C.14. Small Leak Detection Requirements for SNR-300 Steam Generator Operation

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Abstract:

The leak detection philosophy of the SNR-300 steam generators is described. Due to operational demands small leaks have already to be detectable at a stage where secondary tube damage has not yet occurred. The requirements on a leak detection instrument are developed and the instrument itself is described.

1. Introduction

Small water/steam leaks in sodium heated steam generators form a flame type reaction zone. Adjacent tubes located within the range of such a flame will be affected by a combined erosion-corrosion process [1]. In the case of the leak remaining undetected it may produce larger secondary leaks. To prevent this propagation the leak must be detected during operation by a reliable instrumentation. Countermeasures can only be enforced after detection. Normally for leak detection purposes nickel membrane systems are used by which the hydrogen content of the sodium is controlled. The response of these type of detectors is influenced to a large extent by the transport behaviour of the reaction products such as hydrogen. All load conditions of the reactor plant have to be covered by the hydrogen detectors in order to maintain a safe operation. As described in literature [1] wastage for a given leak rate increases by decreasing sodium flow, which means wastage and detection time are in complete contradiction. Based on these facts a safe and reliable leak detection system for the SNR-300 steam generators had to be developed.

2. SNR-300 secondary heat transfer system

As far as leak detection is concerned one of the secondary heat transfer systems is illustrated in Fig. 1. Two loops will be equipped with straight tube steam generators while the third loop will be operated with helical coil steam generators (see Fig. 2 and 3).

Some interesting data on steam generators and secondary systems can be found in Table I. A hydrogen detector is installed on each of the module outlets. Two additional detectors are located in the main coolant pipe behind the evaporator outlets. The large number of detectors per loop was considered to be necessary for the identification of a failed module by means of comparing the different signals.

Normally the reactor will be operated within the power generating range of 30 to 100 % output.

After having had a reactor shut down one intends to maintain the steam generators at full water pressure up to 24 hours while the decay heat removal is maintained by a sodium flow of 1 to 2 % of nominal flow. As previously mentioned this is the worst case with respect to small leak detection because of extremely long transport times. Therefore the leak detection philosophy has to take this into account.

3. Formation and behaviour of hydrogen in sodium

3.1 Detector sensitivity requirements

As has already been described, even during decay heat removal when the steam generators are kept at operation pressure secondary tube failures due to wastage have to be avoided. When the leaks which are detectable are so small that they only produce flames which are shorter than the free spacing between the steam generator tubes secondary wastage cannot occur. Fig. 4 shows the tube arrangements of the two steam generators in question. Evaluations of the reaction flame [1] allow the determination of a critical leak size below which wastage is not possible. Adopting the data stated in Table I the following results were calculated:

- With a minimum free spacing of 11,1 mm the critical leak size diameter is 0,0915 mm.
- This leak will produce a steam leakage of 493 gr/h.

- In the assumption that all the injected hydrogen is available for detection purposes the steam leakage will lead to an increase in hydrogen concentration of

  0,503 ppm/h in the case of straight tube design and
  0,428 ppm/h in the case of the helical coil design

Alternatively the increase in hydrogen content per sodium circulation can be calculated in order to determine a necessary sensitivity. Due to the primary reaction

$$Na + H_2O \longrightarrow NaOH + 1/2\ H_2$$

only 50 % of the hydrogen contained in the reacting steam should be considered. For one circulation time the hydrogen level will rise as follows:

Detector position	Dim.	100 % power	30 % power	decay heat 1 % flow
Module outlet	ppm	27.10^{-3}	85.10^{-3}	2,1
Main coolant pipe	ppm	7.10^{-3}	28.10^{-3}	0,7

The secondary reaction

$$Na + NaOH \longrightarrow Na_2O + 1/2\ H_2$$

has not been taken into account for the 1 % flow condition although there the transport time is long enough to also complete this secondary reaction.

3.2 Hydrogen background

A literature survey has been made in order to gain information on the hydrogen background in large steam generator test facilities. Information could be gained from the following installations:

- 50 MW circuit, Les Renardieres [2]
- 50 MW circuit, Hengelo
- 35 MW circuit, Liquid Metal Engineering Center [3, 4]
- 5 MW circuit, INTERATOM [5]

The formation of a hydrogen background in the sodium is mainly due to a diffusion process from the water side through the tube walls. At the inner tube surface a magnetite layer is formed and continuously regenerated according to the reaction:

$$3\ Fe + 4\ H_2O \rightleftharpoons Fe_3O_4 + 4\ H_2$$

A part of this hydrogen diffuses through the tube walls while another part is transported by the water/steam. Corrosion data for 2 1/4 Cr 1 Mo steel evaluated from [6] show a fairly good agreement with hydrogen measurements. This is demonstrated in Fig. 5.

The hydrogen background can be controlled by cold trap operation. Background levels in the range of 0,04 to 0,08 ppm can be maintained. Therefore the hydrogen content of the SNR-300 sodium has been defined as being 0,10 ppm when the steam generators start operation.

3.3 Collection and application of data

Hydrogen diffusion, background intensities and hydrogen signals from the defined critical leak for different flow conditions are collected in Fig. 6. It demonstrates the comparably high hydrogen background at which it becomes useless to develop detectors with an extremely high sensitivity.

The final application of the evaluated data is shown in Fig. 7. During steam generator start up the diffusion is assumed to be five times greater than at normal operation. The alarm level is set at a hydrogen rate of 0,3 ppm/h. Thereby a flame length of approximately 9 mm will be adjusted. A leak propagation is avoided.

The decision to use a rampe rate signal instead of an absolute hydrogen level was made in order to enable operation performance independently from the cold trap influenced background signals.

4. The hydrogen detector

The hydrogen detector which was developed at INTERATOM is illustrated in Fig. 8.
The basis of the measuring principle (as used all over the world) is the diffusion of hydrogen through a nickel membrane and the detection of this hydrogen by means of an ion getter pump, the electric current consumption of which determines the intensity of the hydrogen diffusion.

In order to remain independent from the flow conditions in the main loop the detector system is equipped with a small electro-magnetic pump having a capacity of 0,3 - 1 m^3/h.

The sodium is heated up to 500°C by passing through a recuperative heat exchanger and an electrical heater. Temperature changes at the inlet of the detection system are compensated by a combined control of sodium flow and heating capacity. Thereby the nickel membrane is maintained at a constant temperature of 500°C. The membrane is designed as a 4-finger system having a surface of 55 cm^2 with a wall thickness of 1 mm.
The ion getter pump has a pump capacity of 4 liter/s hydrogen and an operating range of 10^{-4} to 10^{-9} mbar. To control the sodium flow the system is completed by a permanent magnetic flow meter. Some prototypes have already been manufactured and are being tested. Some of the preliminary results are:

- lower sensitivity limit	4.10^{-2} ppm H_2
- electrical sensitivity	115 µA/ppm H_2
- temperature sensitivity (500°C)	1 %/°C

In the next test program special attention must be paid to questions on long time behaviour and stability.

5. Literature

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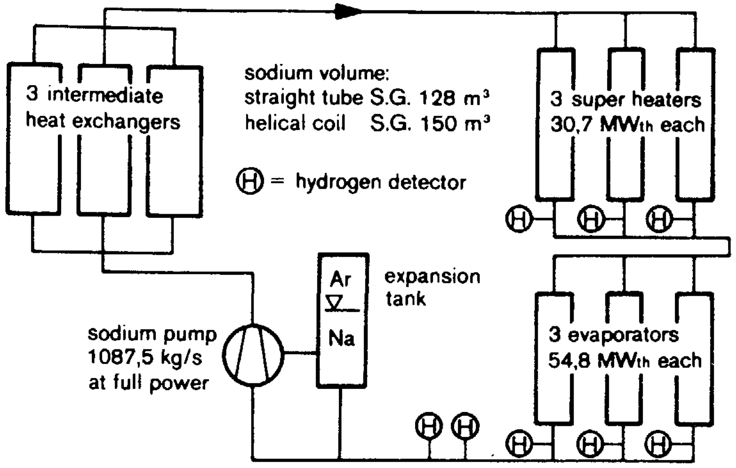
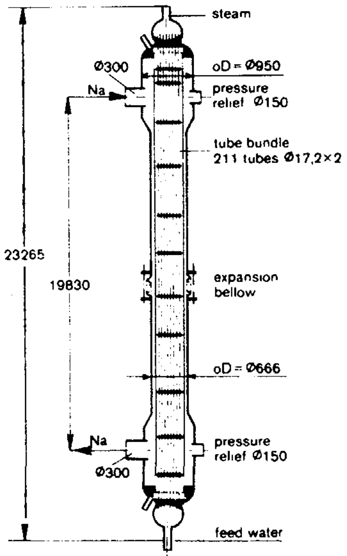
Table I

Technical data of steam generators and secondary system

	dimension	straight tube steam generator	helical coil steam generator
tube outer diameter	mm	17,2	26,9
tube wall	mm	2,0/2,9	2,9/4,5
tube pitch	mm	30	40/38
free tube spacing	mm	12,8	13,1/11,1
number of tubes per module	-	211	77
sodium flow per module at 100 % load	kg/s	362,5	362,5
sodium velocity in tube bundle at 100 % load	m/s	3,5	1,6
total sodium volume per loop	m^3	128	150
quasistagnant sodium volume per loop	m^3	28	41
sodium circulation time at 100 % load	sec	78	85
sodium inlet pressure	bar	8,5	8,5
sodium outlet temperature	°C	335	335
sodium inlet temperature	°C	520	520
feed water pressure	bar	188	188
steam pressure	bar	166	166
feed water temperature	°C	253	253
steam temperature	°C	500	500

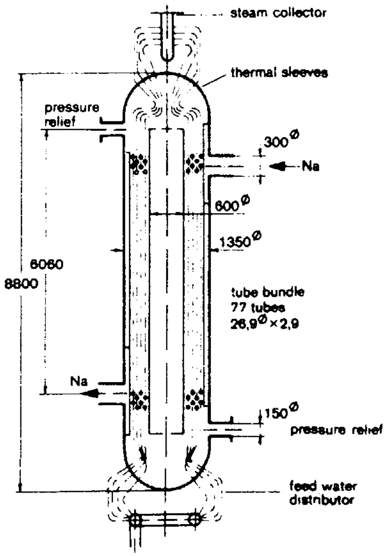


SNR 300, SECONDARY HEAT TRANSFER SYSTEM FIG. 1.



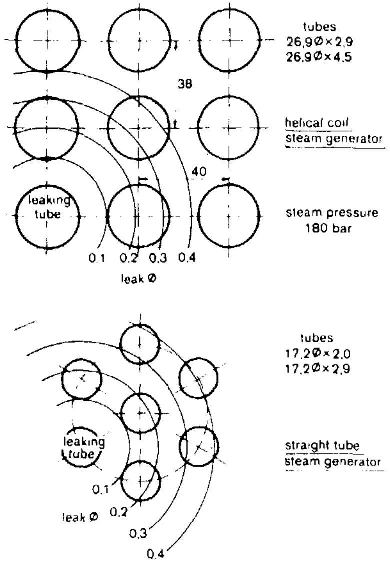
SNR-STRAIGHT TUBE STEAM GENERATOR -EVAPORATOR-

FIG. 2.



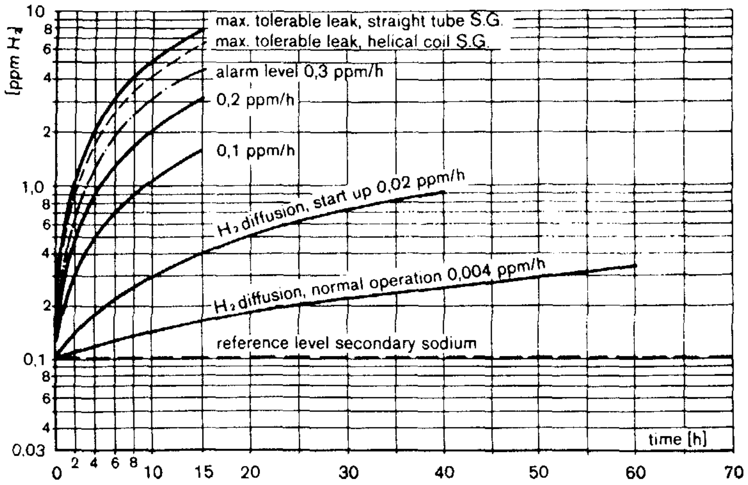
SNR HELICAL COIL STEAM GENERATOR -EVAPORATOR-

FIG. 3.



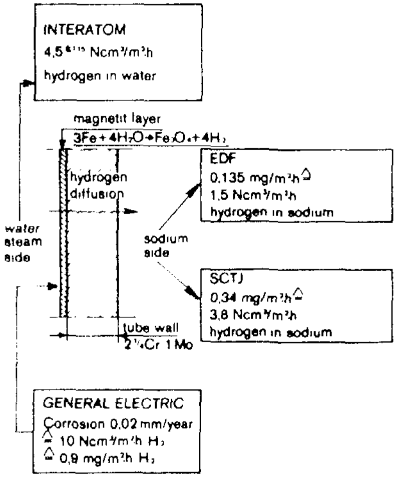
FLAME INFLUENCED REGIONS IN DIFFERENT TUBE ARRANGEMENTS

FIG. 4.



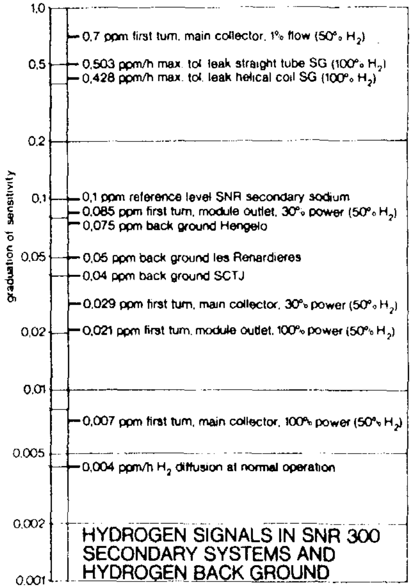
HYDROGEN BEHAVIOUR VERSUS TIME

FIG. 7.



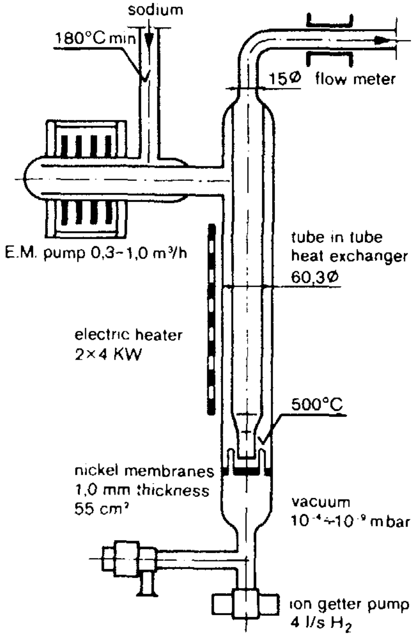
FORMATION AND CONTRIBUTION OF HYDROGEN IN SODIUM HEATED STEAM GENERATORS

FIG. 5.



HYDROGEN SIGNALS IN SNR 300 SECONDARY SYSTEMS AND HYDROGEN BACK GROUND

FIG. 6.



HYDROGEN DETECTOR

FIG. 8.