Behaviour of the Prestressed Concrete Pressure Vessel of the HTR–500 at Severe Accident Temperatures

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ABSTRACT

For the risk of medium-sized High Temperature Reactors with PCRV the behaviour of the vessel during a hypothetical core heat-up accident is decisive. Tests up to extremely high severe accident temperatures with representative models are carried out. The results of these tests are:

During a core heat-up accident after total failure of afterheat removal systems the prestressed concrete reactor pressure vessel of the HTR-500 can also be cooled with only one train of the liner cooling system (LCS); refeed of the failed system is possible up to at least 450 °C; insulation and liner will not fail during long-term outage of the LCS and do not aggravate the accident in the long run.

1. INTRODUCTION

Since about one decade the behaviour of PCRV of different HTR plants during core heat-up accidents is analysed (Altes et al 1981, Schimmelpfennig et al 1983, Altes et al 1987). These studies are part of risk analyses. Accidents which might lead to an unrestricted heat-up of the reactor core are hypothetical; for the HTR-500 the frequency of such an accident is one in ten million years. Studies on HTR safety have indicated the great significance of processes resulting during temperature stressing of the pressure vessel concrete for the sequence and consequences of accidents, particularly those with unrestricted core heat-up. For this accident it is assumed that all active cooling systems - main cooling system, afterheat removal systems and liner cooling system - have failed. In the course of the accident, the vessel is therefore slowly heated up.

In the following paper the results of tests on a representative section of the top of a HTR-500 PCRV will be given.

2. EXPERIMENTAL SETUP

In the experiments the sections of the PCRV with an area of 1.0 x 1.5 m and a thickness of 0.5 m were heated by being suspended over an electric chamber furnace (Fig. 1). There are 12 silit heating rods in the furnace chamber which make working temperatures of up to 1 500 °C possible. A preset accident temperature-time curve can be simulated. There are several inspection holes with quartz glass in the sides of the furnace in order to observe the test specimen or to make a photographic record of the processes at the test specimen during the experiment.

The third test specimen is a representative section cut from HTR-500 prestressed concrete vessel on the original scale. It consists of basaltic concrete and a

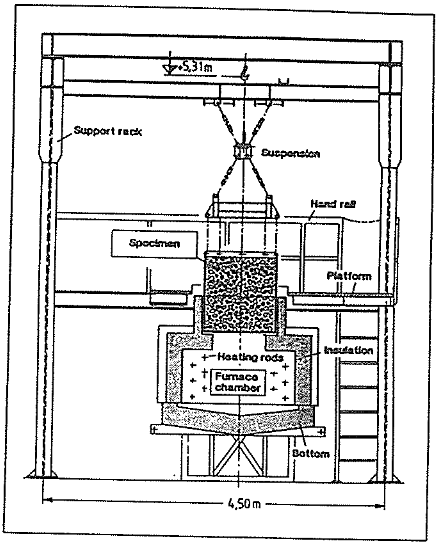

Fig. 1: Experimental setup

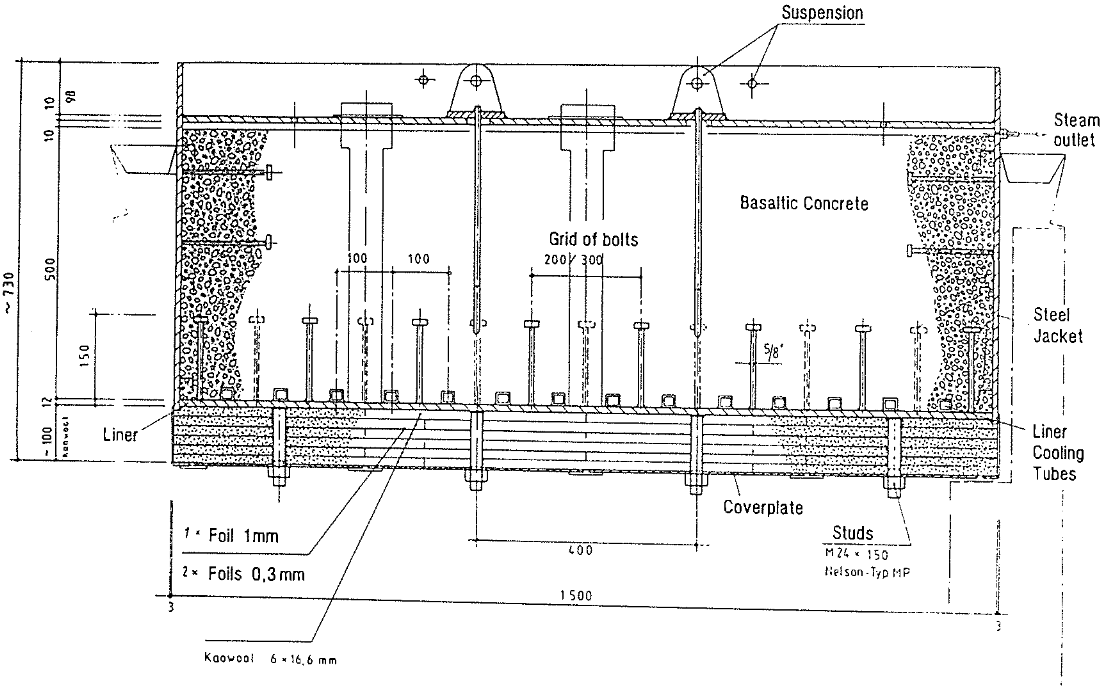

Fig. 2: Model block with HTR-500 design

12 mm liner plate anchored with 5/8" bolts and cooling pipes (Fig. 2). The model is equipped with thermocouples and pressure gauges. The concrete block is jacket with steel plates so that the amount of released water and gas can be measured. The insulation consists of 10 cm Kaowool with 5 mm thick steel coverplates and a two-train liner cooling system. The inlet temperature of the cooling water was 43 °C.

3. EXPERIMENTAL RESULTS

The test specimen was exposed to the temperature transient calculated for the hypothetical core heat-up accident, i. e. the maximum temperature at the cover plates was 1130 °C after about 12.5 weeks (Fig. 3). At a temperature of 265 °C (reactor cold gas temperature), at 620 °C and 900 °C the temperature was hold constant for 100 hours each time to control the behaviour of the insulation. During this temperature increase both liner cooling systems were operating. The liner reached 55 °C. The insulation remained intact at these temperatures even when only one train of the liner cooling system was in operation. For this case the temperature of the liner increased to 85 °C. Only the edges of the cover plates were slightly lifted from the insulation, however without dropping down.

It was furthermore investigated up to which temperature of the cooling tubes and thus until which time a refeed of the liner cooling system is possible. For this the flow of cooling water in both liner cooling systems was stopped and the increase of temperature in the liner cooling tubes was measured. At a fixed temperature the flow was started again and the processes during refeeding were recorded. It was possible to refeed the liner cooling system up to 450 °C. Higher temperatures were not examined due to the limits given by the test facility. The time elapsed between failure of the liner cooling system and reaching the tube temperature of 450 °C was 17.3 h, i.e. sufficient time is available for restoring or emergency feed of the LCS (e. g. fire brigade). In a further test only one train was refeed at 350 °C. As in all the other tests it was again possible to cool down the model to a steady-state temperature condition.

Immediately after opening the inlet valve of the LCS steam was produced in the hot cooling tubes. Since the occuring steam pressure of about 10 - 15 bar was higher than the water pressure of 5 bar the water flow was stopped. Because the LSC was open at the outlet the steam pressure was reduced and after becoming less than 5 bar water flowed again into the tubes. Now again steam was produced and so on. After a few minutes the tubes were cooled down so that no steam could be produced and a steady water flow occured in the systems. The temperature time curve for a refeeding at 350 °C tube temperature is given in Fig. 4. It can be seen that the temperature in the cooling tubes drops down almost immediately and the concrete temperature follows delayed. Far away from the liner the temperature increases for about one hour and then also falls down. At present a computer code is established to comprehend the processes during refeeding of a hot liner cooling tube.

After these tests a long-term failed liner cooling system was simulated. The liner and concrete reached maximum temperatures of 770 °C after 8 days in the quasi-steady-state condition. The only phenomenon observed was a slightly increased deflection at the ends of the cover plates. No failure of the insulation occured.

Therefore the temperature at the cover plates was increased that is the theoretical possible highest temperatures were exceeded (see Fig. 3). This further increase in temperature caused the cover plates to fold downwards at 1400 °C without the bolts and insulation as a whole dropping. The liner and concrete were heated in this case up to 1100 °C.

After the test the insulation were removed. The bolts showed no cracks or other defects. Also the liner was completely intact. Then we sawed the block in the middle and inspected the inside of the tubes. No cracks were observed. From different places cylinders were drilled out of the concrete and the strength was determined. Compared with the strength at room temperature after 90 days of app. 75 N/mm^2 the basaltic concrete gave still values of about 20 % at an exposed temperature of 720 °C. From places where the concrete got higher temperatures it was not possible to drill cylinders though the concrete was not destroyed.

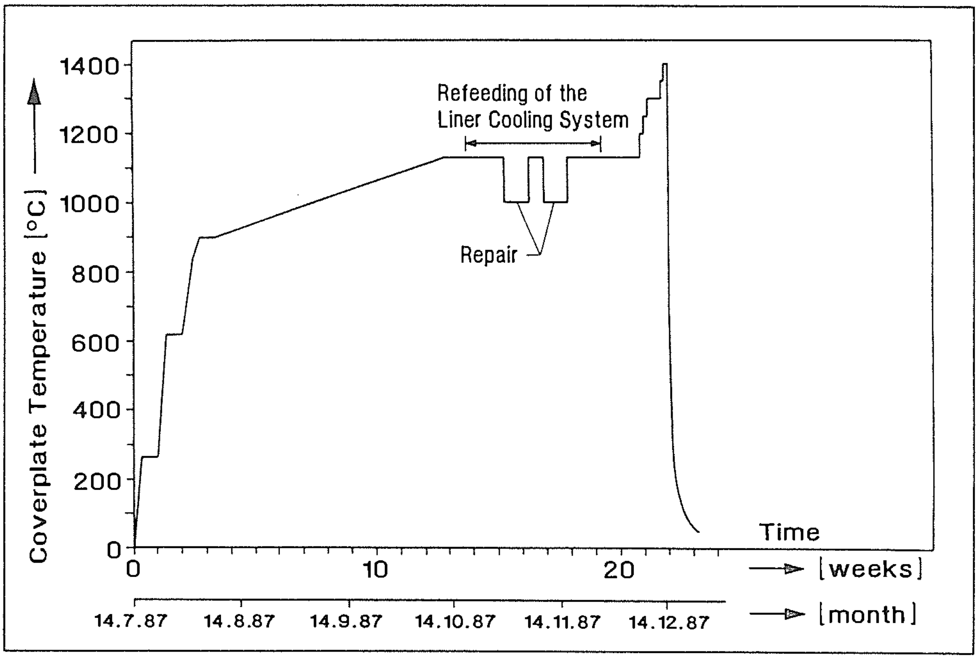

Fig. 3: Temperature-time curve for the cover plates

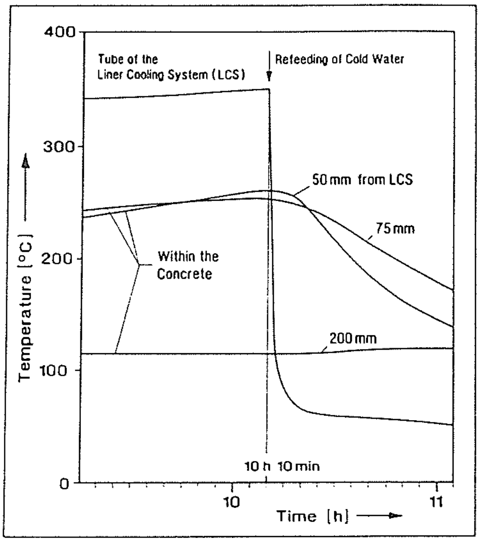

Fig. 4: Temperature-time curves during refeeding

4. CONCLUSION

The test showed that during a hypothetical core heat-up accident with a supposed failure of all active heat sinks including the liner cooling system the PCRV of a HTR-500 will not be damaged excessively. It is possible to refeed the liner cooling system after more than 17 hours of the beginning of this accident. If the liner cooling system operates even with one train the afterheat can be removed without heating up the vessel.

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