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Acoustic Leak Detection Requirements for a SFR Steam Generator Protection

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1. Introduction

A large volume of fast reactor research has been executed in Russia, Japan, France, India and the United Kingdom. At present, an unique fast reactor named BN-600 is operating in Russia. Also, the operation of research reactors such as Phenix (France), JOYO (Japan), BOR-60 (Russia) and FBTR (India) proceeds. The last project to be completed was the reactor Monju (Japan) which is now stopped. In addition activities for the development of fast reactors are being conducted in China, India, and South Korea.

Fast reactors are a choice for the subsequent nuclear power generation in Korea, and their increased safety is one of the basic requirements. The basis for a tightening of the requirements on safety is the emergencies in NPPs in Russia, USA, France, Japan and other countries. These emergencies testify that the existing monitoring systems do not fully provide a well-timed detection of the distresses arising in a NPP, because of a poor sensitivity and response, thus the necessity for a better diagnostic system is obvious.

In accordance with the USA GNEP initiative in Obninsk, Russia, 2007 the main efforts should be directed toward a sodium-water steam generator safety increase due to improvement of the hydrogen monitoring system and the acoustic leak detection system.

2. Design Conditions

The SFR SG [1] designed in KAERI is a helical coil, vertically oriented one, There are two steam generators (l SG / loop) and the conceptual design and outline drawing of the steam generator is shown in Fig. 1. The overall size of the SG is 17.6 m high and 4.1 m in diameter.

It is important to note, that the designed SFR SG tube bundle arrangement allows one to realize a more beneficial possibility with a comparison between the SG conditions of the BN-600 and SuperPhenix for a leak detection and a secondary leak protection. That provides more time for detecting a leak of the same rate [2]. Experimentally it has been established that the water steam into sodium leak in an SG represents a long-lived multi-stage intrinsic process by the real design of a tube bundle of an SG, the structure material of the heat-transfer tube of a SG, the origin of a leak and thermal parameters of the water steam and sodium. Nevertheless, for the capability of a leak detection system and the avoidance of secondary leaks, the classification of a water steam into sodium leak for a large, >1kg/sec, intermediate, 1g/sec ~ 1kg/sec, and small leak, ~1g/sec is generally accepted [2].

From the point of view of thermodynamics and acoustics there exists two deferent leak flow modes, at first the bubble mode in a range of an increase for the water steam leak from 0.01g/sec up to 1kg/sec, and then a jet mode of the water steam into a sodium leak.

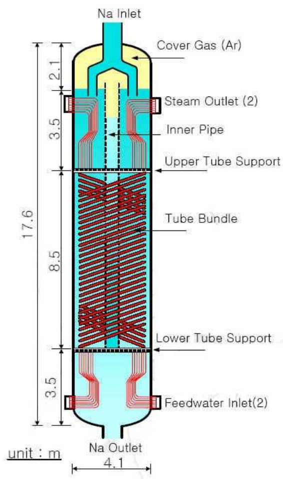

Figure 1. K-600 steam generator.

The chemical reaction of hydrogen gas with liquid sodium is a fast-acting process, dependent on the sodium temperature and initial radius of the hydrogen bubbles. Thus, the lifetime of a hydrogen bubble in liquid sodium is determined by the kinetics of the reacting hydrogen gas. Under the conditions of a water-into-sodium micro-leak with a value of 0.005 g/s, the lifetime of a bubble in sodium lasts for no more than 3 sec for a hydrogen bubble with the largest radius [3].

3. Results and Discussion

3.1 Comparisons with hydrogen detection systems

The leak detection system monitors and alarms water or steam leaks in a SFR SG and identifies the fault SG [3]. In accordance with the location of a leak the transition of a leak from a bubble mode to a jet mode will descend with the determining influence by the kinematic viscosity and rate of sound velocity in an elapsed steam-water mixture. Therefore, the volume-flow of a small water steam leak in the sub-cooled regime of an SG will be in the range from 0.013 cm^3/sec based on a water-steam leak of 0.01g/sec up to 1.3 cm^3/sec based on a water-steam leak of 1g/sec. In the super-heated regime of a SG it will be equal to 0.131 ~ 13.1 cm^3/sec based on water-steam leak of 0.01 ~ 1 g/sec, and a transition to a turbulence regime for a SFR SG in its bottom tube bundle part is expected [3].

The results [4] of the calculations for the detection of a leak in a flow rate range of 0.001 ~10g/s are presented for a maximal achievable sensitivity for a sodium hydrogen meter and for a cover gas hydrogen meter. Calculations were executed on the basis of the big volume of leaks self-development time experimental data at various values of the sodium temperature and a neighboring heat transfer tubes destruction time. The admissible time for a leak detection is a result of a certain application of the hydrogen meters, at which there will be no destruction of a neighboring tube and a time protection against all risks from dangerous emergency SG conditions. In Table 1 the comparisons for in time leak detection parameters [4] with the real parameters of a SFR SG are presented.

Table 1. Comparisons with the hydrogen detection systems in K-600 (KALIMER-600).

No.	Parameter	Ideal Hydrogen detection system [4]	K-600 Hydrogen detection system	Adequacy
1	Thermal power, MWt	≤ 50	764.45	-
2	Tube structural metal	2.25Cr-1Mo	2.25Cr-1Mo	+
3	Sodium temperature, ℃	≤ 500	526	-
4	Water steam drainage time, sec	≤ 10	≤ 90	-
5	Water steam shutdown time, sec	≤ 5	≤ 30	-
6	Hydrogen gas share output in a cover gas space of a SG	≥ 0.1	≥ 0.3	-
7	Cover gas space, m^3	≤ 0.2	< 15	-
8	Leak rate range, g/s	0,01 ~ 10	≤ 10	-
9	Leak detection time, sec	≤ 15	≤ 30	-
10	Hydrogen meter in sodium sensitivity, ppm	≤ 0.1	0.04 ~ 2	-
11	Hydrogen meter in cover gas sensitivity, %	≤ 0.001	≤ 0.1	-

From these comparisons it is visible that real parameters of a SFR SG are not completely adequate for the required parameters. It means that not all leaks of a range of 0.001 ~10g/s in a SFR SG will be detected in time with a hydrogen detection system, till the moment of a neighboring tube destruction.

3.2 Requirements for an acoustic leak detection system

The main requirements for the water-steam acoustic leak detection system in a SFR SG are for the sensitivity and response time of the system. The response time of an acoustic system in a SFR SG is perceived as the time from the moment a leak begins up to the moment of its detection.

Other main requirements for a water-steam leak detection system in a SFR SG are set up in [3]. These requirements follow from the necessity of avoiding a secondary leak owing to a destruction adjacent to a defective tube in a SFR SG. This does not contradict modern submissions about the mechanisms and dynamics of a defective tube self-development. The findings of an investigation on a leak self-development and wastage of tube - targets executed in IPPE using 2.25Cr-1Mo of a SFR SG is shown in Fig. 2.

It is necessary to note the relevance of these results, as they are unique results on a micro leak self-development and allow for a detection before a sharp increase of the leak rate (initial leak rate from 0.005 ~ 0.01g/s increases to 0.22 ~ 0.8g/s) which could correspond to the destruction of a tube wall and which is generally 40 ~ 100 minutes from the beginning of a leak [2].

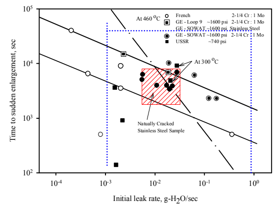

Fig. 2. Time to a sudden enlargement vs. initial leak rate (•; data of IPPE using structure material, 2.25Cr 1Mo).

3. Conclusion

The detection of micro and small leaks will allow for a control of a leak development, to avoid a secondary leak and to avoid large destruction of a tube bundle in a SFR SG. On the whole the detection of micro and small leaks will allow for an increased safety for a SFR SG.

For the development of a SFR acoustic leak detection system it is necessary to execute a study of the background noises in a SFR SG, and to test the prototype acoustic leak detection system in the conditions of a SFR SG with a hydrogen detection system during an injection experiment for water-steam into sodium for a verification and confirmation of the required sensitivity and required response time for a leak detection.

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