Experimental Study of the Behaviour of the Prestressed Concrete Pressure Vessel of the THTR-300 at Severe Accident Temperatures

J. ALTES, K. H. ESCHERICH, M. NICKEL, J. WOLTERS
Institut für Sicherheitsforschung und Reaktortechnik Forschungszentrum Jülich GmbH, Jülich, FRG

ABSTRACT

The risk of medium-sized High Temperature Reactors (HTR-500, THTR-300) with PCRV is dominated by the behaviour of the vessel during a hypothetical core heat-up accident. 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 THTR-300 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 650 °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, 1989). These studies are part of risk analyses and checking of the safety of nuclear power plants by the German reactor safety commission. Accidents which might lead to an unrestricted heat-up of the reactor core are hypothetical with a very low probability of occurence. 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 THTR-300 PCRV will be given.

2. EXPERIMENTAL SETUP

In the experiments 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

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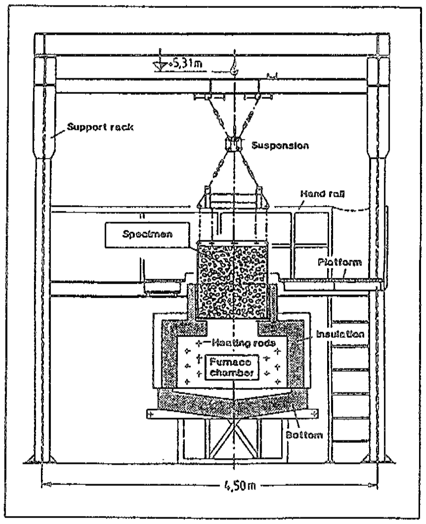

Fig. 1: Experimental setup

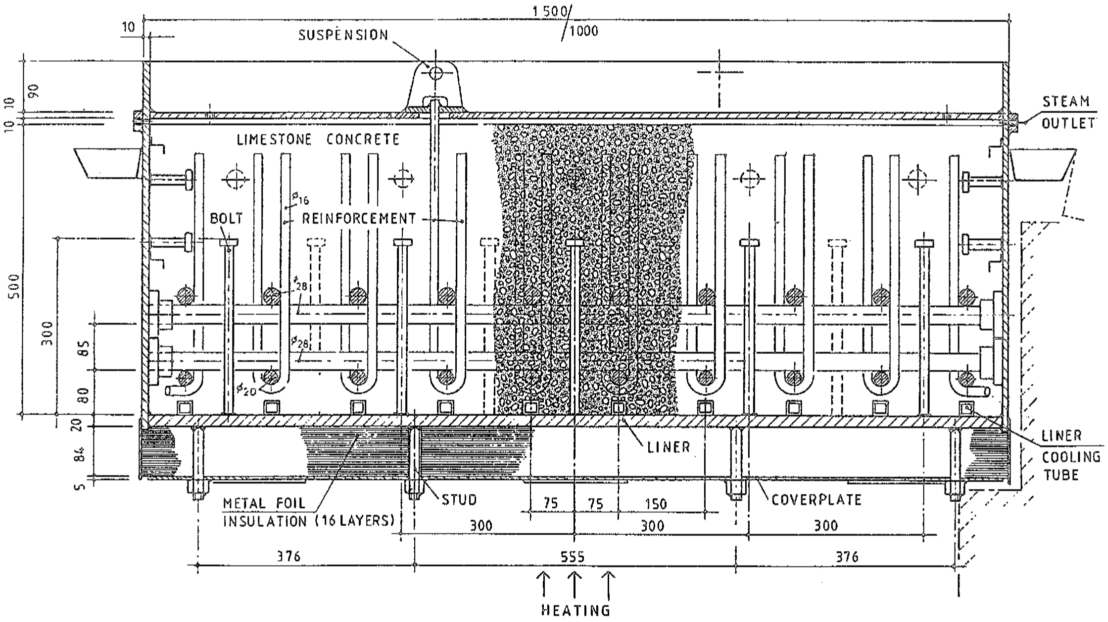

Fig. 2: Model block with THTR-300 design

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 fourth test specimen is a representative section of the THTR-300 prestressed concrete vessel on the original scale. It consists of limestone concrete and a 20 mm liner plate anchored with 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 is a 8.4 cm metal foil insulation with 5 mm thick steel coverplates and a two-train liner cooling system. The inlet temperature of the cooling water was 33 °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 1080 °C after about 50 days (Fig. 3). At 250 °C (reactor cold gas temperature), the temperature was hold constant for 100 hours to control the behaviour of the insulation. During the temperature increase both liner cooling systems were operating. The liner reached 106 °C between and 75 °C below the liner cooling tubes. 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 165 °C resp. 95 °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 650 °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 650 °C was 14.5 h, i.e. sufficient time is available for restoring or emergency feed of the LCS (e. g. fire brigade). In further tests only one train was refeeded at 200, 300 and 400 °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 dependent on the feeding rate. 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 curves for a refeeding at 300 °C tube temperature is given in Fig. 4. It can be seen that the temperature in the cooling tubes drops down almost immediately dependent on the distance from the inlet valve. At present a computer code is established to comprehend the processes during refeeding of a hot liner cooling tube.

Also a long-term failed liner cooling system was simulated. The liner and concrete reached maximum temperatures of 900 °C after 4 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.

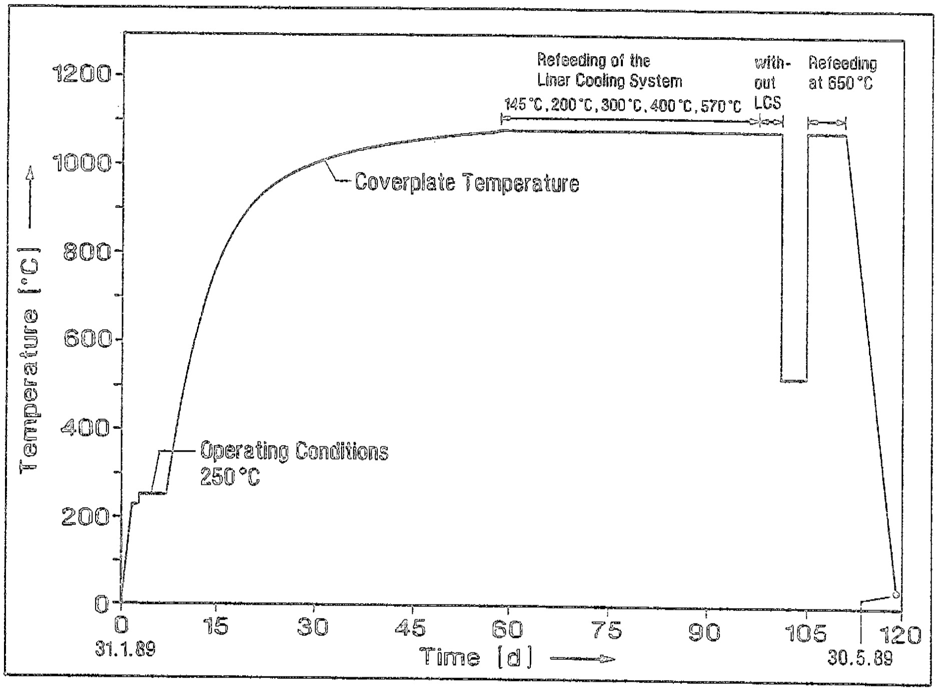

Fig. 3: Temperature-time curve for the cover plates

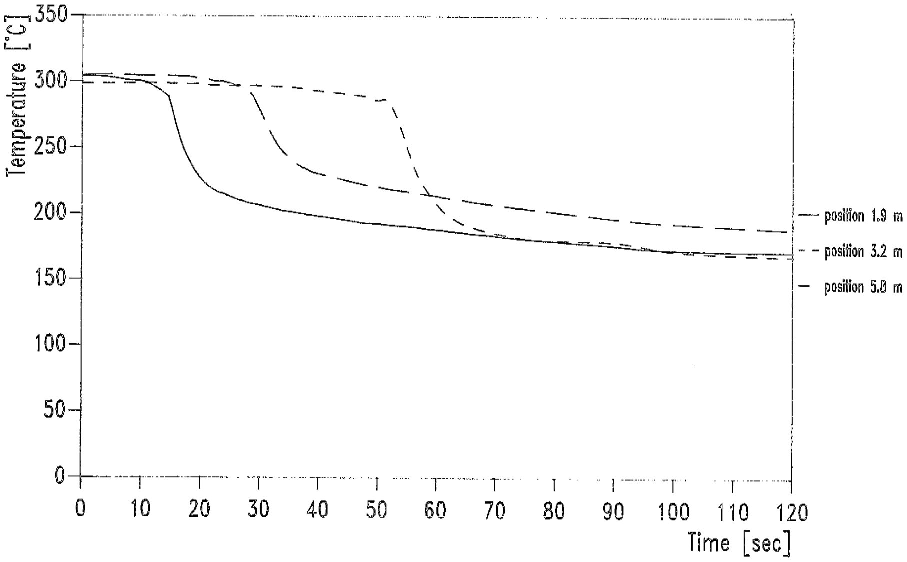

Fig. 4: Temperature-time curves during refeeding (Kim 1991)

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 of app. 45 N/mm^2 the limestone concrete gave still values of about 50 % at an exposed temperature of 725 °C.

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 THTR-300 will not be damaged excessively. It is possible to refeed the liner cooling system after more than 14 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.

In the next experiment a model with penetrations will be tested.

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