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EXPERIMENTAL STUDY OF THE BEHAVIOUR OF A PRESTRESSED CONCRETE PRESSURE VESSEL OF A HTR 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 core heat-up accident is decisive. Tests up to extremely high accident temperatures with representative models are carried out.

The fifth test in this series was carried out on a section model (dimensions 1.5 m * 1.0 m * 1.0 m) of the vessel top of a HTR. Additionally to the preceeding tests the model included two penetrations - one for a reflector rod and one for an incore rod. The test specimen was exposed to the temperature transients calculated for the hypothetical core heat-up accident, i.e. the maximum temperature at the cover plates was 1260 °C including a 10 % margin. Since the accidents at HTR's develop very slowly this temperature will be reached after 6 weeks. The insulation remained intact at these temperatures. Only the edges of the cover plates were slightly lifted from the insulation but without dropping down.

It was furthermore investigated up to which temperature of the cooling tubes and thus until which time a refeeding of the liner cooling system is possible after a complete failure of this system.

From all five tests the following conclusions can be drawn:

During a core heat-up accident caused by a total failure of the afterheat removal systems the prestressed concrete reactor pressure vessel can also be cooled with only one train of the liner cooling system. Refeeding of the system (i.e. by the fire brigade) is possible up to high temperatures. The insulation and the liner will not fail during long-term outage of the LCS. The processes during refeeding of the LCS and the water release out of the concrete can be calculated with computer codes.

1. INTRODUCTION

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 [1], [2]. Accidents which might lead to an unrestricted heat-up of the reactor core are hypothetical with a very low probability of occurence ($< 10^{-7}$). 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. Since about more than one decade the behaviour of PCRV of different HTR plants during core heat-up accidents is analysed [3]-[8].

2. EXPERIMENTAL SETUP

In the experiments sections of the PCRV with an area of 1.0 m * 1.5 m and a thickness of up to 1.0 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. In the chamber exists a helium atmosphere with a very low content of oxygen (< 0.5 %). 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.

Five tests have been carried out. The Specimens are representative sections of the THTR-300 prestressed concrete vessel consisting of limestone concrete on the original scale and the HTR-500 vessel consisting of basaltic concrete.The sections are from the middle and the boundary part of the top. The thermal insulations were metal foils or Kaowool dependent on the type of reactor. They are anchored with bolts to the liner. The liner plate is anchored with bolts and cooling pipes of a two-train liner cooling system (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.

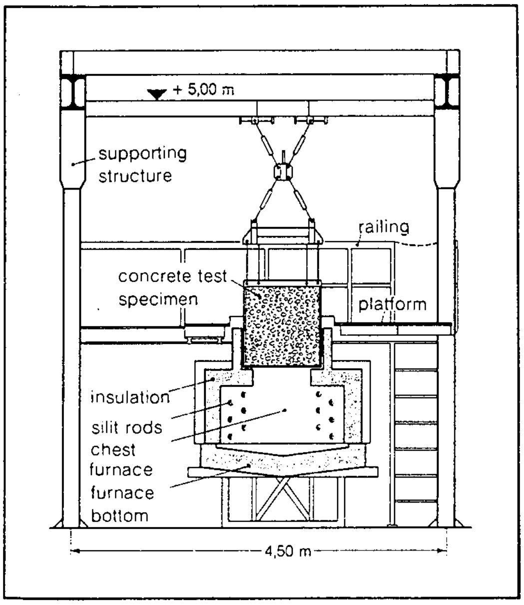

Fig. 1: Experimental setup

3. EXPERIMENTAL RESULTS

The test specimen were exposed to the temperature transient calculated for the hypothetical core heat-up accident, i. e. the maximum temperature at the cover plates were 1080 °C (THTR-300) resp. 1260 °C (HTR-550) after about 50 to 60 days (Fig. 3). At 250 °C resp. 265 °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 55 °C resp. 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

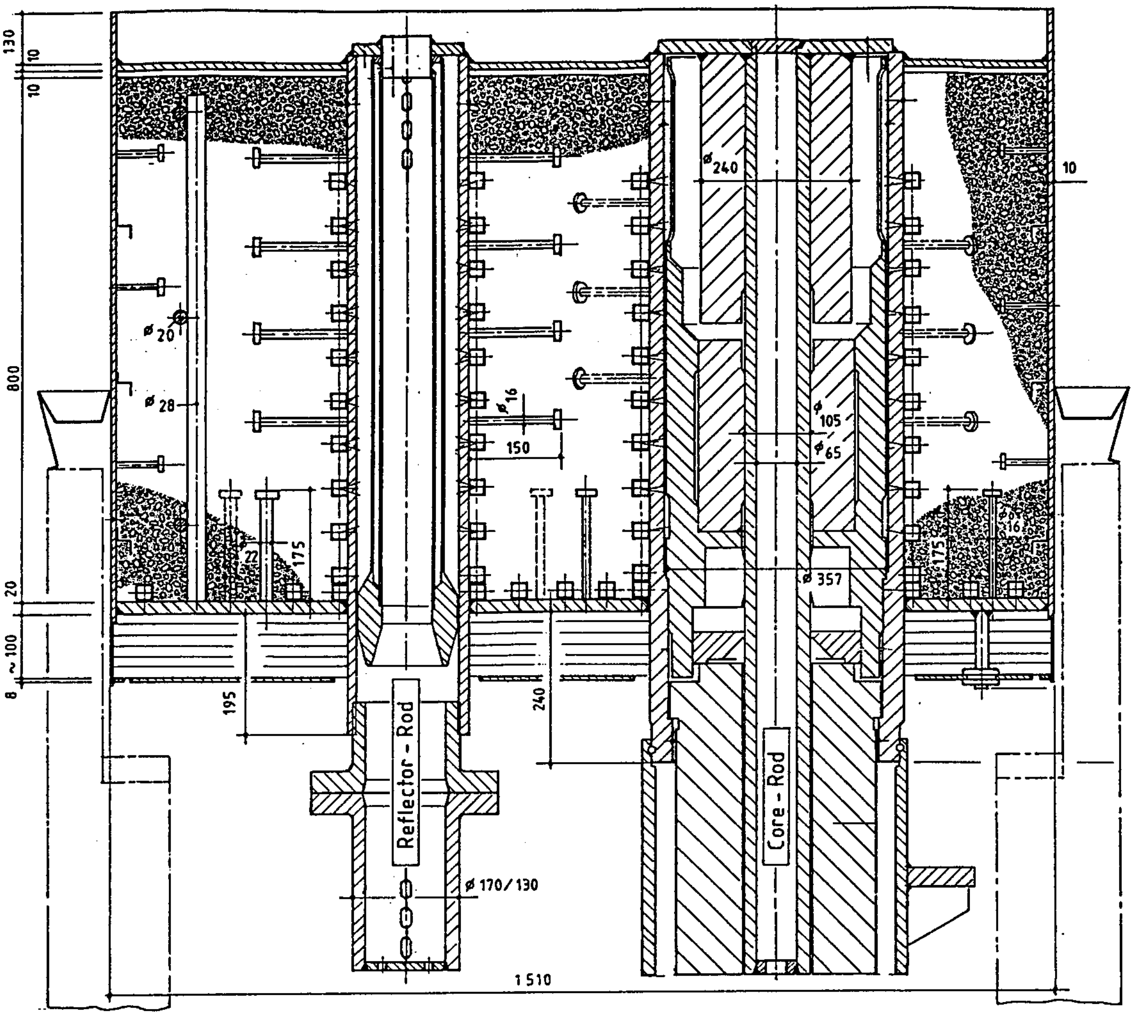

Fig. 2: Model block with HTR-500 design

the edges of the cover plates were slightly lifted from the insulation, however without dropping down. Additionally at 600 and 900 °C the temperature was held constant to control the behaviour of the insulation.

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.

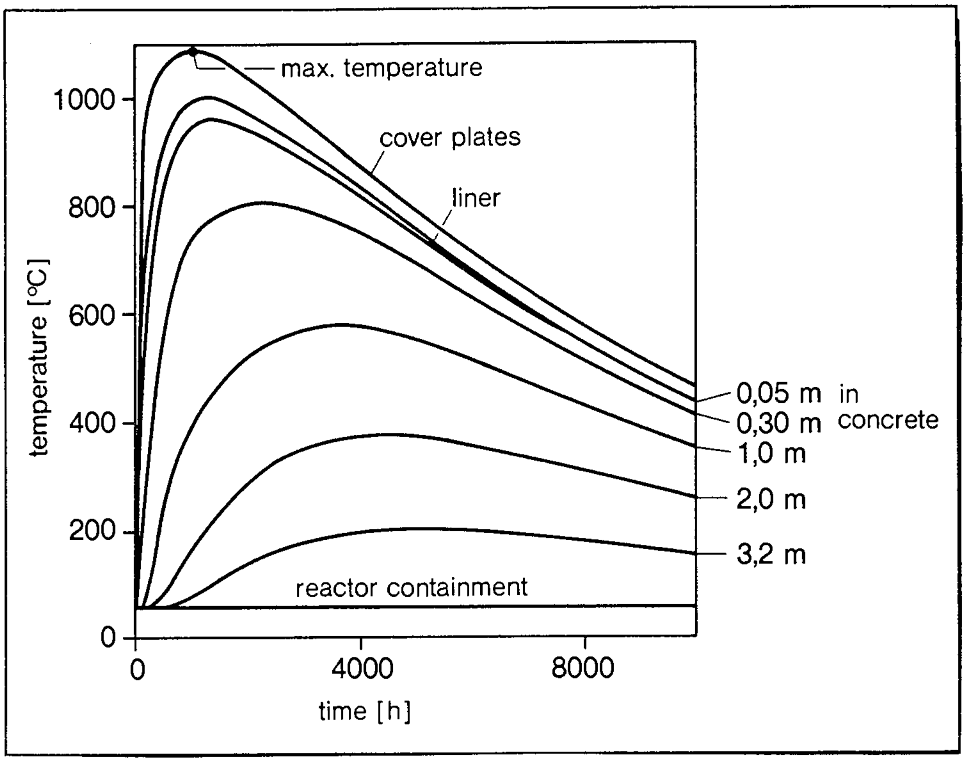

Fig. 3: Temperature-time curve for the cover plates of the THTR-300

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. Parallel to the tests the computer program SIKADE-2 was developed for calculating the refeeding processes in the tests and in real reactor vessels [9]. The calculated temperatures resp. pressure-time curves show good agreement with the measured once (Fig. 4).

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.

After the test the insulation was 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.

The masses of steam and gas released from the concrete during beating were measured. The release rates and the integrated masses calculated with the USINT [10] code show good agreement - especially for the steam - with the measurements [11] (Fig. 5).

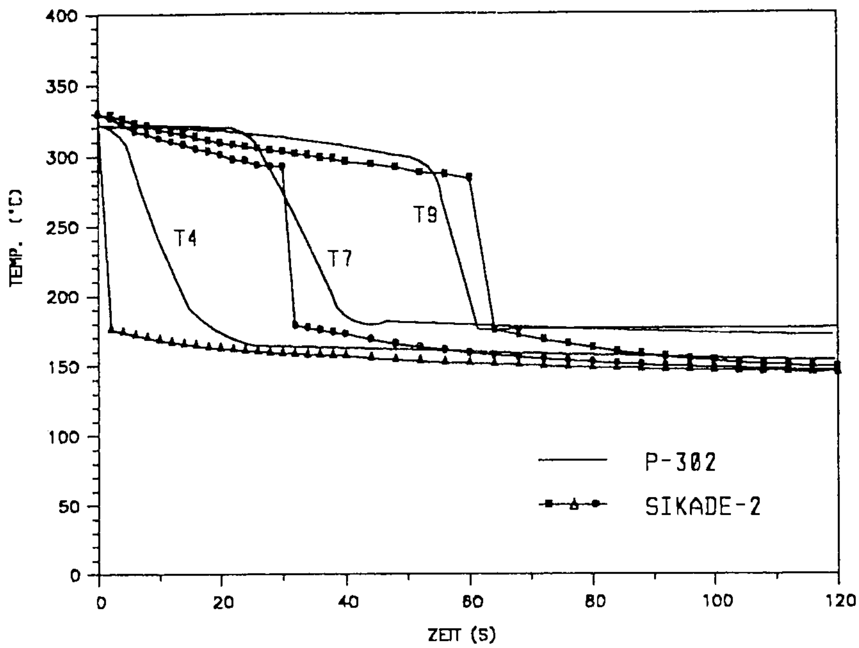

Fig. 4: Temperature-time curves for the LCS during refeeding

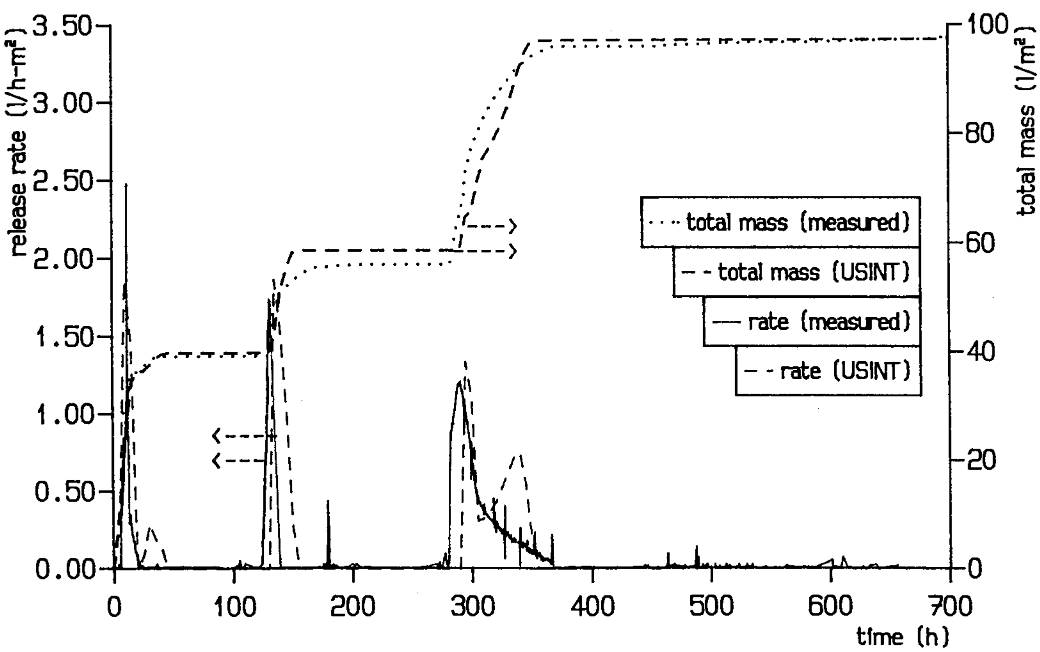

Fig. 5: Measured and with USINT calculated water release of the concrete

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 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.

The processes during refeeding of the liner cooling system and the water release out of the concrete can be calculated with computer codes.

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