Proceedings of the Korean Nuclear Society Spring Meeting Cheju, Korea, May 1996

Remote Nozzle Blocking Device of RCS Pipe during Mid-Loop Operation in Nuclear Power Plants

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Abstract

Currently most nuclear power plants(NPPs) are adopted the mid-loop operation to minimize the overhaul period and save the operating cost. For mid-loop operation it is essential to install nozzle dam between RCS pipe and steam generator(SG). Because SG remains more highly contaminated with radioactive material than any other parts of the NPPs, the repairmen are very reluctant to carry out installing nozzle dam inside the SG. Until now, unfortunately, it appears that no practically applicable device was developed to provide the longstanding demand. Also the accidents have been reported by licenser event report during this operation mode due to loss of residual heat removal(RHR).

The purpose of this paper is to conduct remotely blocking and disintegration of nozzle of a SG which has the highest radiation exposure during the maintenance in NPPs. The remote nozzle blocking device of a SG includes three bladders, hubs, air controller provisions to supply and contract air pressure into the bladders. This remote nozzle block device will give the larger operation margin to prevent the loss of RHR and minimize the radiation exposure dose to the repairman and shorten the overhaul periods.

I. Introduction

Superannuation of NNPs makes it inevitable that inspection, repair and overhaul should be performed periodically, with the suspension of reactor operation, to avoid fatal accidents which might otherwise occur due to a failure of essential parts in NPPs. During the overhaul period the level of radiation exposure dose should be controlled and regulated by utility and regulatory body under the fundamental rule that it should be maintained as low as reasonably achievable.

Although the radiation exposure dose has been considered unavoidable to some extent, significant reduction in the radiation exposure dose can be achieved by way of improving the manner in which the overhaul work is done.

One way of shortening the overhaul period is to perform more than one repair works for different parts of the NPPs concurrently with the replacement of fuel rods. Typical examples of the repair work include conducting an eddy current test of SG U tubes, plugging up those tubes which are no longer usable due to certain defects, and fitting a sleeve to defective portions of the tubes.

Since the SG remains more highly contaminated with radioactive material than any other parts of the NPP, the repairmen are very reluctant to carry out their tasks inside the SG, which has motivated the researchers to make a great deal of efforts in developing a device, e.g., remote-controlled robot, which may eliminate the need for the repairmen to personally enter the SG. Until now, unfortunately, it appears that no practically applicable robotic device was developed to provide the longstanding demand.

Also during the inspection the risk is reported in significant. Specially the loss of the residual heat removal(RHR) function during mid-loop operation has been of increasing concern for years. It can be caused by the loss of electric power, inadvertent closure of isolation valves, air ingestion to the RHR suction piping, and others. Several incidents have been reported and some of them resulted in core boiling. Although the incidents did not lead to core damage, they showed the potential for a rapid core uncovery under shutdown conditions.

To prevent risk due to the lose of RHR during mid-loop operation and to decrease the radiation exposure when install the nozzle dam for mid-loop operation, the remote nozzle blocking device is invented to provide a way of repairing/equipping of the nozzle dam inside SG remotely which is one of the most demanding services. Since the work can be done remotely, this protects the repairmen from the radiation exposure, and furthermore shorten the repair time and prevent the loss of RHR function which may occur during the working period.

II. Plant configuration in shutdown periods

The Youg Gwang NPPs 3 & 4 are two loop, 2815 MWt, PWR plant. The RCS contains two primary coolant loops, each of which has a hot leg. a SG, two reactor coolant pumps, and two cold legs. In post shutdown periods, the reactor coolant is taken from the two hot legs, and cooled by the RHR heat exchangers, and then returned to the four cold legs.

Mid-loop operation has performed two times during the overhaul period. To repair the SG simultaneously with the refueling of the reactor, it will be necessary to leave the coolant chamber of the SG empty. This can be done by blocking the coolant inlet pipe and draining the coolant out of the coolant chamber. One conventional technique of choking up coolant inlet pipe is shown in Fig. 1 where the SG has a manway through which the repairmen may gain access to the coolant chamber. The conditions of installation of nozzle dam is severe and narrow and high radiation area. Also the risk is evaluated as high based on below reasons.

1) Decay heat still generated.
2) Equipment unavailability is increasing due to planned maintenance

3) Plant configurations were changed as below;

- Reduced RCS inventory
- Opened RCS boundary
- Opened containment hatch and penetration

As depicted in Fig. 2 on an enlarged scale, the nozzle dam is of generally circular configuration and consists of three pieces, i.e., a center plate and a pair of side plates which are hingedly affixed to the lateral edges of the center plate so that the side plates can be folded relative to the center plate.

With the coolant pipe blocking arrangement referred to the above, it is time-consuming and arduous to mount the nozzle dam onto the holddown nozzle ring mainly because a large number of bolts have to be manually tightened one by one. Additionally and more important, the repairmen are highly likely to be exposed to some great radiation does during the process of securing the nozzle dam, due to the fact that the coolant chamber tends to be heavily contaminated with radioactivity. Radiation exposure dose of Kori 1 & 2 NPPs is shown in table 1.

A further drawback of the prior art pipe blocking arrangement is that the holddown nozzle ring may create a vortex flow as the coolant is admitted into the SG chamber in the normal operation of the power plant, thus resulting in a pressure drop and hence a loss of hydraulic energy. Table 2 is shown loss of RHR experience in U.S.A.

Table 1. Radiation Exposure Dose based on activity (man-rem)

Activity	1991.4	1991.5	Total	Rate(%)
Refueling	6.886	7.130	14.016	24.14
S/G manway	0.522	1.539	2.061	3.35
SG ECT	1.933	3.625	5.558	9.57
SG Tube repair	0.000	8.359	8.359	14.40
SG Nozzle Dam	7.141	2.485	9.626	16.58
SG Lancing	2.056	0.074	2.130	3.67
RCP maintenance	0.781	2.778	3.559	6.13
I.S.I	0.674	3.408	4.082	7.03
RHR Pump inspection	0.000	0.080	0.080	0.14
Total	23.730	34.323	58.053	100.00

Table 2. Loss of RHR Experience in U.S.A

Event	Period	Events	Frequency		Reference
			per year	per RHR hour	
Loss of RHR	1977-1986				NSAC - 52 (1977 -1981)
Suction Loss		75	0.16	4.7×10^{-5}	Seabrook(1981 - 1986) covers 455 reactors and estimated 60% availability factor
Pump Cavitation		37	0.8	2.3×10^{-5}	
Hardware Failures		37	0.8	2.3×10^{-5}	
	Total	149			NUREG - 1410 plus estimate of 715 reactor-years and 60% availability factor
Loss of RHR at Mid - Loop	1973 - 1989	52	0.073	2.3×10^{-5}	

III. Detailed Description of Remote Nozzle Blocking Device

Figs. 3 and 4 show a coolant pipe remote nozzle blocking device which helps temporarily plug up a coolant inlet pipe to inhibit fluid communication between a reactor and a SG, thus enabling maintenance or repair to be carried out within the SG. In the illustrated embodiment, the coolant blocking device includes a bladder assembly that can be pushed into the coolant inlet pipe to block up the latter in a fluid-tight manner.

The bladder assembly is composed of first to fourth hub segments of generally circular configuration which arranged along a longitudinal axis substantially with a uniform spacing to one another. Each of the hub segments has a V-shaped grooves on its outer circumference.

Shaping the bladders into such a configuration makes sure that they can be deflated to the smallest size as indicated in phantom lines in Fig. 3, when the air is evacuated from the respective air chamber. It should be understood that the smaller the size of the bladders in their deflated state, the easier the pushing-into and pulling-out operation of the bladder assembly through the SG.

Stated briefly, each bladder should preferably be sized so as to, when deflated, move freely into and out of the coolant inlet pipe and, when inflated, make a fluid-tight contact with an inner surface of the coolant inlet pipe. The bladders may preferably be made of rubber or like material such reinforcing elements as carcass, belt or ply cord that, when inflated, can conform to the inner surface of the coolant inlet pipe and, therefore, make a frictional contact therewith in a leak-free fashion.

First, second and third air hoses are adapted to extend along the elongated support rod into each of the air chambers. These air hoses have tail extensions each, projecting away from the fourth, rearmost, hub segment with the tail extension of the elongated support rod. Moreover, the air hoses are provided at their distant ends with first, second and third nozzles opened into the corresponding air chambers. Since the air hoses are mutually discrete and does not communicate with each other, the bladders can be deflated and inflated independently by virtue of evacuating and charging the air from and into the air chambers via the air hoses. Fig. 4 is illustrating an example of a pneumatic unit that is the pipe blocking device. The pneumatic control unit includes a vacuum pump, a compressor, control valves and chambers.

The procedure of mounting and dismounting the pipe blocking device inside the coolant inlet pipe will be set forth in the following with reference to Fig. 5 through 6. At the outset, as shown in Fig. 5, the manway is first opened to gain access to the coolant chamber of the SG, after which the coolant chamber is decontaminated to remove radioactive material possibly present therein. With the directional control valve remained in the neutral position, as indicated in Fig. 4, the vacuum pump is then caused to operate until a sufficient level of negative pressure develops in the accumulator.

The next step is to bring the bladders so contracted into the coolant inlet pipe by way of the manway and the coolant chamber, as clearly shown in Fig. 5. The exact position of the bladders in the coolant inlet pipe is properly selected by the user and may be changed merely applying push-pull forces to the tail cable at the location outside the SG. Once the bladders are properly positioned inside the coolant inlet pipe, the compression pump will be caused to operate such that a sufficient level of positive pressure can be created in the accumulator.

This will cause the leading, middle and trailing bladders to be inflated into frictional contact with the inner surface of the coolant inlet pipe, as shown in Fig. 6. as described herein above, since the support rod has a flexibility enough to lend itself to deformation, each of the bladders can make an intimate contact with the inner surface of the coolant inlet pipe in the inflated state even if the coolant inlet pipe is of a curved shape.

As illustrated in Fig. 5, the guide sleeve can be inserted through the manway of the SG up to the downstream end of the coolant inlet pipe so to span the coolant chamber of the SG. This enables the bladders to be readily pushed into and pulled out of the coolant inlet pipe through the guide sleeve.

IV. Summary

Remote nozzle blocking device of RCS pipe during mid-loop operation is suggested in this paper. The purpose of the work is two folds. One is to provide a coolant pipe blocking device during mid-loop operation which can enable the repairmen to block up a coolant inlet pipe with a minimized possibility of radioactivity exposure.

Another is to provide a coolant pipe blocking device which can be readily brought into and taken out of the coolant inlet pipe with little or no need for the repairmen to enter into a radioactively contaminated SG. And a loss of hydraulic energy is decreased due to elimination of holddown nozzle ringe. In addition, this system provides RCS water high level and this gives the operating margin to operator during the mid-loop operation.

Finally the effect of advantage of remote nozzle blocking device are expected as follows;

1) reduce of radiation exposure dose when working the block of the RCS pipe
2) reduce of number of repairman
3) wide operating range in mid-loop operation
4) shorten the overhaul period

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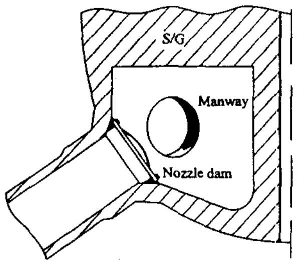

Fig. 1 Partially cutaway sectional view

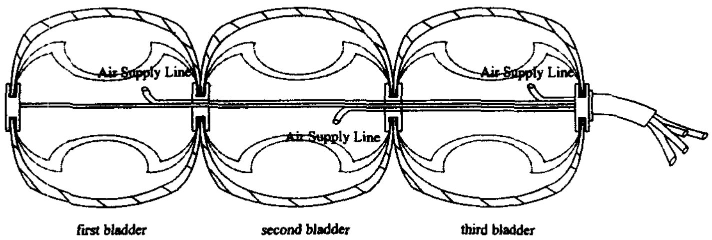

Fig. 3 Remote nozzle blocking device

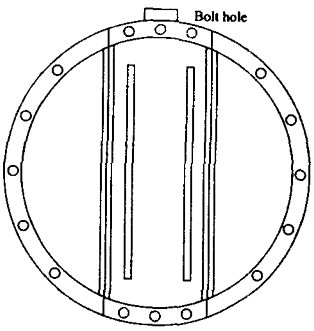

Fig. 2 Prior art nozzle dam

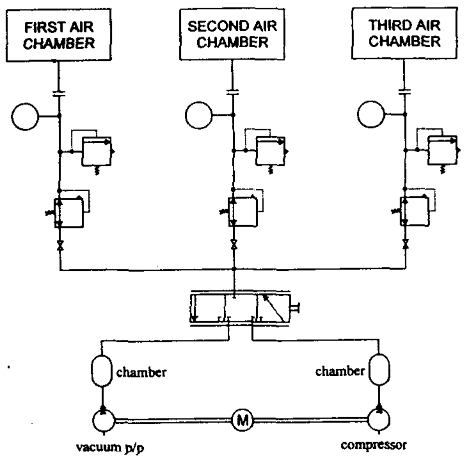

Fig. 4 Pneumatic circuit diagram

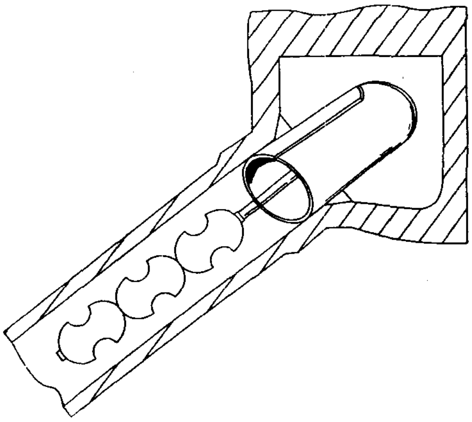

Fig. 5 Blocking device in a contracted state

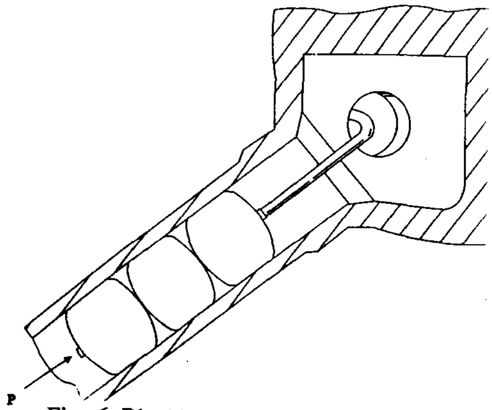

Fig. 6 Blocking device in a expanded state