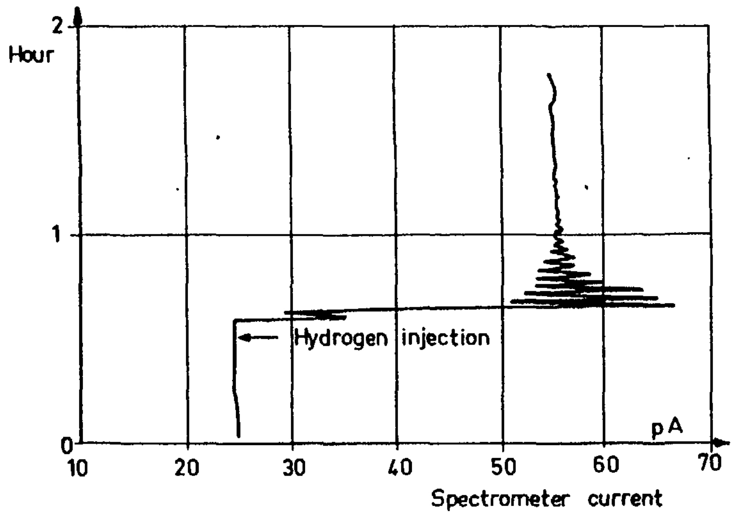


FIG. 6: SUPER PHENIX PROTOTYPE SYSTEM FOR HYDROGEN MEASUREMENT IN SODIUM .SPECTROMETER CURRENT AS A FUNCTION OF TIME DURING A HYDROGEN INJECTION.

LEAK DETECTION IN LMFBR STEAM GENERATORS DURING OPERATION

K. DUMM
INTERATOM,
Bergisch Gladbach,
Federal Republic of Germany

The paper deals with the 4 main aspects:

1. Requirements on the leak detection systems of SNR-300 steam generators.

2. The hydrogen detector of SNR-300.

3. Remarks on the disadvantages of impurity detectors.

4. A first approach on acoustic leak detection systems.

1. Requirements on the leak detection systems of SNR-300 steam generators.

These requirements are strongly influenced by requisitions of the German licensing authorities:

- The steam generators have to be designed such that the simultaneous rupture of several water/steam tubes can be excluded.

- Otherwise the simultaneous rupture of several water/steam tubes has to be taken into account in the design of the secondary transfer system in order to avoid any damages at the intermediate heat exchangers.

- Measures for the detection of small leaks have to be provided by which fast actions in the case of tube failures can be introduced.

These rules have been established in 1971 and are still valid. At that time there was nearly no knowledge available concerning e.g. self wastage, plugging of micro-leaks, sudden enlargement of micro-leaks, etc.

The SNR-300 systems have been designed as shown in figure 1.1. The design failure is defined as the total rupture of 1 tube where water flow from both broken ends is considered. Each module is equipped with two rupture discs which have to cater for sufficient pressure relief.
Small leak detection is provided by hydrogen detectors at the outlet of each module and in the main cold leg pipe.

A detection of medium sized leaks is possible by the measurement of level changes in the expansion tank.

The figures 1.2 and 1.3 show in more details the already well known SNR-steam generator modules.

Regarding a water/steam leak the following philosophy has been established and is - a very important fact - accepted by our licensing authorities (see figure 1.4):

A leak starts always with a comparably small size and grows slowly step by step. First it becomes detectable by the hydrogen detectors. If no action occurs the leak grows further to an intermediate leak and becomes detectable by the level gauges in the expansion tank. Reaching a leak rate of about 500 gr/s automatic pressure relief of the water/steam side is initiated. Rupture discs are activated already at 10% leak flow of the design failure. By this step by step detection and protection leaks above the design leak are unlikely.

The signal processing of the hydrogen detectors is shown in fig. 1.5.

The two detectors in the main pipe are used to measure the absolute value of hydrogen content in the sodium. This is on one hand to control the hydrogen diffusion from the water side into the sodium and on the other hand to control the effectivity of cold trap operation.

Also the rate of change of the hydrogen concentration is controlled by these instruments. An increase of 0,1 ppm/h will signalize a "pre alarm" while 0,3 ppm/h is followed by a "wastage alarm" (Wastage on adjacent tubes starts at appr. 0,42 ppm/h).

The signals of the 6 detectors at the module outlets serve for identification of a failed module. This is achieved by the measurement of differences in concentration between each module outlet and the main pipe detectors.

The operator should convince himself which is the failed module before he initiates the water side depressurisation.

In conclusion: The accepted leak philosophy demonstrates that leaks above the design leak are extremely unlikely. Independent from that, small leaks should be detectable reliably in order to safe capital costs.

2. The hydrogen detector of SNR-300

Fig. 2.1 shows schematically the detector. The most important part of it, the temperature controlled nickel membrane is fed with sodium by a small e.m. pump with a flow rate up to 1 m^3/h. A membrane temperature of 500°C is achieved, independently from the loop temperature, by an electric heater system and an additional tube in tube heat exchanger. The electric current of a continuously operating ion getter pump serves as a measure for the amount of hydrogen diffusing through the nickel membrane. Interesting technical data of the system are given in fig. 2.2. More details of the membrane, which consists of 4 fingers and the ion getter pump with its internals are depicted in the fig. 2.3, 2.4 and 2.5. Ion getter pump characteristics such as sensitivity and pump capacity are plotted in fig. 2.6 for ambient temperatures of 20° and 60°C. The curves show a sufficient stable behaviour over the whole pressure and temperature range. Of course it demonstrates too, that the final sensitivity in µA/ppm is indeed not a constant value and will be reduced at extremely low pressures.
Fig. 2.7 shows a comparison between a theoretical calibration curve and experimental values measured by an ionisation gauge and an ion getter pump. The figure shows a

fairly good agreement and demonstrates the possibility of predicting the sensitivity of a nickel membrane - ion getter pump system quite well. It should be pointed out that the used nickel membrane was different from those which will be introduced in SNR-300. The theoretical curve is based on the equations given by my collegue Rainer Hans and myself in our last year's IAEA publication

> "Leak detection of steam or water into sodium in steam generators of liquid-metal fast breeder reactors"
> Atomic Energy Review, Vol. 15, No. 4 (1977)

A number of calibration tests have been performed in the meantime. Two detectors are running continuously now for more than 30,000 hours each in test loops at INTERATOM. Two others are under operation in the KNK-II secondary heat transfer systems; operating time at the moment (end of May) appr. 3000 hours.
Fig. 2.8 shows some results of earlier steam injection tests in a sodium loop. Using a "shock-like" injection (2 gr H_2O in 5 s) the signal reflects the revolution period of the loop quite well. When a more continuous injection mode is used also a continuous signal increase can be observed. But there is still another difference in these two diagrams. In the first case the sodium temperature was 500°C, while in the latter case this temperature was only 250°C. This results in a different behaviour of the hydrogen. In the first case all the hydrogen contained in the injected steam is nearly immediately available for detection while in the second case there is a remarkable delay in the total liberation of the hydrogen due to the strongly temperature dependent secondary reactions (see fig. 2.10). The delayed liberation of hydrogen can be clearly observed in the second diagram after the injection has already been finished.

As a next step of calibration work, a SNR-prototype detector has been introduced into the 50 MW steam generator test loop at Hengelo. These tests are still under performance. Fig. 2.9 illustrates two of the first results from those tests. C means the theoretical concentration of hydrogen in the sodium assuming that all hydrogen contained in the injected steam is immediately available for detection. Again, as already shown in the earlier tests, the influence of the sodium temperature on the hydrogen signals is obvious. Further injection tests have to be performed in order to complete the understanding in large loop systems.

With respect to SNR-300 it is intended to have a complete calibration of all detectors in situ by steam injections.

3. Remarks on the disadvantages of impurity detectors

The situation is shown in fig. 3.1.
A micro leak can occur the size of which is below or near the resolution level of a hydrogen detector. After a few seconds this leak will be plugged by reaction - or corrosion products. Thus the leak remains undetected. Minutes, hours or even days and weeks later this leak will reopen with an remarkable increase in size due to corrosion effects during the time when it was plugged.

Regarding wastage on adjacent tubes the most pessimistic leak size i.e. the maximum wastage rate has to be taken into consideration. At this very moment a competition begins:
In the tube bundle of the failed steam generator the wastage on adjacent tubes starts, resulting in a possible leak propagation. On the other hand, the formed reaction products have to be transported from the leak point to the detection system by the sodium flow. Having detected the leak by the impurity monitor, the depressurisation of the water side can be initiated in order to avoid further propagations.

Figure 3.2 demonstrates more clearly how this competition will end under pessimistic assumptions in a SNR-300 steam generator:

The maximum wastage rate of stabilized 2 1/4 Cr 1 Mo observed in experiments amounts to appr. 0,1 mm/s. Considering the wall thicknesses of the water/steam tubes pessimistic propagation steps of 20 - 45 s are possible.

When assuming a leak near the sodium inlet of a superheater the reaction products need at least 42 s to meet the sensing part of the detectors in the main pipe.

As it is not intended to initiate an automatic depressurisation of the water side by a hydrogen signal, the very unknown "response time" of the operator has additionally to be taken into consideration.

Result: There are leak- and load configurations possible by which a leak propagation can not be avoided mainly because of the transport times. That means one has to learn to accept and to live with leak propagations. Finally, wastage on neighbouring tubes has to be accepted.

4. A first approach on acoustic leak detection systems

The main advantage of an acoustic detection system is given by the fact that transport times become negligible. On the other hand with acoustics the difficulty occurs that a leak signal has to be clearly separated from other noise sources. But if fast detection is requested in order to avoid further propagation steps only a combination of acoustic detection with automatic water side depressurisation will be an acceptable solution. Especially in the case of SNR-300 there is a number of additional demands which have to be taken into consideration. This is shown in fig. 4.1. In SNR-300 the decay heat is removed by the

main heat transfer system. In order to avoid the loss of one decay heat removal chain by a false alarm - followed by an automatic water side depressurisation - a highly reliable signal is requested. Therefore in our opinion an alarm signal should be adjusted at an already high leakage level. For LMFBR systems having an independent decay heat removal system those alarm levels can be reduced remarkably.

A possible introduction of an acoustic system in SNR-300 is shown in fig. 4.2. The leakage level for automatic water side depressurisation could be reduced by a factor of 10 or even more compared with the level increase signal which is the lowest automatic action level now.

The most important part of an acoustic detection system is the detector itself. Some examples for the choice of suitable detectors are given in the following figures. These results were obtained by special steam injection experiments at INTERATOM.

The noise generated by the leaks is compared with the background noise of the used sodium loop and the noise of an electro-mechanical exciter connected to the test vessel.
The loop background noise contains mostly noise emissions from a centrifugal pump, air blowers, valves and of course the noise generated by the sodium flow. There is no steam generation in that loop. The influence of steam generation noise has to be studied in the next future, when the detector systems have been sufficiently optimized.

Fig. 4.3 shows the results of a badly conditioned piezo-electric accelerometer which was connected to the outside of the used test vessel. Due to an insufficient sensitivity at higher frequencies the comparison of power spectra densities does not allow a clear separation of the different noise sources.

Fig. 4.4 shows in contrast to the foregoing figure the power spectra densities of a well conditioned piezo-electric accelerometer, also connected to the outside of the vessel wall. The separation of the different noise sources is well demonstrated. The background noise can be neglected completely. Noise generated by the exciter shows a highest frequency of about 55 kcps. Above that point only leak-specific noise is recorded.

Fig. 4.5 shows the behaviour of a well conditioned magnetostrictive pressure sensor which was located in the sodium of the test vessel. At frequencies above 40 kcps the noise generated by the loop and by the electro-mechanical exciter becomes negligible. In the higher frequency ranges even a separation of different leak rates seems to be possible.

Additional information are given in figure 4.6 which demonstrates RMS signals of the different detectors. It can be seen that by the broad band techniques (0,2 - 300 kcps) a separation of leakage and exciter signals is not possible. A much better picture is shown in figure 4.7. There the broad band technique has been changed into a more selected band technique (40 - 300 kcps) where by band pass filters the lower frequencies were suppressed. While the badly conditioned accelerometer shows no improvement in its signal, the other two start to separate exciter and leak noise. The pressure sensor shows already a nearly complete suppression of the loop background noise.

These are very preliminary results from the development of acoustic leak detection systems at INTERATOM. The development has just begun and we are still in "baby shoes". But nevertheless the advantages of an acoustic detection system are so large that we all should follow on this way.

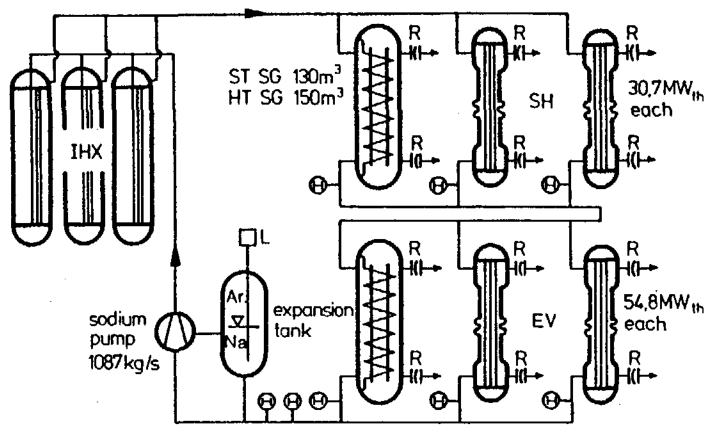
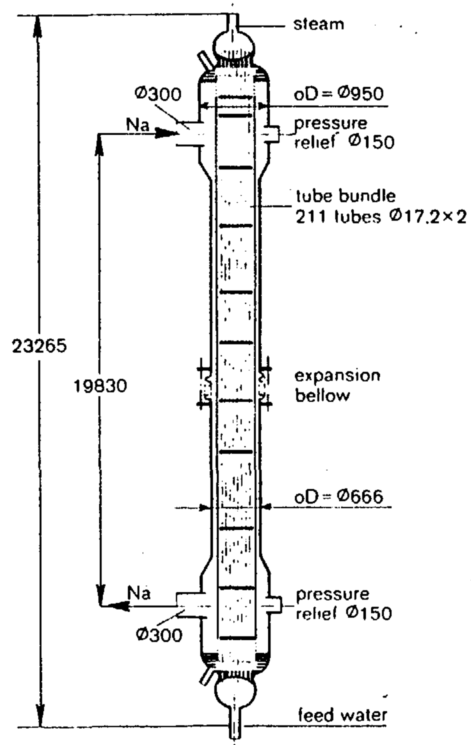
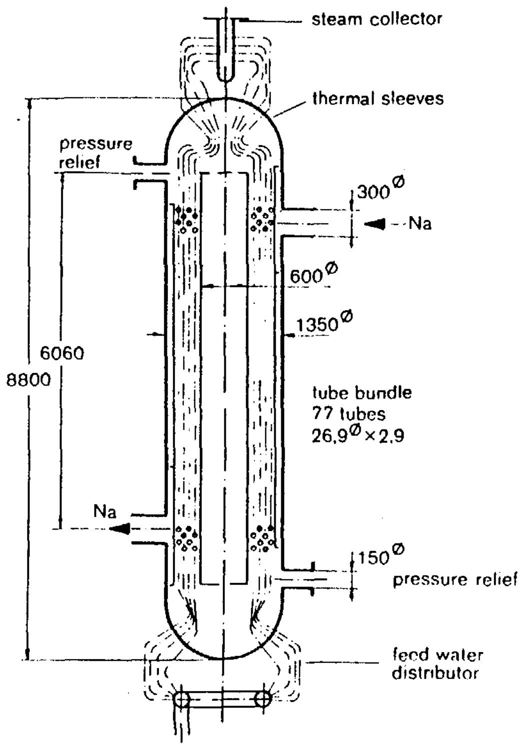


fig.1.1 secondary heat transfer system



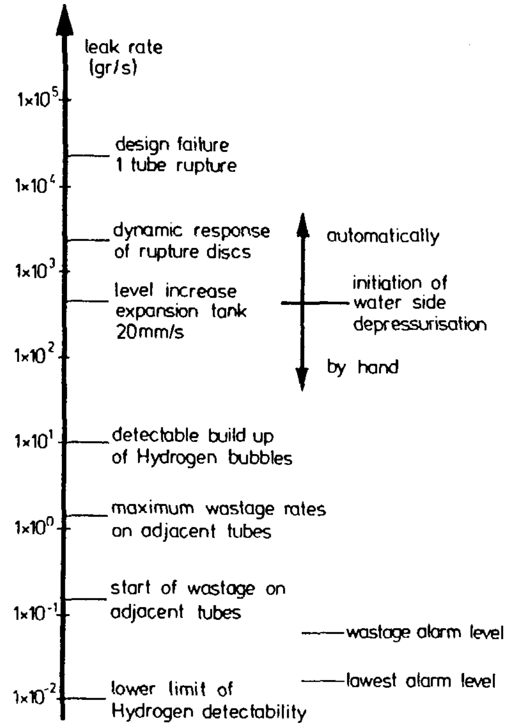
SNR-STRAIGHT TUBE STEAM GENERATOR -EVAPORATOR-

fig.1.2



SNR HELICAL COIL
STEAM GENERATOR -EVAPORATOR-

fig. 1.3



leak detection systems SNR 300

fig. 1.4

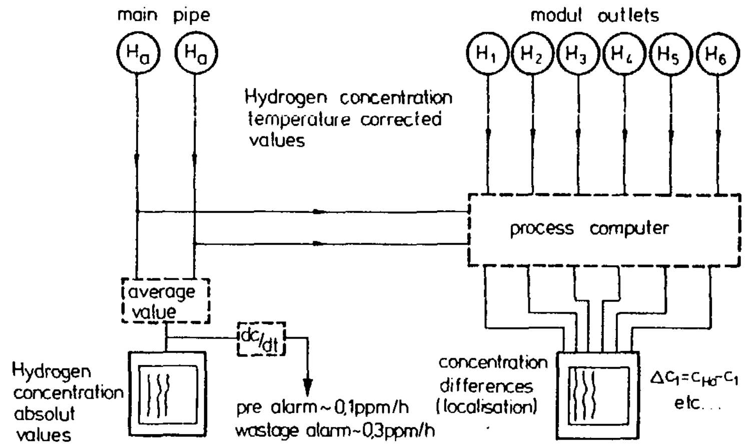
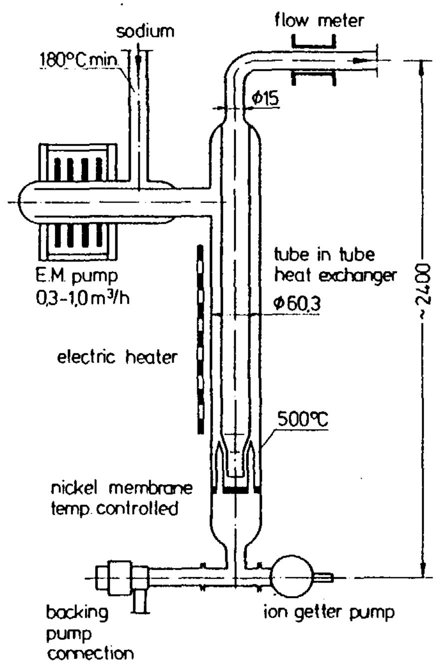


fig. 1.5 SNR300 signal processing, Hydrogen detectors



Hydrogen detector

fig. 2.1

1. Nickel membrane

material	Ni 201 ≙ LC Ni 99
surface	65,5 cm^2
wall thickness	1mm
operating temperature	500°C
life time	2×10^5 h

2. Ion getter pump

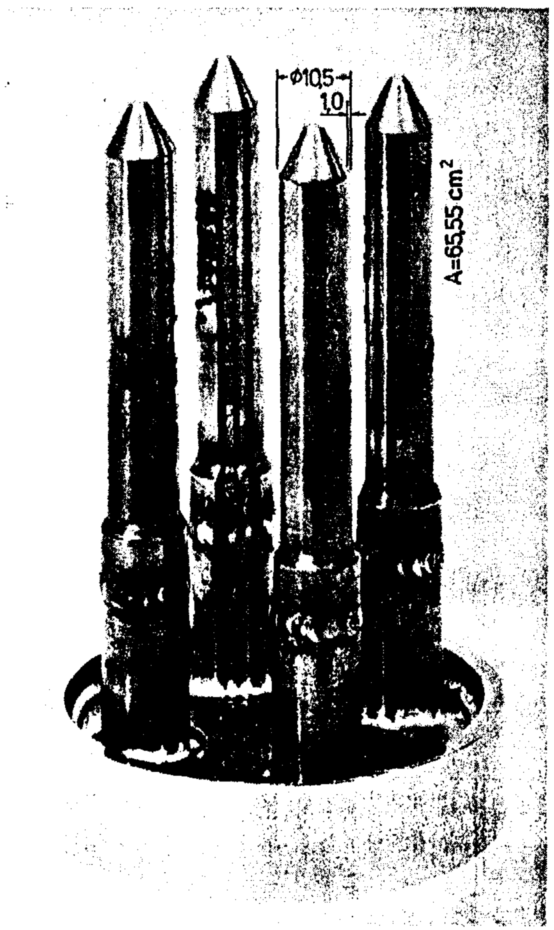
pump speed	~3,5 l/s (H_2)
measuring range	0-2 ppm H_2
envisaged life time	2-4 years
operating temperature	20-60°C
operating pressure	1×10^{-8}-5×10^{-6} mbar

3. System data

lower detection limit	1×10^{-2} ppm H_2
sensitivity	~90 µA/ppm H_2
dynamic mode response time	negligible
(static mode response time)	100 s (0-63%)
temperature effect on signal	~1,1% per K

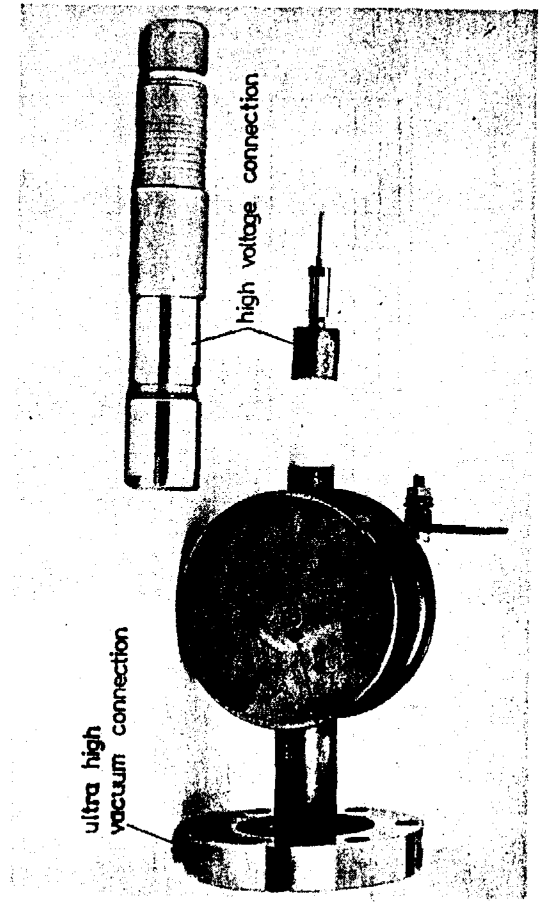
SNR 300 Hydrogen detector, technical data

fig. 2.2



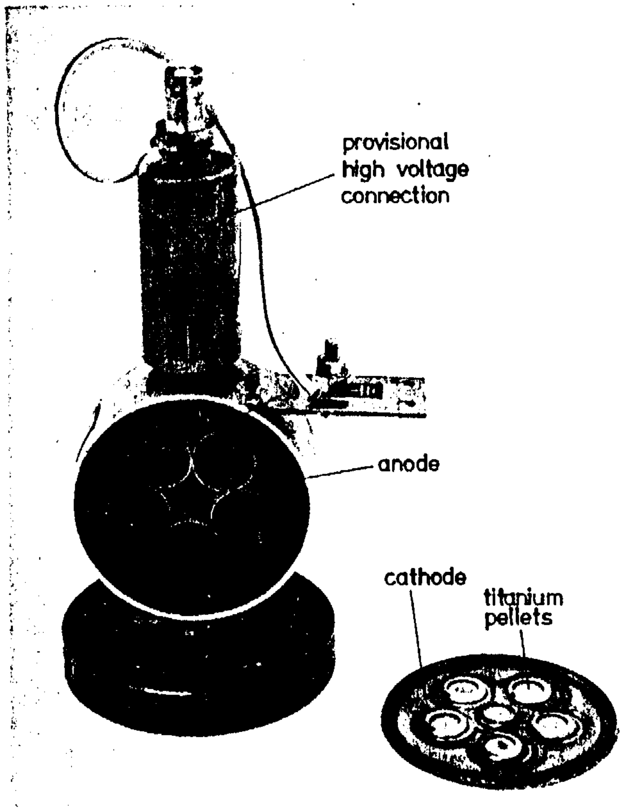
Hydrogen detector, Nickel membrane

fig. 2.3



ion getter pump IZ-2

fig. 2.4



ion getter pump IZ-2 fig. 2.5

ambient temp.:293K(20°C) / 333K(60°C)

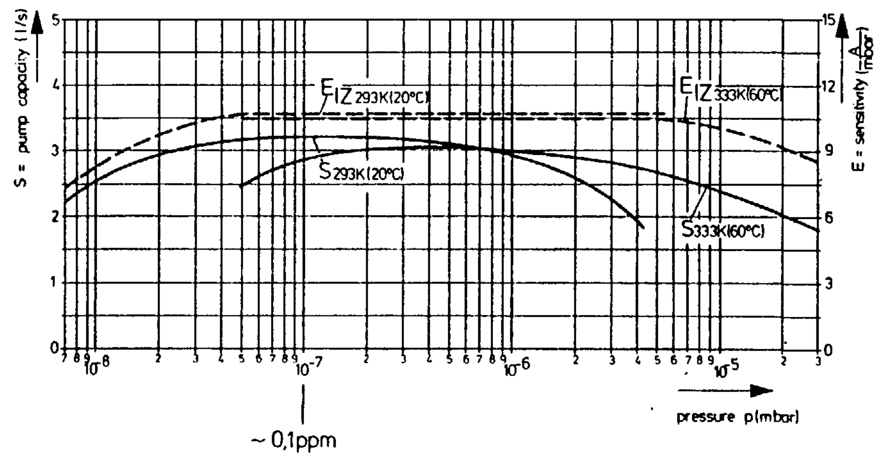
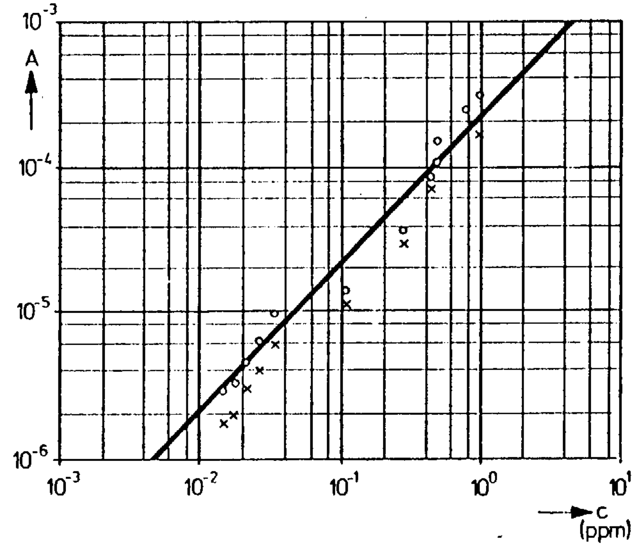


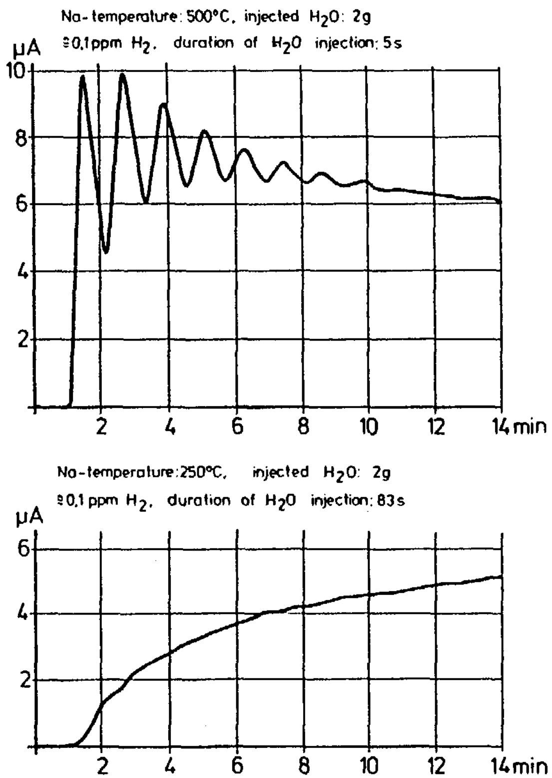
fig.2.6 pump capacity and sensitivity, ion getter pump IZ2



o. measured with ionization manometer gauge
x measured with ion getter pump
membrane 0,5mm thick, 54,3 cm²

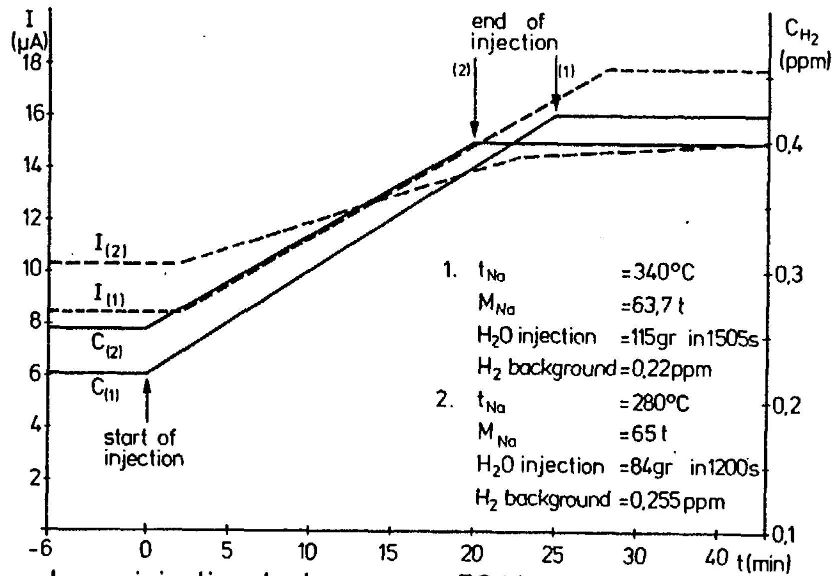
calibration curve Hydrogen detector

fig. 27



water injection tests at different temperatures (membrane 0,5mm, 54,3 cm^2)

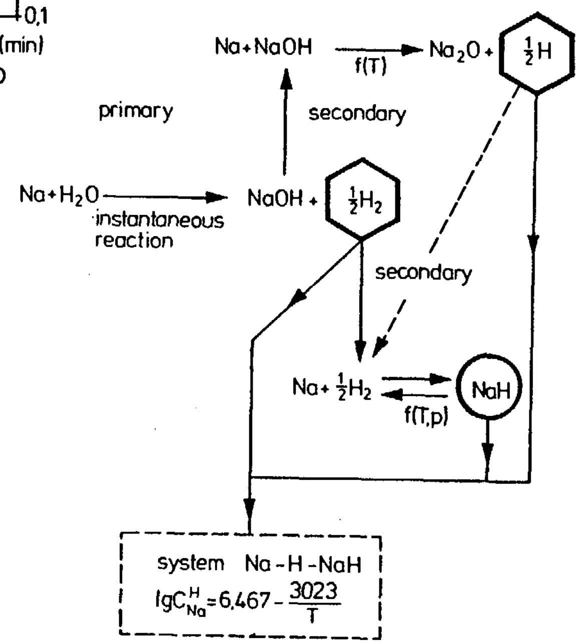
fig. 2.8



steam injection tests 50 MW loop Hengelo

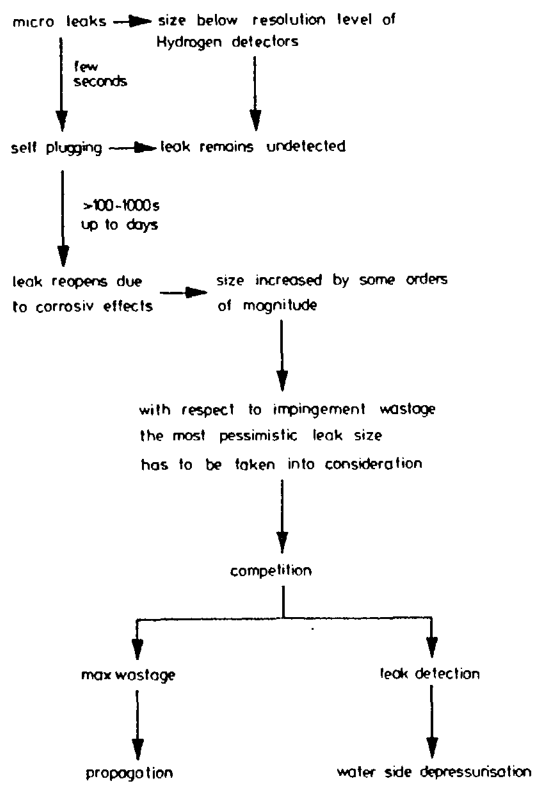
SNR-300 Hydrogen detector

fig. 2.9



chemical reactions

fig. 2.10



initial leak situation

fig.3.1

Propagation

$2\,^{1}/_{4}$ Cr 1Mo stab. max. wastage rate	~ 0,1 mm/s
tube walls:	
straight tube evaporator	2,0 mm
straight tube superheater	2,9 mm
helical tube evaporator	2,9 mm
helical tube superheater	4,5 mm
pessimistic propagation time	20 - 45 s

Detection

full load transport time superheater inlet - main pipe detectors	27 s
transport time in detector (load independent)	15 s
response time of detector	~1 s
manual action by operator	X s
depressuration of water side	23 s
minimum time	66 s + X s

small leak time table

fig.3.2

1 acoustics ≙ fastest detection system of all

2 necessary to avoid propagation damages

3 automatic water side depressurisation required

4 in case of SNR 300 depressurised loop is lost for decay heat removal

5 influence on reliability of decay heat removal is obvious

6 false alarms from detection system have to be avoided

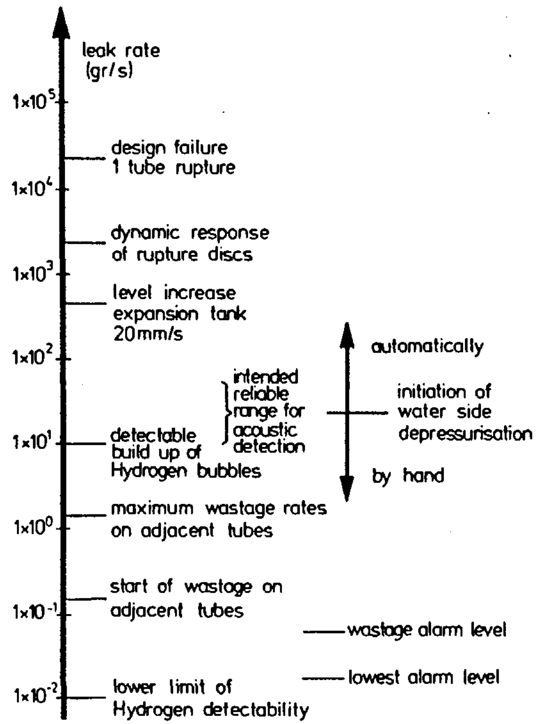
7 high reliability of signal is requested

8 depressurisation signal has to be adjusted at a comparatively high leakage level

9 alarm level can be reduced remarkably for steam generating systems with independent decay heat removal installations of high reliability

general remarks on acoustic detection systems, esp. for SNR-300

fig.4.1



introduction of acoustic detection in SNR300
fig.4.2

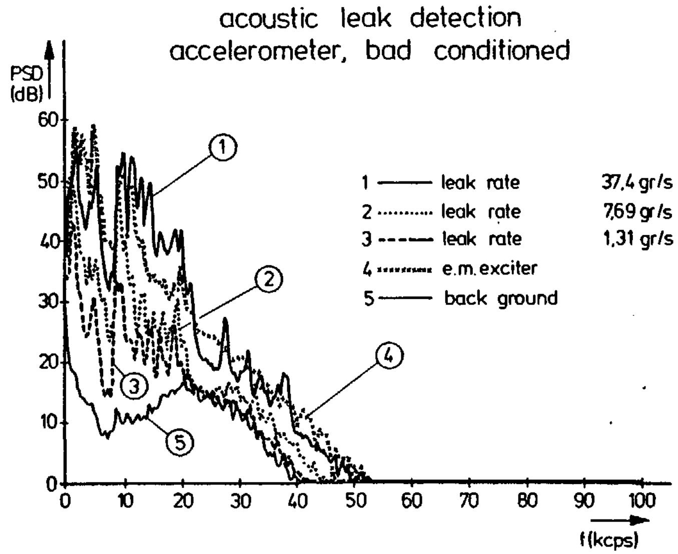


fig.4.3

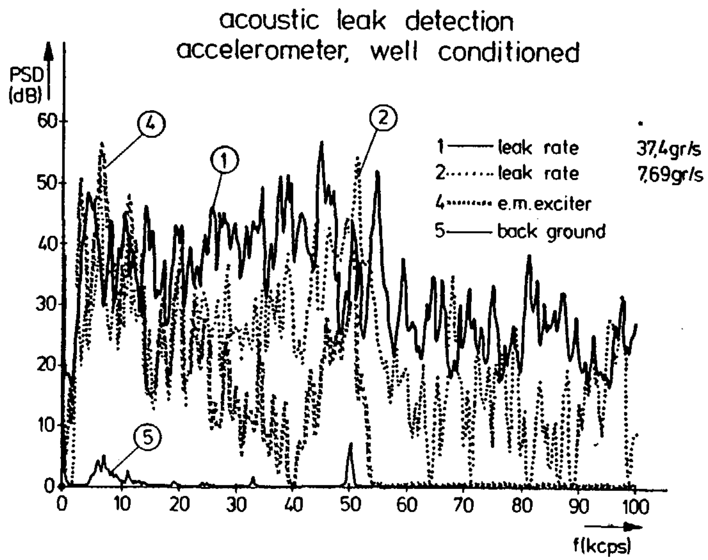


fig.4.4

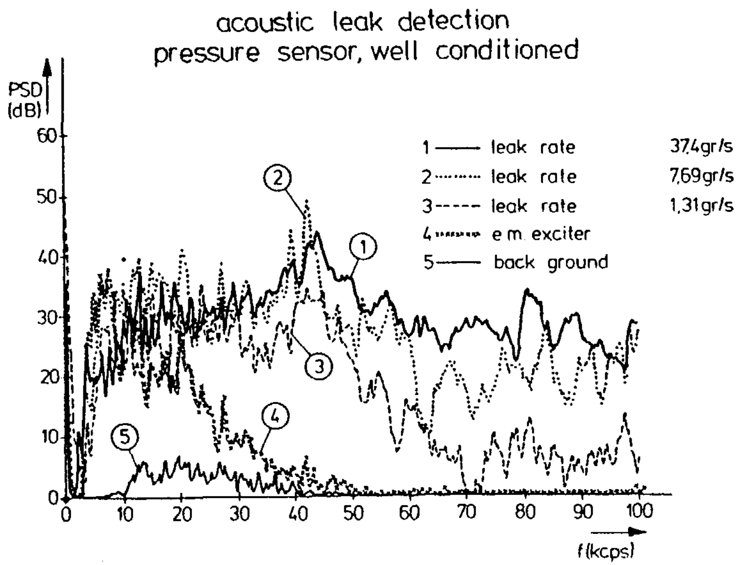
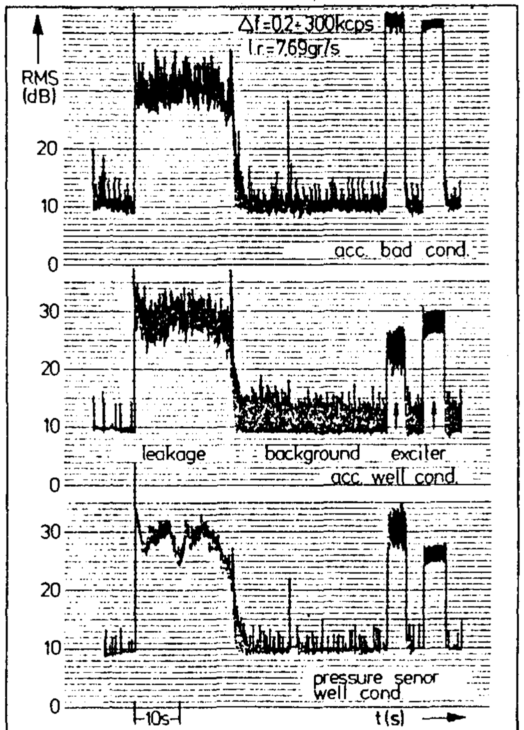
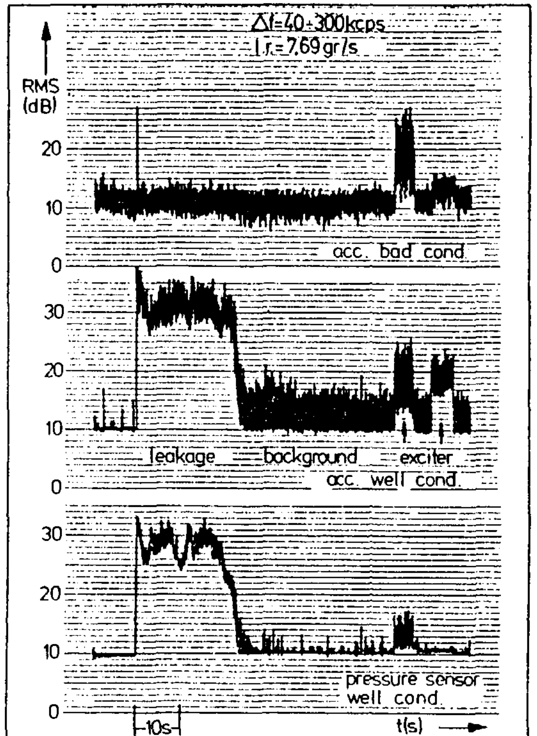


fig.4.5



comparison of RMS signals
leakage, background, mech. exciter

fig.4.6



comparison of RMS signals
leakage, background, mech. exciter

fig.4.7