INFLUENCE OF FEED WATER DISTRIBUTION PIPE REPLACEMENT ON THE WATER CHEMISTRY IN THE STEAM GENERATOR AT LOVIISA NPP

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ABSTRACT

Imatran Voima Oy , (IVO) operates two Russian designed nuclear power plants of type VVER440/213. Unit 1 has been operating since 1977 and unit 2 since 1981. First damage of feed water distribution (FWD) pipes was observed in 1989. In closer examinations FWD-pipe T-connection and distribution nozzles suffered from severe erosion corrosion damage. Similar damages have been found also in other VVER-440 type NPPs.

In 1994 the first FWD-pipe was replaced by a new design mounted over the tube bundle instead of the old FWD-pipe, which was located inside the tube bundle.

The purpose of this paper is to describe the new FWD-pipe and discuss its effects on the steam generator chemistry.

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INTRODUCTION

Horizontal steam generators are one of the typical features of Russian designed pressure water nuclear reactor power plants of type VVER-440. In VVER-440 type reactors the original FWD-pipe is manufactured of carbon steel and located in the middle of the heat exchanger tube bundle. The design of the VVER-440 horizontal steam generator is illustrated in Figure 1.

The first damage of the FWD-pipes in Loviisa NPP was observed during the 1989 refuelling outage. The FWD-pipe T-connection had suffered from severe erosion corrosion failures, Figure 2. Similar damages were found also in other VVER-440 plants before. During the outage the damaged FWD-pipe was repaired temporarily. Also the feed water distribution nozzles of the steam generator YB11 were inspected, but no signs of damage or erosion were detected. In connection with the repair work of the FWD-pipe T-connection in 1992, damaged nozzles were found in steam generators at both units.

In autumn 1992 various options to repair the damaged FWD-nozzles were studied. Since the old distributor is situated inside the heat exchanger tube bundle it was determined to replace it with a new design.

In 1991 two new feed water distributors, designed by Vítkovice company, had been assembled at Dukovany NPP. Additionally, OKB Gidropress, Russia, the designer of the steam generator, had presented their design for a new FWD-pipe. IVO was also planning its own FWD-pipe construction.

In spring 1994 all the six steam generators of Rovno NPP unit 1, Ukraine, were replaced with FWD-pipes designed by OKB Gidropress. After the installation of the new FWD-pipes an experimental program during start up and operation of the plant was carried out. Due to the successful experiments at Rovno NPP Unit 1, it was decided to implement the 'Gidropress solution' into the steam generator YB52 at Loviisa Unit 2 during the 1994 refuelling outage. The Loviisa specific distribution pipe was designed by OKB Gidropress together with Loviisa NPP and IVO Power Engineering.

The new feed water distributor, first version, is illustrated in Figure 3.

DESIGN OF THE NEW FEED WATER DISTRIBUTION PIPE

The new FWD-pipe differs radically from the old design. The concept of this new design in which the feed water is injected over the tube bundle, was proven in the Russian VVER-1000 steam generators. /1/

The main features of the new design are described below:

- In the old design the feed water distribution pipe was located in the middle of the tube bundle and the water was injected into the hot side of the tube bundle. The new FWD-pipe is located above the tube bundle. The feed water is distributed from above the tube bundle into the hot part of the heat transfer tubes.
- In the old design the number and location of distribution nozzles were symmetric to the hot primary collector, and along the distribution pipe. the The nozzles on the new FWD-pipe are located unsymmetrically. The water distribution is in proportion 2:1 to the hot side of the steam generator.
- The density of the nozzles in the distribution pipe is higher close to the hot primary collector. Only a few nozzles are located at the end of the distribution pipe.
- The material of the FWD-pipe is changed from carbon steel to stainless steel.

The reasons for these changes are as follows:
- By injecting feed water close to the hot collector the swell-level is pushed down toward the hot collector.
- By injecting feed water to the hot side of the steam generator the intention is to concentrate the impurities at the cold end of the steam generator, which make it possible to remove the impurities by the blow-down system.

For Loviisa NPP, our own design was needed because:

- The lay out of the steam generator room differs from other VVER-440 plants because of the steel containment, which means that the FWD-pipe may only be installed in parts no longer than one meter.
- The need to install the different parts by flange connections to reduce the time spending inside the steam generator resulting in a reduction of the radiation exposure.

After successful experiments with the basic design of new FWD-pipe at Rovno NPP a final decision was made to replace the first distribution pipe at steam generator YB52 at Loviisa 2 during the annual refuelling outage 1994.

The Finnish regulatory body, STUK, gave a conditional permission for the new design FWD-pipe requiring IVO to study water hammer phenomenon inside the FWD-pipe, and the heat transfer tube's response to cold emergency feed water injection.

PERFORMANCE TEST AT THE LOVIISA NPP

In addition to the experiments and test done at Rovno NPP, Loviisa NPP also introduced a test program to prove the design of the new FWD-pipe. The performed tests were as follows:

- Measuring the distribution of impurities in the blow down pipe line and from installed sampling lines in the steam generator.
- Measuring the vibration of the new FWD-pipe.
- measuring the steam moisture.

A test program for the heat transfer tube response to cold emergency feed water was developed by the VTT Energy and IVO Power Engineering. Experiments using the PACTEL test facility were done in co-operation with Lappeenranta Technical University in spring 1995. The PACTEL steam generator was retrofitted with original exchanger tubes for the experiments. The experiments were successful and the results were verified by calculations.

The tests at the plant were done during start up and operation. During the normal start up test of the feed water system a possible water hammering was observed by vibration measurements. After these observations large scale experiments on condensation induced water hammers were decided to be carried out. The performance and results of these experiments are presented and described elsewhere ./2/ Based on the results of these experiments the feed water nozzle design was changed, see Figure 4.

DISTRIBUTION OF IMPURITIES MEASUREMENTS

The measurements of impurity concentrations in other VVERs have shown that the highest levels of impurities in horizontal steam generators are about 300 mm below the water level. Therefore this level was chosen also in Loviisa. Sampling lines were installed in the steam generator (SG A) with the new feed water distributor and for the reference in a steam generator (SG B) with old feed water distributor.

The sampling lines were installed at both ends (hot and cold) and in the middle of the steam generators, Figure 5. The terms hot and cold refer to the nearest primary coolant collector.

The measurements from other VVER-plants have also shown that the impurities will concentrate at the cold end in steam generator with feed water distributor of the new design.

Sodium-, iron- and ammonia concentrations from the steam generators (SG A and SG B) were measured and the results are shown in Table 1. Despite quite low concentrations of sodium a concentration gradient towards the cold end was revealed for both types of feed water distributor. This gradient was more pronounced in SG B. The same kind of gradient was observed for iron. No real differences in iron concentration were observed between the two steam generators.

A possible reason for the lower sodium concentrations in SG A is that the feed water is distributed mainly to the hottest part of the SG and is in considerable amount carried with the steam /3/.

The behaviour of ammonia is the opposite to that of sodium and iron as it concentrates at the hot end. This is possible due to the volatility of ammonia /3/. The results for ammonia from the new sampling lines show that there is no big difference between the described feed water distributor designs. However, additional measurements revealed that the amount of ammonia which concentrations in the blow-down water from SG A is much lower than the corresponding value in SG B. This can be due to the location of the feed water distributor above the tube bundle in SG A compared to SG B, where the feed water distributor is in the middle of the tube bundle /3/.

Table 1 Sodium, iron and ammonia concentrations in steam generators A and B

	SG A	*SG B*	*SG A*	*SG B*	*SG A*	*SG B*
Sample	Na µg/kg		Fe µg/kg		NH_3 µg/kg	
hot	1.0	2.1	17	15	220	200
middle	2.6	2.9			160	150
cold	3.0	7.2	56	43	50	50
blowdown					170	130

STEAM MOISTURE MEASUREMENTS

A project for uprating the units at Loviisa started in 1996. The aim of the project is to uprate the units to 109 %. One part of this project was to determine how the uprating will influence the steam moisture. Therefore moisture measurements were performed at different power levels , i.e. 103, 105, 107 and 109 % /4/.

The determination was performed by injecting lithium hydroxide into the feed water. Lithium was then analyzed in the steam generator water, steam and blow-down water. The moisture content in the steam was calculated in two different ways 1) using the lithium concentration in the steam and 2) using the lithium concentration decrease in the steam generator water. In Table 2 the moisture content in the steam is shown calculated according to the methods mentioned above.

Table 2 Moisture content in steam

	Moisture content %	
Power stage	***Method 1***	***Method 2***
103 %	0.09	0.13
105 %	0.10	0.09
107 %	0.09	0.09
109 %	0.11	-

Beside the moisture content in the steam the performed measurements gave interesting information on the behaviour of lithium in the steam generator. The measurements were performed in SG A, a steam generator with the new type of feed water distributor.

From Figure 6 can be seen that lithium shows a behaviour similar to that of ammonia, i.e. the lowest concentration is found in the cold end of the steam generator and the highest in the hot end. According to the results in Table 1, sodium concentrates at the cold end. The reason for the observed differences in behaviour of sodium and lithium still needs to be interpreted in more detail.

The blow-down water is sampled from the bottom in the middle of the steam generator. If the results from this sampling point in the upper part is compared the conclusion can be drawn that lithium is equally distributed in depth, Figure 7.

Just after the injection of the needed lithium hydroxide amount the lithium concentration was slightly above 100 µg/l which corresponds very well with the calculated value. During the first 24 h the lithium concentration drops mostly due to hide-out in the steam generators. For calculation of the moisture content in the steam, the results from the "middle phase" i.e. a time between 30 – 50 h have been used. This is based on the assumption that the decrease of lithium during this phase depends on carry-over of lithium with the steam.

If the lithium in the steam generator is normalized one can compare the hide-out rate for the different power stages. It is clearly shown in Figure 8 that at higher power the hide-out rate is higher. The effect of the hide-out on the performance of the steam generators from a chemical point of view will be monitored in the future.

CONCLUSIONS

The corrosion damage of the feed water distribution (FWD) pipes and nozzles necessitated the replacement of the FWD-pipes. A new design required that the replacement FWD-pipe was located inside the tube bundle. The results of the tests and experiments show that the implementation of a new radically changed FWD-pipe design is also possible in operating plants. An extensive research and test program was performed for to fulfil the requirements for operation and safety. The operating experience we have had with the new FWD-pipe since 1994 shows no deterious effects on the operation of the steam generator.

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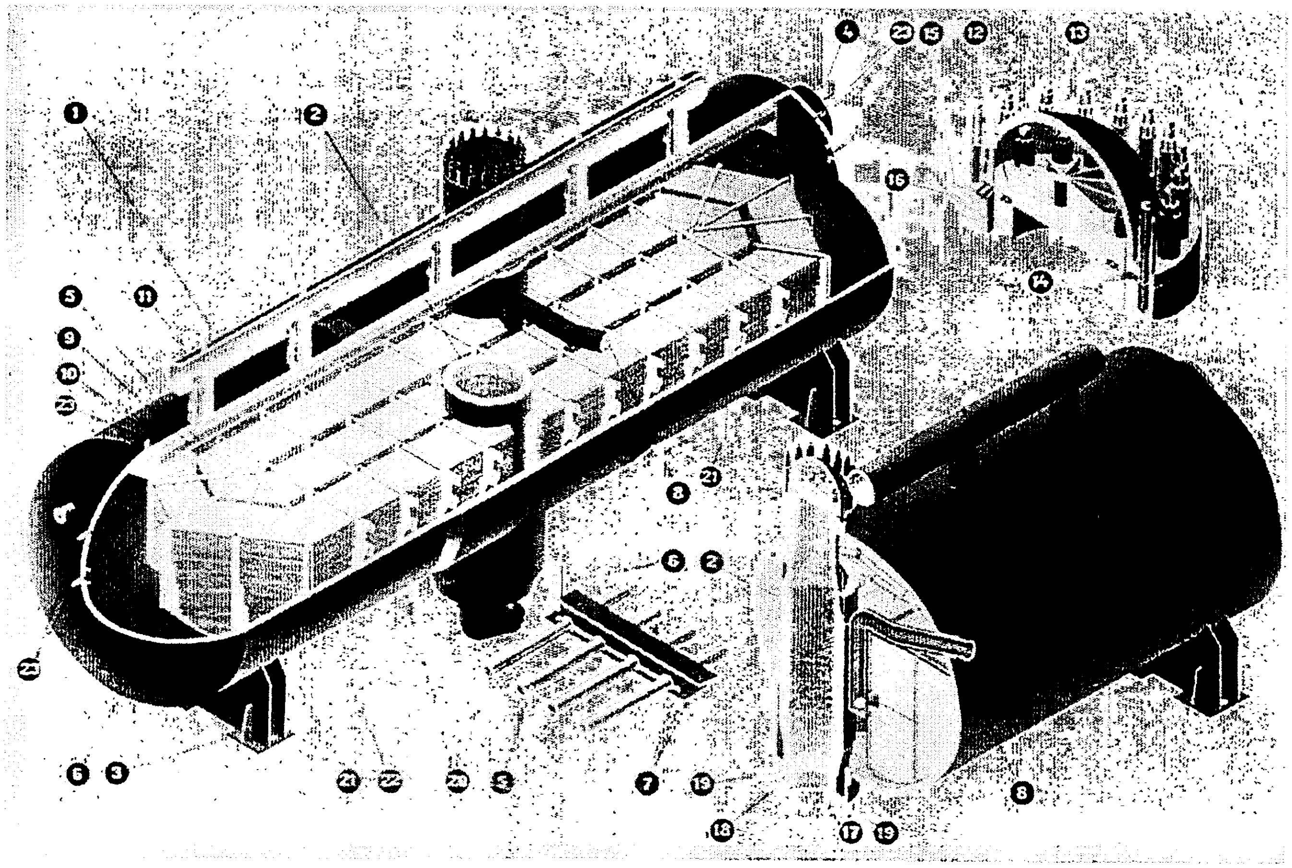


Figure 1   VVER-440, steam generator, old feed water distributor

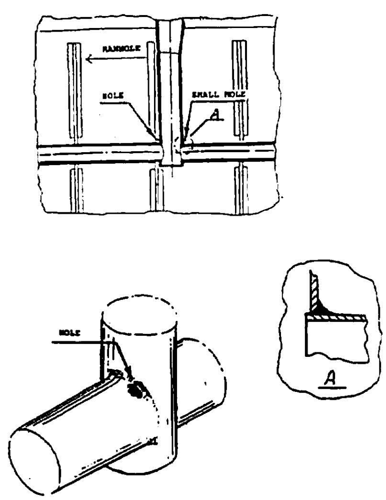


Figure 2   Corrosion damage at T-piece

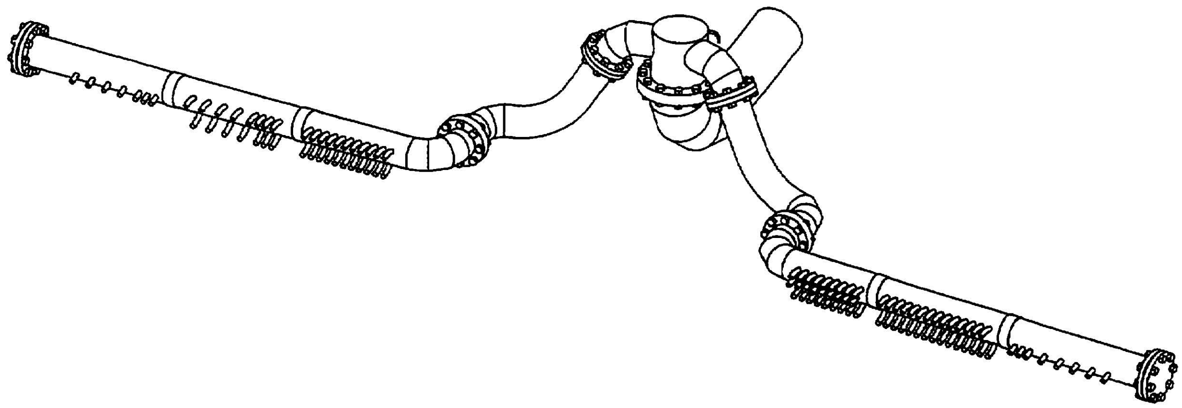


Figure 3 New feed water distributor, first version

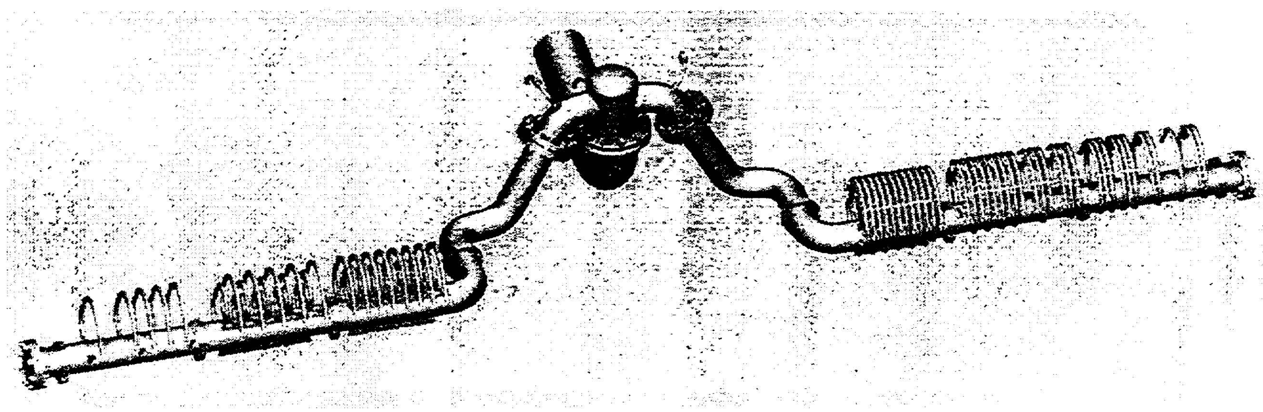


Figure 4 New feed water distributor, final version

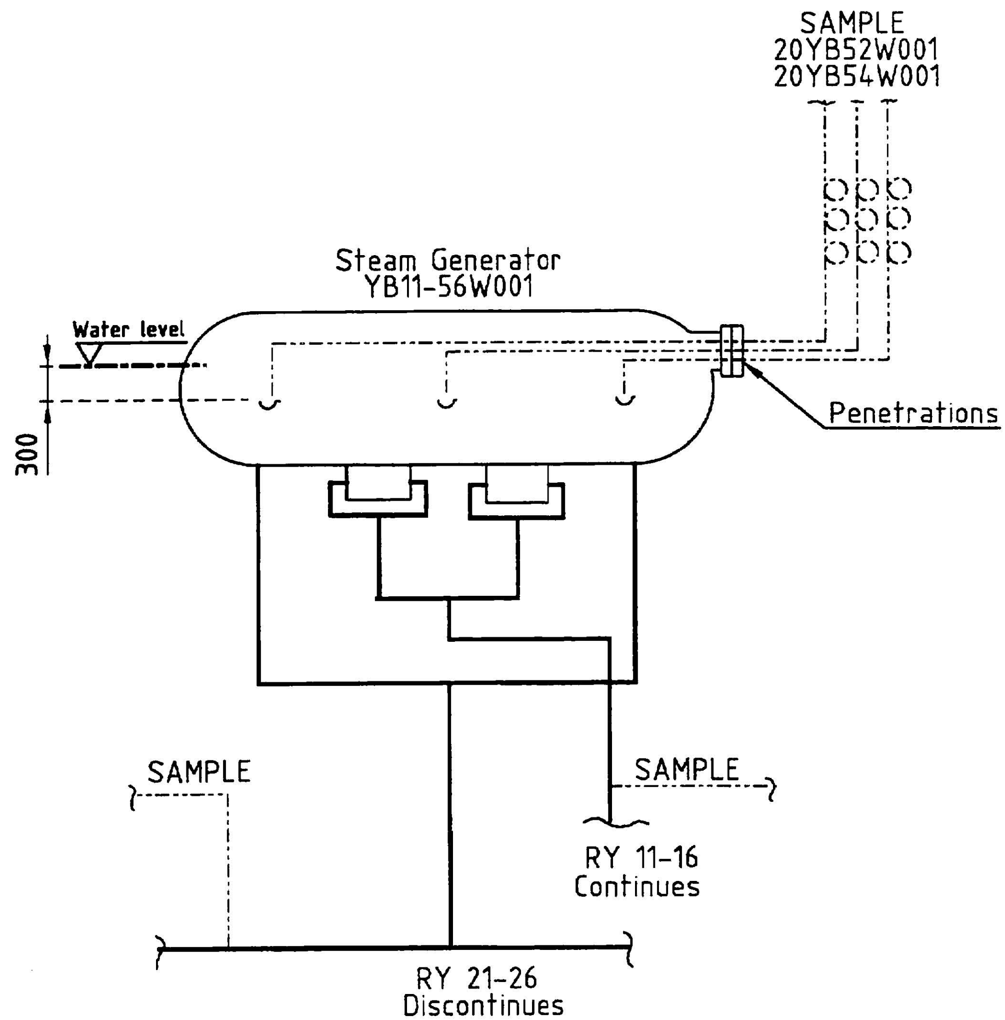
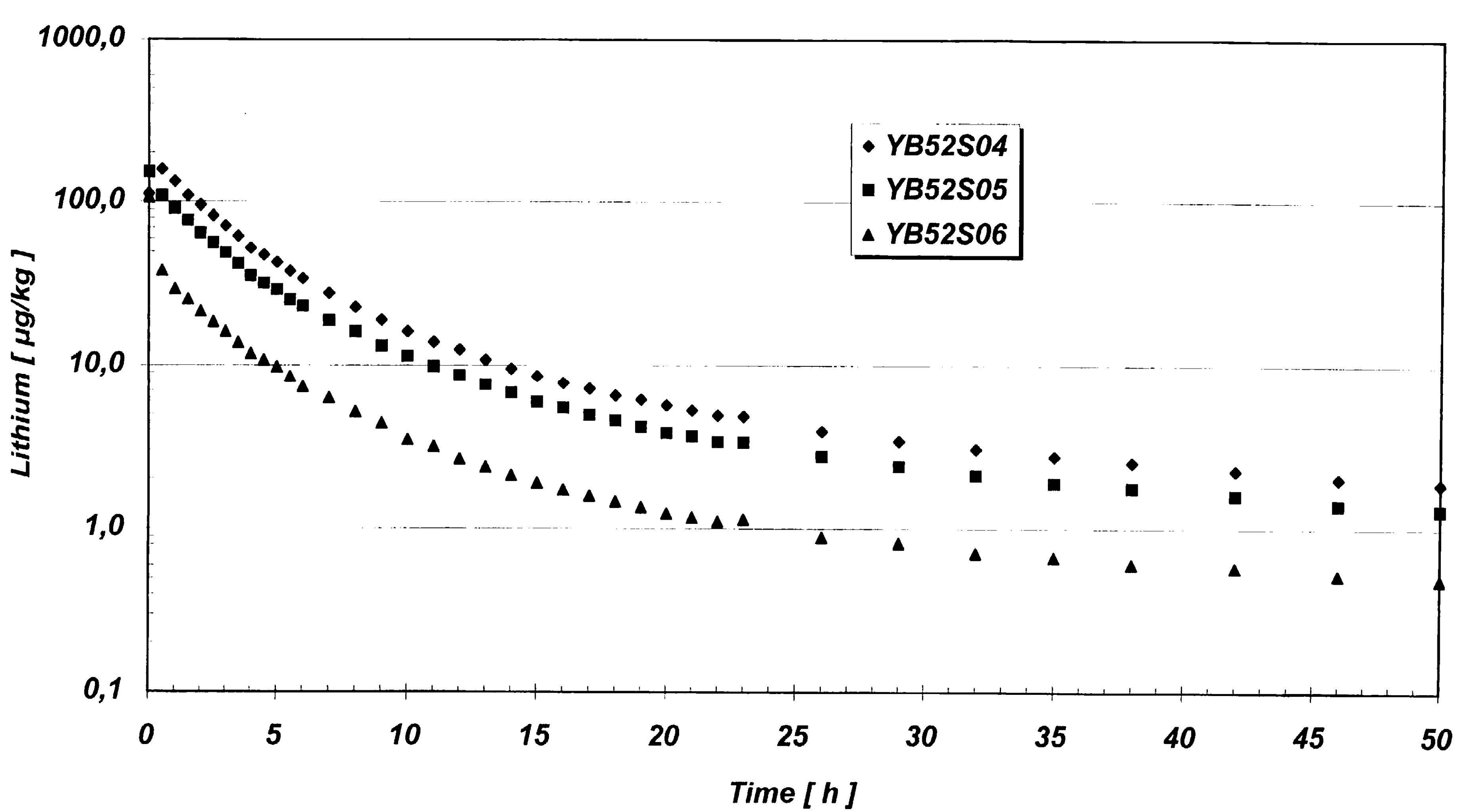


Figure 5   Blow-down sampling system

Figure 6: Tracer Concentration in SG A



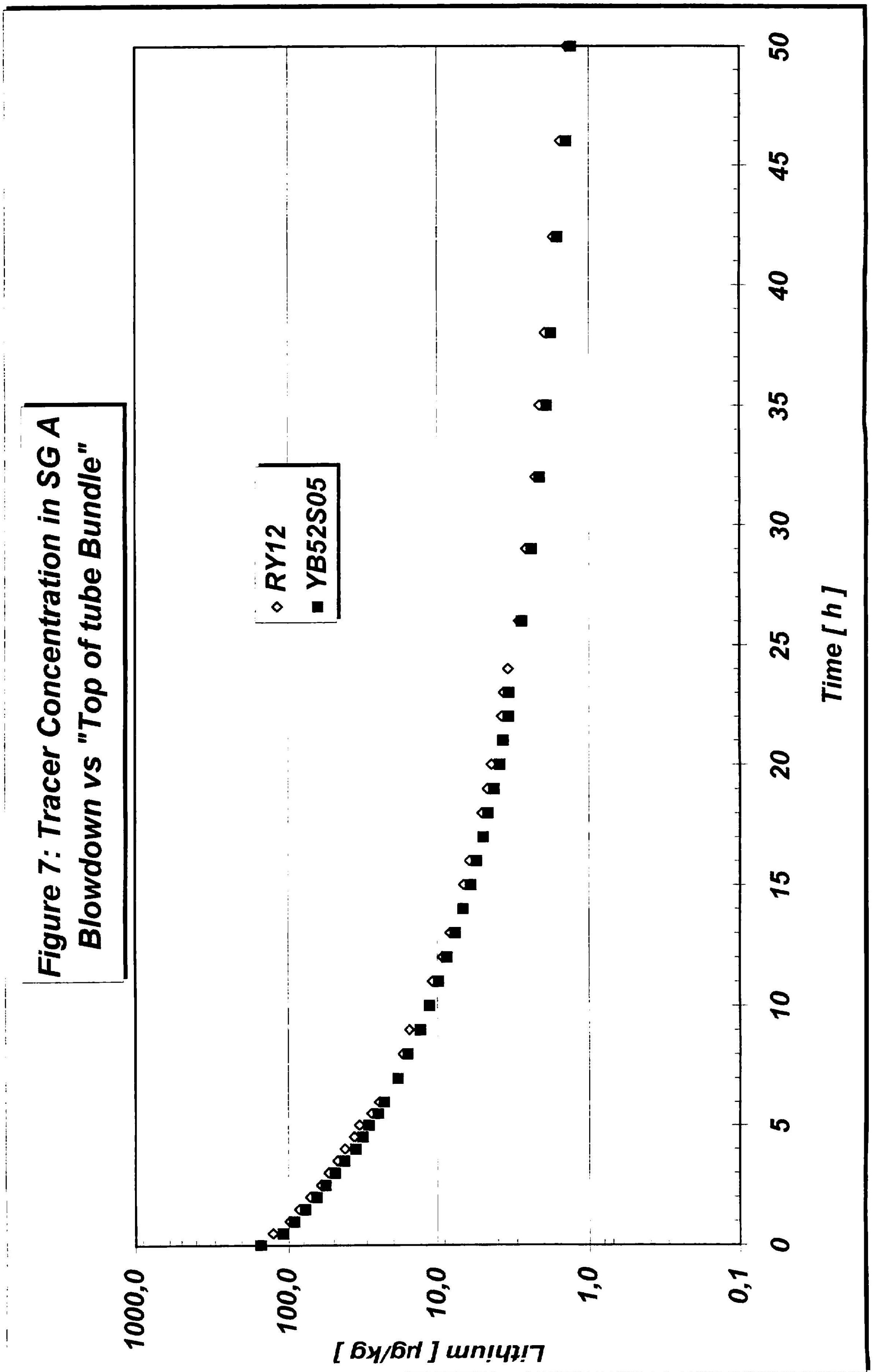
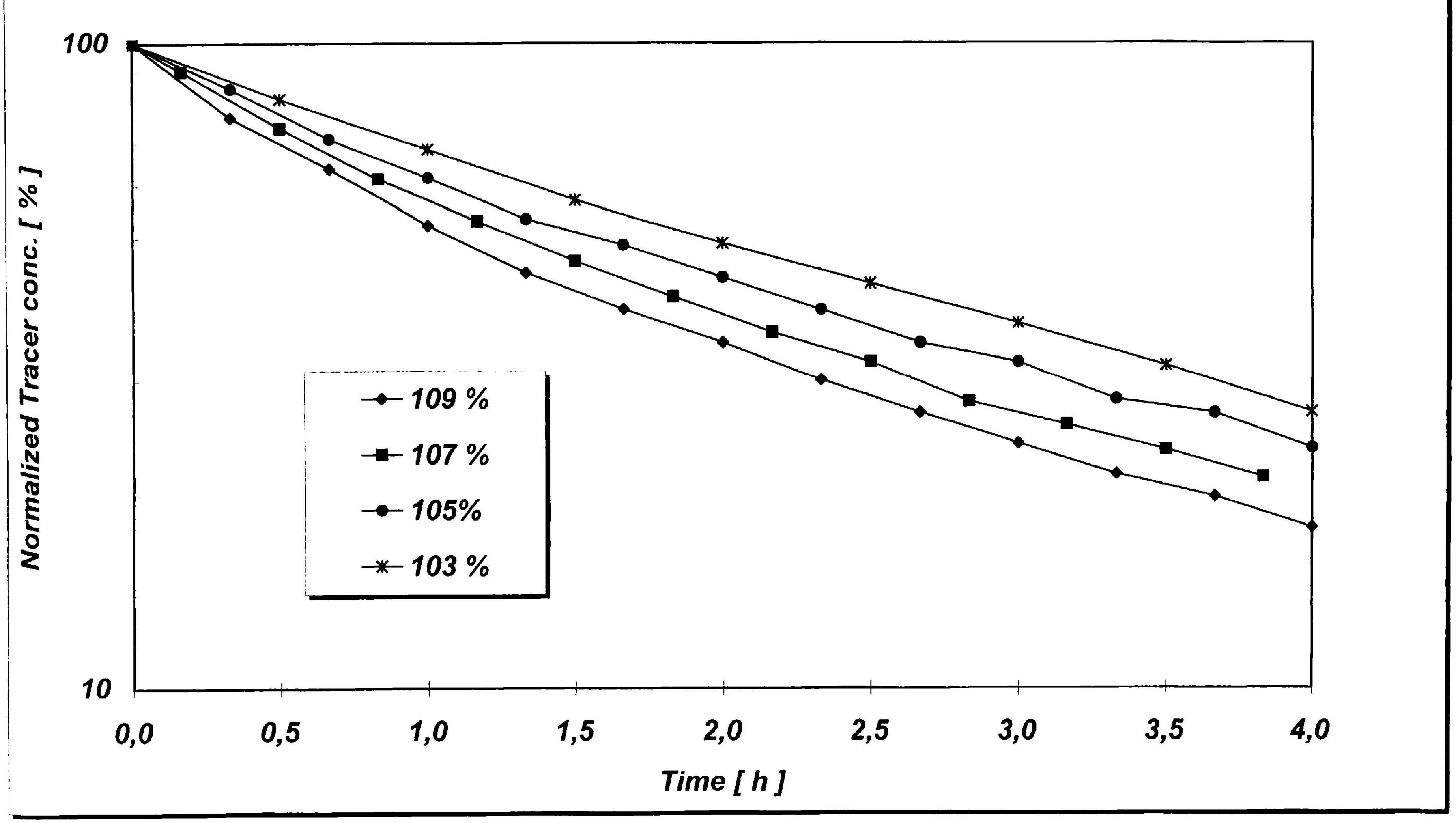


Figure 7: Tracer Concentration in SG A Blowdown vs "Top of tube Bundle"

Figure 8: Normalized Tracer Concentration in SG A



DISCUSSION

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Questioner: J. Gorman

Question/Comment:

(1) What material experienced erosion-corrosion, and what was used for replacement?
(2) Have you observed any influence of hydrazine on FAC?

Response:

Old FWD pipe - carbon steel
New FWD pipe - stainless steel

The changeover from neutral chemistry has so far been seen in a decreasing iron concentration in the feedwater, 20-50 → 5-10 μg/l.

Questioner: PJ. Prabhu

Question/Comment:

I did not quite follow your explanation of why the Li tracer concentration decreased at a faster rate at higher power levels. Could it be due to higher moisture carry-over at higher power?

Response:

It can, but this is not supported by the moisture results. On the other hand, we have not interpreted the results in more detail.