and surface concentration of tritium is assumed in Eqs. (5) and (6). The inner diameter of long borosilicate glass is assumed to be 5 mm and the outer diameter, 9 mm. The tritium production rate depends on the boron content in the glass and the neutron flux. Although the boron content changes with the irradiation period, the tritium production rate here is assumed to be a constant value as expressed in Eq. (7). This value is the average tritium production rate for 3 years of irradiation (ϕ fast = 2.1 x 10^2m/cm^2,ϕthermal = 3.6 x 10^2n/cm^2) in a typical PWR core, which was calculated by means of the conventional ORIGEN code. The irradiation temperature is assumed to be 300°C, and the diffusion coefficient of tritiated water is expressed in Eq. (8)[4]. The diffusion equation is solved under the following conditions:

The fractional release of tritium at t as defined by Eq. (9) is computed, and the amount of tritiated water released during irradiation is - 1/1000 of that produced in borosilicate glass.

$$F = \frac{s \times (t-t_o)V - \int cdV}{S \times (t-t_o)V} \quad (9)$$

where

F = fractional release, the ratio of tritium released to that produced

V = volume of borosilicate glass.

An order of millicuries of tritium in a BP rod would be released in the case of a rupture of the rod and the necessity of tritium recovery unit for the conditioning system will have to be considered based upon plant conditions, such as the capacity of blowers, volume of the operating room and permissible release of tritium. As for the release of tritium from storage or disposal container, the evaluation can be performed by the diffusion model as clarified above. Anyway safety analysis in connection with tritium release for the whole system including storage or disposal container, which is one of the most important safety aspects, can be carried out in accordance with the above analysis.

CONCLUSIONS

The following conclusions were reached in this paper:

(1) A new consolidation system with sequence control robot operated underwater has been introduced with actual experience of operation at PWR sites.

(2) A new conditioning system for dry storage or disposal has been clarified and proposed.

(3) Consolidation and conditioning process have been summarized in accordance with the existing options on spent fuel and waste management options.

(4) Basic safety analysis method in connection with tritium release has been summarized based upon PIE and diffusion model.

ACKNOWLEDGEMENT

We would like to thank Prof. Dr. M. Miyake of Osaka University for his kindest cooperation in the safety analysis of the system.

REFERENCE

1. A. STRASSER and W. YARIO, "Control Rod Materials and Burnable Poisons, "EPRI NP-1974, Electric Power Research Institute, (1981).

2. K.C. RADFORD et al., "Fabrication Development and Application of an Annular Al_2O_3-B_4C Burnable Absorber", Nucl. Technol., 60,344 (1983).

3. Y. YAMAMOTO et al., "A Consolidation Process for Spent Burnable Poison Rod Asseblies, "Nucl. Tech. 70 (Aug. 1985).

4. Y. YAMAMOTO et al., "Diffusion Analysis of the Thermal Release of Tritium from a Neutron Absorbing Material", J. Nucl. Mater., 120, 2/3 (1984).