3. Unit description

The integrated solution is composed of 2 MEC units disposed on a circumference carring at the center the secondary sodium pump.
The assembly is shown in fig. 1
Nevertheless the modules could be assembled in a more convencional way as in the NIRA actual S.G. design.

4. Experimental program for M.E.C. module

To develop the described solution the following test have to be carried out:

a) stability and heat exchange test on a 1 Mw or 5 Mw test section;

b) industrial poiting out of the brazed joint;

c) brazed joint non distructive testing;

d) thermal shocks on brazed different materials joints;

e) theorical and experimental studies on the integrated assembly behaviour;

f) long term behaviour of a 50 mw prototype.

L.4.	Future Aspects for Liquid Metal Heated Steam Generators	W. Jansing W. Ratzel K. Vinzens	Fed. Rep.Germany

Abstract:

The present status of steam generators is shown. The experience gained until now is expressed in form of basic points. The most important design criteria for steam generator systems are outlined. On the basis of these design criteria, two possible steam generator concepts are shown. Costs in relationship to the repair concepts of two modular steam generators (thermal output 156 and 625 MW) and a pool design of 625 MW_{th} are compared.

1. Present status of development of sodium-heated steam generators

The efforts to outline the development tendencies of sodium-heated steam generator systems require a critical evaluation of the present level of development and of the experience gained until now. In the first figure the attempt is made to show in tabular form some of the steam generators designed built [1,2,3], tested and in operation. No claim is made that this table is all inclusive. It should give an impression about the range of work already done and the variety of steam generator types.

The most important experience will be outlined in the following "basic points".

- In spite of some failures which resulted in sodium water reactions in steam generators - mostly during the commissioning steps - their overall reliability is encouraging [5,6].

- It is still necessary to design for and operate steam generator systems to be able to accommodate sodium-water reactions.

- Damage to neighbouring tubes resulting from pinhole leaks is possible and can only be calculated to a limited extent [6].

- In-place repair of steam generators is difficult to carry out and time-consuming.

- In case of a failure in a steam generator, it is necessary to take the system quickly out of service to prevent further damage to the steam generator itself as well as to the circuit.

- The detection of hydrogen is possible in the sodium and

XA0055733

in the cover gas. Measurable signals are limited by the sodium flow rate through and the sodium volume in the steam generator as well as in the circuit. The design of the steam generator is, in this case particularly important.

- Many different configurations (for example straight tube and helical type and operational modes, such as in once-through and re-circulating steam generator systems) are probably technically sound. The key issues in steam generator reliability are the quality of fabrication and inspection.

- Before beginning the construction of the series for installation in a nuclear power plant it is still considered essential to test suitable steam generator prototypes in test rigs.

- The steam generator units are so far limited in size mainly because of the possibility of sodium water reactions resulting in failures as well as the difficulties in making in-place repairs.

- Decay heat removal is possible by means of the steam generator system since no difficulties normally arise in operating steam generators with minimal power.

- It seems possible to eliminate the secondary sodium system by the direct connection of steam generators to the primary sodium system. However, there are problems which might make such an arrangement difficult, at least in the next generation of sodium-cooled fast breeders.

2. Common design criteria for future steam generator systems

Based on the points listed above, an attempt will be made to identify the most important parameters of future steam generator concepts (see figure 2) [4].

The electrical power of the nuclear reactor system and the number of circuits are of decisive importance. With rising power capacity, the necessity grows to limit the number of steam generator failures and to minimize the necessary time for repair.

At the same time the early detection of steam generator failures with resulting sodium-water reactions in larger systems will become more difficult. Taking this aspect into consideration, many small steam generator systems must be built. However, because of this, the costs of steam generator systems, that is steam generators, piping system and pressure relief systems, will be increased.

The necessity for early detection of failures has a direct influence on the design details of the steam generator, for instance the spacing of the pipes, the wall thickness, the choice of materials and choice and development of the detection system.

An appropriate response during transients and power changes is necessary.

In addition to a careful optimization, the experience gained to date, including the resulting failure statistics will lead to a determination of the size and the design of the individual units.

Furthermore future technical developments, for example, in materials, are of great importance for design.
This progress could, for example, lead back to the familiar, proven, and possibly slightly modified ferritic materials in future steam generator systems.

Manufacturing techniques and manufacturing control will have a strong influence on the design.

3. Costs of steam generator systems and repair concepts

The design and the unit size of steam generators cannot be planned without taking into account those problems which arise after a steam generator failure.

In the third section of our report we therefore will try to make a comparison of costs for a 2000 MW_e power plant with 4 loops. We consider modular-type steam generators of 625 and 156 MW_{th} (that means 2 and 8 units per loop) and a pool type with 7 units as described in section 4.

Several methods of repair are discussed:

1. Disconnecting of the failed unit and continuation of operation at reduced power. Reinstallation of the repaired unit at the following planned shutdown (e.g. for core refuelling).

2. Replacement of the failed unit by a spare unit.

3. In-place repair of the unit.

4. Replacement of the failed bundle in the pool by a spare unit.

The cost comparison is based on the following considerations:

- loss of money caused by reduced electrical power output during repair or exchange time and continuation without the failed unit,
- costs of the steam generator systems including piping etc. depending on the size of a unit,
- time for in-place repair, 25 days for the modular type of 625 MW_{th}, 20 days for 156 MW_{th},
- time for exchange, 10 days for a 625 MW unit, 6 days for a 156 MW unit, and 3 days for the pool type,
- time for removal without replacement by a spare unit: 5 days for a 625 MW unit, 3 days for a 156 MW unit; max. time until replacement 180 days.

The results of our cost estimate are shown in the next figure. There is no doubt that this figure only can show tendencies, but some facts seem to come out comparatively clear.

Case 1, dismounting without replacement by a spare unit seems to be unfavourable both for the 156 and the 625 MW units if the number of failures exceeds two over the whole lifetime of the plant, even if the time until the replacement is less than 180 days.

Case 2, removal and replacement seems to have a lot of advantages even if a comparatively big spare unit has to be provided.

Case 3, in-place repair is interesting for large units if the number of failures does not exceed 2 or 3, but because of a lot of unsolved problems connected with the in-place repair concept it still contains too much risk.

Case 4, the pool concept is charged with high fabrication costs but worthwhile to be considered in more detail.

Drawing a conclusion from this discussion, we can say at present that in-place repair or removal of steam generators without replacement by a spare unit seem to be unfavourable solutions.

4. Examples of steam generator systems for future plants

On the basis of the considerations in the first three sections, we would like to discuss two alternative steam generator systems.

The first of these is a pool concept embodying a large sodium tank with a number of replaceable modules inserted from the top, as shown in figure 4. For a

625 MW_{th} pool, the tank would be about 5 - 6 meters in diameter and contains 7 replaceable modules of 90 MW each. Two subconfigurations are possible.

Type 1 is a helical steam generator, type 2 is a straight tube steam generator with separate compensation of the tubes by means of tube bends or some similar arrangement, both have a central open-top thimble, which is immersed in the sodium system. Centered in this thimble is the feedwater pipe with the header at the lower end. With the helical type, individual tubes are led from this header through the thimble wall by thermal sleeves and are coiled around the thimble on the sodium side.

Evaporator and superheater can be either integrated or separated in the pool. At least the helical type should be integrated. The steam tubes penetrate the shell of the module or the thimble at the top and are again brought together in headers. The bundle is surrounded by a suitable liner. The sodium flow through the bundle from top to bottom, is guaranteed by horizontally-mounted plates which prevent by-pass.
Suitable instrumentation for the recording of vibration or pinhole leaks (for example sound recorders) could be easily placed in the thimbles.

In case a free sodium surface with cover-gas atmosphere under normal operation in the pool is employed, conventional flange devices with conventional joints can be used in the upper part.

A faulty unit may be replaced by pulling it into an exchange vessel provided for this purpose. By this concept it is not necessary to disconnect any tubes in the sodium system. For the feedwater and steam systems, disconnecting is accomplished by valves and flanges, corresponding to conventional techniques.

In type 2, which is designed as a straight-tube steam generator, the tubes are not led through thermal sleeves into the sodium system. The feedwater enters from the lower header through main tubes into a ring header and from there through tube sheets into the preheating zone.

A detection system, for instance, for oxygen or hydrogen can be provided on the sodium side below each unit in both helical-type and straight-tube steam generators.

The number of units in the pool is not fixed. It also is possible to plan a separate pool per each unit, which means the steam generator can be taken out of the shell as a single unit.

The second one is an integrated "three fluid steam generator". The fundamental design of the coiled, integrated steam generator is shown in figure 5.
The coiled sodium and water/steam piping is arranged in a tube cluster. Heat transfer from the primary sodium to the water/steam is achieved by a static heat transfer medium, for example, liquid metal. For that purpose a Lead-Bismuth-alloy can be used since no exothermic reaction occurs between the two coolants, and there will be no reaction between the intermediate fluid and probable piping materials. There is also a possibility of using sodium as the heat transfer medium.

The headers are mounted outside the once-through steam generator. The individual tubes penetrate the shell above the surface of the liquid metal in the cover gas chamber.

The detection of a leak into the heavy metal can be accomplished either in the cover gas chamber by specially instrumented thimbles or on the surface of the liquid metal. In case of a leak, steam or sodium respectively sodium compounds rise to the surface of the metal bath due to the difference in density, so that a leakage detection is possible there.

One tube unit is composed of one water and two sodium tubes. An estimation of the coolant flow and the necessary tube length, based on the SNR 300 conditions, results in about 240 tube units, each 75 meters long with a total rating of 120 MW.

Finned tubes or other tube forms could be considered. The heat exchanger has the shape of a tall torus. It has been established that the diameter of the innermost coil should measure about 2 meters, the outermost, about 4 meters and the entire cluster height, about 3 meters.

High unit rating, minimal specific liquid metal- and tubing weight and also a not-too-high sodium pressure loss are desirable. In considering the optimal steam generator, the eutectic Pb-Bi liquid metal will cost about DM 25/kg. The density of the alloy is about 10 g/cm^3.

Literature

[1] Soviet power reactors
WASH-1175, 1970, p. 73-75

[2] BNES International Conference Fast Reactor Power Stations, Specialist session I: Steam Generators
London, 11-14 March, 1974, p. 29-34

[3] Engelmann, P., Mausbeck, H.
Stand und Tendenzen der Schnellbrüterentwicklung 1974
Atomwirtschaft - Atomtechnik 8/9, Sept. 1974, p. 397-404

[4] Bakema, U., Poiesz, M., Ratzel, W., Vinzens, K., Zipper, E.
Development of steam generators for SNR projects
19th Rome Nuclear Congress, March 1974

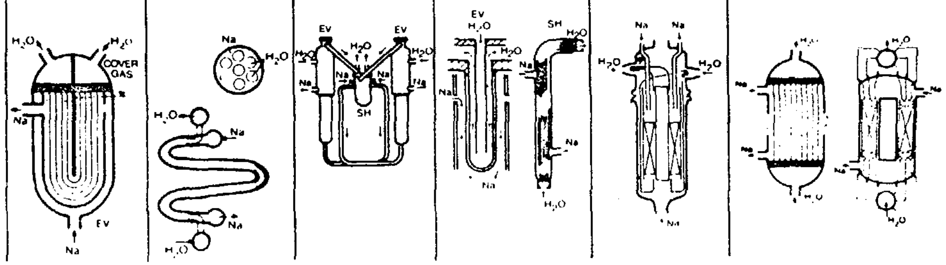
[5] Dumm, K., Ratzel, W.
KNK steam generator leakage evaluations and improvements
IAEA-Study Group Meeting on "Steam Generators for Liquid Metal Fast Breeder Reactors", Oct. 1974

[6] de Clercq, W.J.C.
Sodium-water reaction in the reheater of the 50 MW test facility of Hengelo
Engineering of Fast Reactors for Safe and Reliable Operation, Karlsruhe, Oct. 1972

FIG. 1. SODIUM HEATED STEAM GENERATORS (SG)

	PFR	PHENIX	BN 350	CLINCHRIVER	MONJU	SNR300
SG-SIZE	200 MW	188 MW	200 MW	325 MW	238 MW	85,6 MW
SG-Components	EV,SH,RH	EV,SH,RH 12Modules	2EV,1SH	2EV,1SH,	EV,SH,RH	EV,SH
SG-Process	Recirculation	Once-Through	Recirculation	Recirculation	Once-Through with Water Separation	Once-Through with Water Separation
Material	EV: 10CrMoNb910 SU,RH:AISI316	EV: 10CrMoNb910 SU,RH:AISI321	10Cr Mo 910	10Cr Mo 910 (Incoloy-800)	10Cr Mo 910 Austenitic	10Cr MoNiNb910
Na-Temperature	532/370 °C	550/350 °C	500/300 °C	502/344 °C	515/320 °C	520/325 °C
H_2O-Temperature	516/288 °C	512/246 °C	430/158 °C	432/232 °C	483/240 °C	500/246 °C
Steam Pressure at SH Outlet	164 bar	167 bar	49 bar	105 bar	130 bar	167 bar

Design Scheme



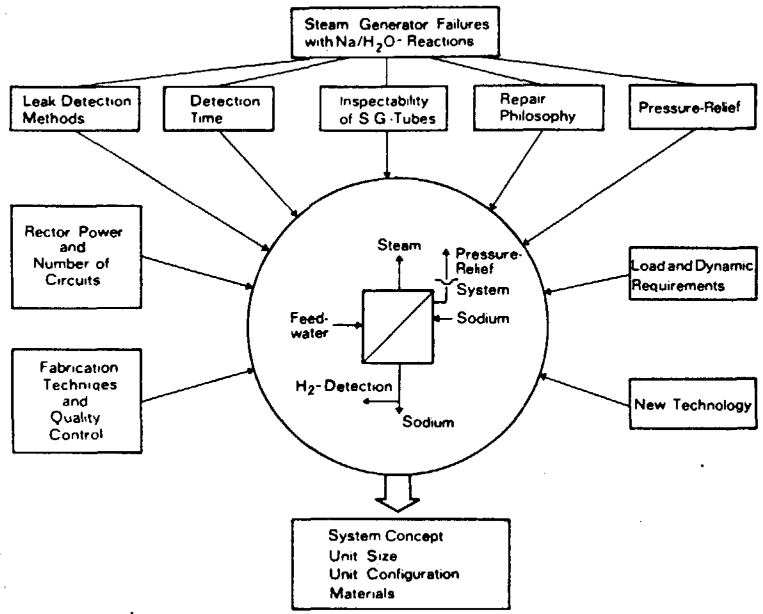


FIG. 2. CRITERIA FOR THE DESIGN OF STEAM GENERATOR SYSTEMS

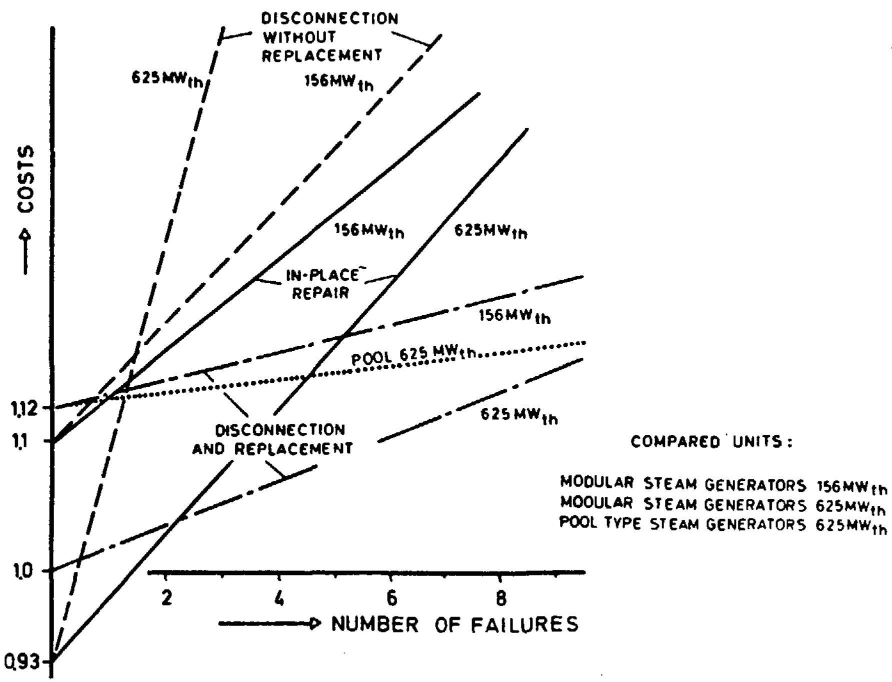


FIG. 3. COSTS OF DIFFERENT REPAIR CONCEPTS

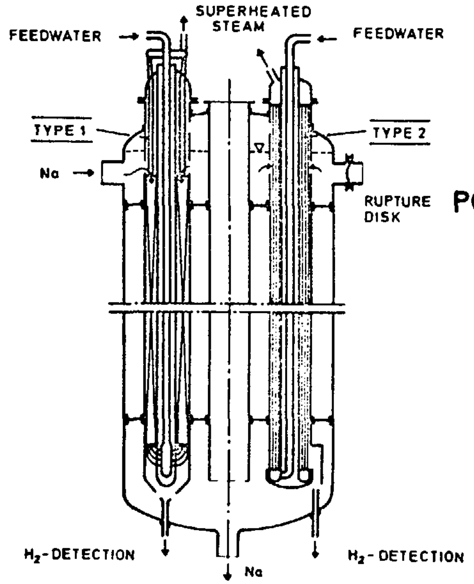


FIG. 4.

POOL-TYPE STEAM GENERATOR

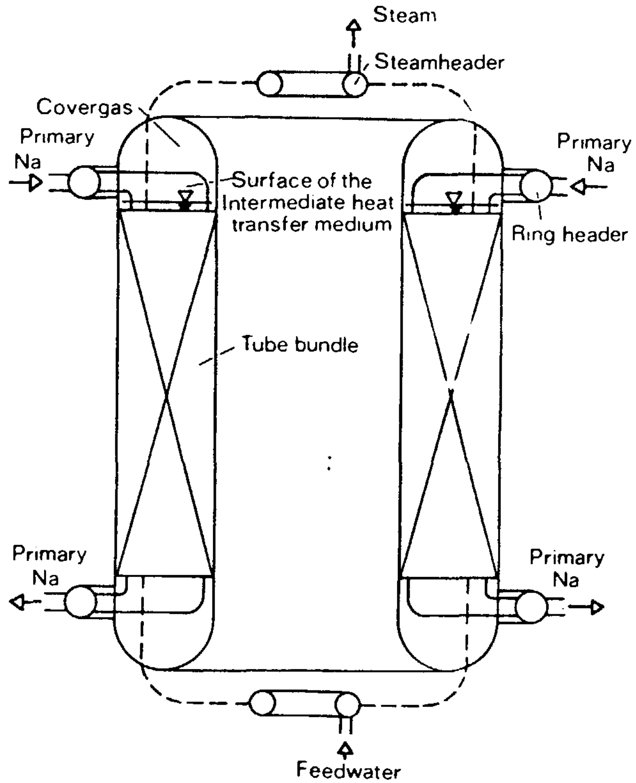


FIG. 5. INTEGRATED "THREE-FLUID STEAM GENERATOR"