8. COMPARISON OF OPERATIONAL CHARACTERISTICS OF THE MMISG AND MISG AND SUMMARY OF THE EXPERIENCE GAINED

The micro module inverse steam generator (MMISG) has been operating at the BOR 60 reactor since September 1981. 56,200 hours of operation with steam generation were achieved in October 1992.

The total number of the MMISG shut down and staring was 108 during all the service time. 32 of them with slow shut down and 76 of them with slow decrease in power. No shut-down was caused by incorrect function of the steam generator or by a leak accident.

The module inverse steam generator (MISG) has been operating at the second loop of the BOR 60 reactor since March 1991. 9,220 hours of operation with steam generation have been achieved until October 1992. The total number of the MISG shut-down and starting was 16 during the all service time. Eight of them with slow shut-down and eight of them with slow decrease in power. No of them was caused by the steam generator itself.

The operating conditions for the MMISG as well as the MISG have been chosen with regard to their design parameters and to the loop characteristics of the BOR 60 reactor.

Consequently:

- the feed water minimum flow rate in the starting period of the MMISG has to be 15 to 20% of nominal value to avoid the hydraulic instability,

- the water temperature at the outlet of each economizer module should not attain the temperature of saturation to avoid fatigue processes in tube plates,

- turbine valves can be turned before the steam temperature ranges the value of 400° and steam pressure the value of 8.3 MPa,

- the heating rate of the sodium in the secondary circuit of the BOR 60 reactor has to be less than 72°C per hour,

- if only the MMISG is taken into operation the sodium flow rate in the loop can reach the nominal value,

- if only the MISG is taken into operation the sodium flow rate in the loop is 65% of the nominal value and increases in accordance to the reactor power increase,

- if both inverse steam generators are in operation the sodium flow rate in each of both loops ranges to the value of 65 to 70% of the nominal.

A typical diagram for the starting period of both inverse steam generators is in Fig.46. Such conditions suite best to the specific design of the BOR 60 reactor.

The MMISG water side is flooded by water and the sodium flow rate is constant at the beginning of the starting period. A constant water level in a steam/water separator is kept by feed water rate control at the steady state power level of the MMISG.

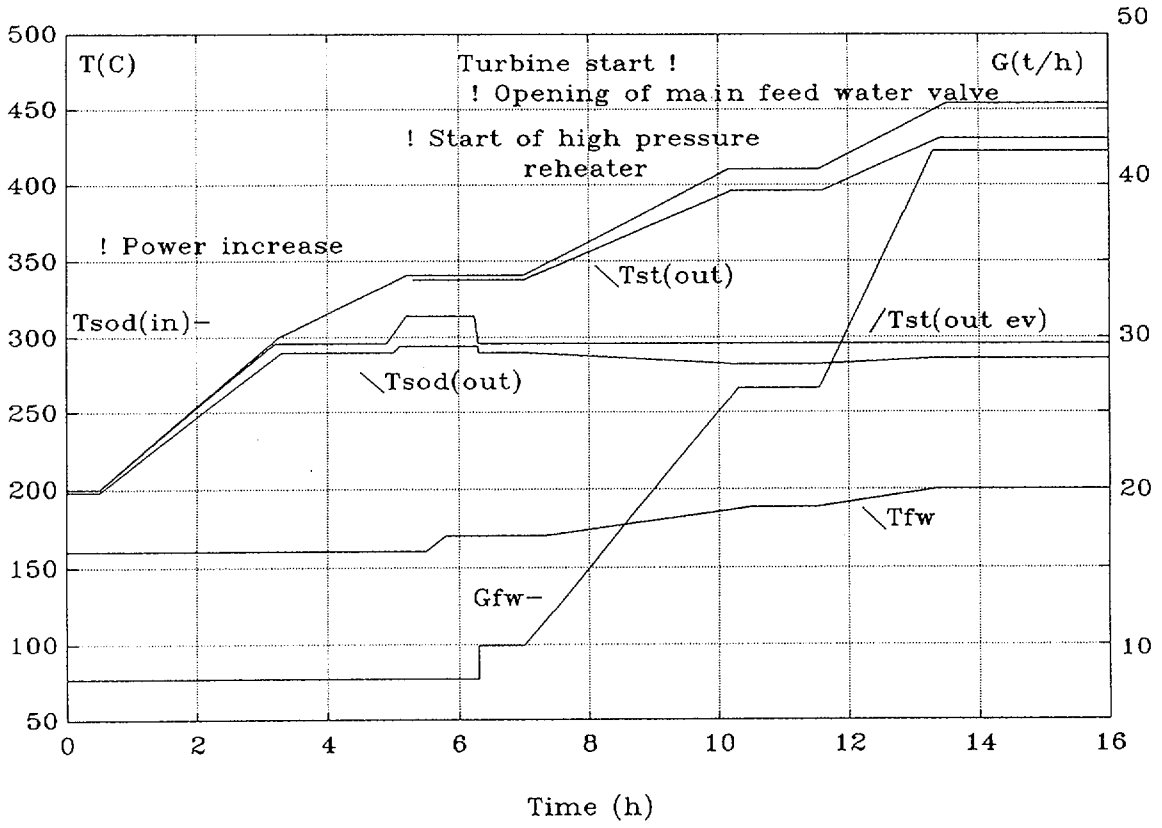

FIG.46.Typical diagram for the starting period of the MMISG as well as for the MISG at BOR 60 reactor

The water flow rate in blow down pipeline connected to the separator ranges up to 3% of the water flow rate.

A constant value of the steam temperature at the outlet of the evaporator region is kept by the feed water rate control at the steady state power level of the MISG.

The indirect sectional heating system and the modular configuration of the MMISG make it possible to heat the MMISG up to the required temperature, even with frozen sodium inside, without the danger of failure.

The heating of the MMISG with frozen sodium had to be uniform pausing at temperatures to avoid local modifications in sodium state of aggregation and damages of the ISG structure in modules and pipelines sealed at both ends by up to then frozen sodium. The sodium started to melt in the free level regions first. The sodium filled pipeline connecting the MMISG sodium outlet chamber with the buffer tank was heated up to 150°C during the experiment pausing about 60 hours at that temperature. The buffer tank sodium was continuously molten prior to and after the experiment. The inlet MMISG sodium pipeline was heated up to 100°C with a pause of 6 hours at temperature. In the next step the temperature of the inlet pipeline was raised to 130°C and simultaneously the MMISG structure immersed in the insulation box was heated to 90°C and both kept at this temperature for about 50 hours. The temperature of sodium pipelines outside the insulation box increased up to 180°C and subsequently the temperature of MMISG metal in the insulation box up to 120°C in the last experimental step.

The results of the above experiment are significant for the analysis of an accident situations at nuclear power plants and for MMISG repair in outage time and they demonstrated also some advantages of an indirect MMISG heating system by electrical heaters and hot air circulation inside the insulation box.

To ensure a safe steam generator shut-down during the slow reactor shut-down, the following procedures should be taken:

- disconnect the sodium pump in the secondary loop. The run-out of the pump is 90 to 120 seconds,

- hold the feed water rate during a period of 40 to 60 seconds after the shut down has been started to avoid thermal shocks, to keep stable field of temperatures in the inverse steam generators and to hold the water level in water/steam separator of the MMISG and to achieve constant value of steam temperature at the outlet of MISG evaporator region for a long time,

- disconnect the feed water pump (run-out time approximately 2 to 5 seconds) and turn out stop valves at the feed water pipeline,

- if an increase of the sodium temperature at the outlet of inverse steam generators is observed, turn out the stop valves at sodium inlet and outlet pipelines,

- drain the inverse steam generator at the water side,

- fill the water side by nitrogen and start the steam generator heating system,

- connect air-sodium heat exchangers and ensure reactor heat removal.

Trends of media parameters during a slow shut-down of the MISG are given in Fig.47. After the sodium pump is run-out, the sodium flow is achieved by natural circulation. After the initial decrease of the outlet sodium temperature media

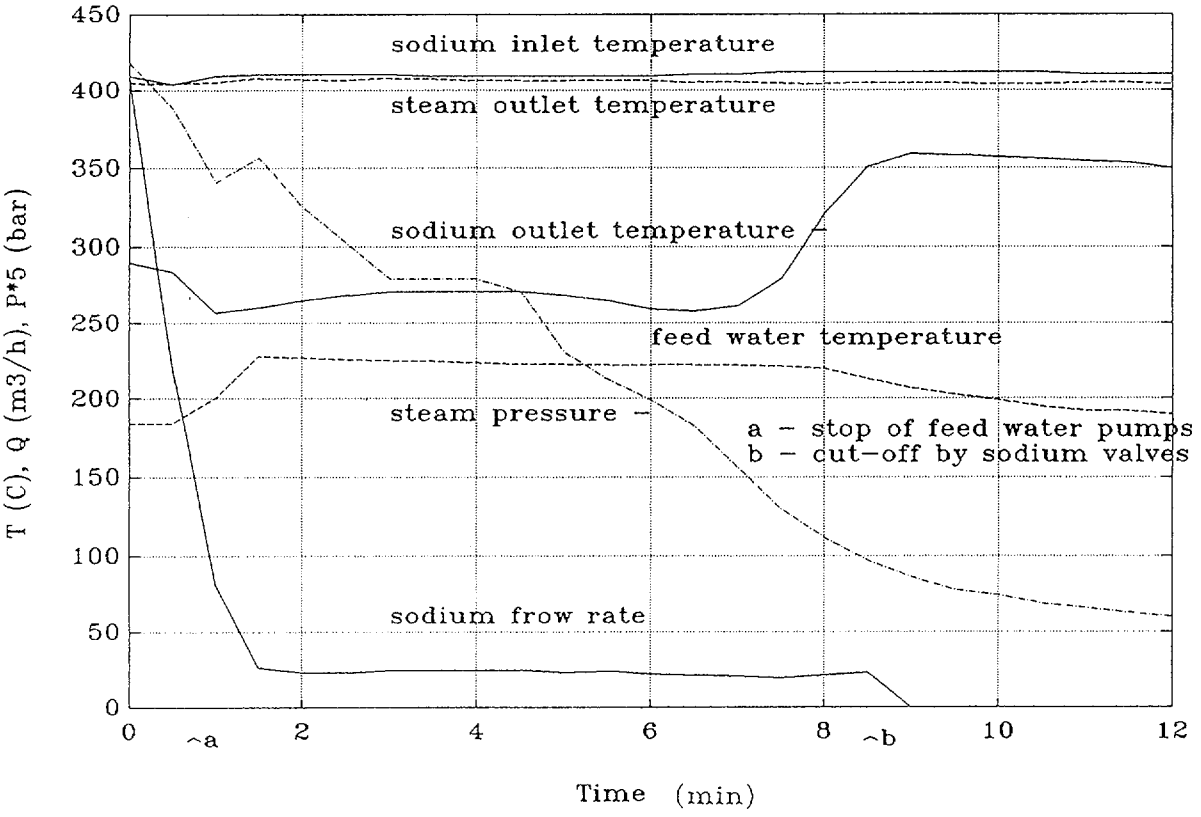

FIG.47.Trends of media parameters during a slow shut-down of the MISG at BOR 60 reactor

temperature stabilized in a time period of a few minutes and at the same time the steam pressure decreased slowly. The hot sodium appears in the outlet in the time of seven minutes. To avoid a thermal shock at the lower tube plate the stop valves at sodium pipelines are attached. The sodium temperature variation at the steam generator outlet ranged from 0.3 to 0.55°C per second.

Trends of media parameters during the slow shut-down of the MMISG are similar to those of the MISG. The existance of the period up 6 to 7 minutes with stabilized parameters enables to transfer carefully both inverse steam generators into the conditions for reactor heat removal if necessary.

Neutral chemical conditions at the water side with pH = 6.5 to 7.4 were used in the first period of MMISG testing. All chemical parameters exept for iron content for a short time corresponded to those of the design. The iron content ranged from 1.10^{-8} to 2.10^{-8} (design value 1.10-8) in the period between 1981 to 1986.

A decrease in the heat transfer characteristics of the MMISG [14] was observed from 1984 to 1985 caused by formation of deposit layers at the outer surface of the tubes. Therefore one of the MMISG branches was cut out to be analysed for structural material characteristics (see chapter 6.6).

After then the iron content in feed water was kept 1.10^{-8}. The specific conductivity of the feed water corresponded to the design value.