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STATUS OF THE RESEARCH REACTOR FRJ-2
AT THE RESEARCH CENTER JÜLICH, GERMANY

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Abstract:

After an outage of more than four years, the FRJ-2 resumed operation on March 10, 1995. The outage was caused in fall 1990 by corrosion detected at the tank pipes within the stuffing boxes. The stuffing boxes were replaced by a new sealing design which uses steel bellows to compensate the different thermal expansion of the reactor tank and its containment. The repair time had to be used by order of the supervisory authority to upgrade the safety concept of the plant so that it meets modern German regulations and standards. The improvements made are related mainly to the protection of the plant against earthquakes and fire. In addition, an emergency handbook had to be issued.

1. Introduction.

The FRJ-2 at the Research Center Jülich (KFA) is the most powerful research reactor in Germany. It was constructed in the years 1958 to 1962 and commissioned in 1962. In 1967, its power was increased from the originally designed power of 10 MW to 15 MW, followed by a second power increase to 25 MW in 1972. In the aftermath of the Chernobyl disaster, a thorough safety review of the plant was carried out by a German engineering company by order of the supervisory authority of the state North Rhine-Westphalia. The results were issued in the middle of 1988 /1/ revealing 13 deficits compared with modern German safety rules and standards. But it was explicitly stated that the findings were not of the order which required immediate action. In addition, an emergency handbook was required in accordance with the practice at German nuclear power stations.

Some of the required safety improvements could be realized very easily, but others needed much greater efforts in planning, evaluation and realization. Among these were the measures concerning earthquake and fire protection. The issue of an emergency handbook also proved to be very time consuming since the necessary knowledge first had to be generated.

Two years later, in November 1990, a longer period of outage was necessary in order to repair damage detected at the stuffing boxes which seal the gap between the reactor tank pipes and their containment steel tubes outside the biological shield /2/. Most effort was focused on this repair in order to resume operation as quickly as possible. But the longer the outage lasted the more it became obvious that the authority would also require most of the detected deficits to be remedied before it would agree to the reactor restart. Finally, almost all of them had to be remedied prolonging the outage to more than four years until 10th March 1995 when the reactor became critical again and it has operated at full power since 24th April.

2. Repair of the Sealing between the Tank Pipes and their Containment Steel Tubes.

The FRJ-2 is a DIDO-class tank-type research reactor cooled and moderated by heavy water. The reactor aluminum tank is housed in a massive reactor block standing on four steel pillars (Fig. 1). The space between the pillars accommodates the primary circuit. Seven aluminum pipes welded to the bottom of the reactor tank and penetrating the biological shield beneath the tank in the vertical direction connect the tank to the primary circuit.

The reactor tank is surrounded by a graphite reflector enclosed within a double-walled steel tank. This steel tank, together with its liner tubes for the various penetrations, constitutes the containment for the graphite-helium system and also for the reactor tank. All penetrations are sealed at the outside of the biological shield so that a leak in the reactor tank and its pipes would only fill the aluminum/steel tank interspace, which is designed such that the water circulation would not be interrupted.

The sealing between the tank pipes and the liner tubes of the steel tank was provided by stuffing boxes as is shown in Fig. 2. The reason for this design was that the fixed point of the tank lies at the top flange so that the thermal expansion of the tank and its pipes requires a free movement of the tank pipes at the sealing.

In the past, leaks in two smaller pipes resulted in the ingress of heavy water into the graphite reflector and thus also into the gaps between the liner tubes of the steel tank and the reactor tank aluminum pipes. Of course, after the events had been detected the water was drained from the graphite reflector, but the moisture left in the bottom part resulted in corrosion of the steel tubes. The gaps were filled with corrosion products which became very solid during the course of time and hindered the movement of the tank pipes so that unacceptable stresses were caused in the bottom of the reactor tank.

The problem became obvious when the movement of the tank pipes against the steel tubes was measured and was found to be inadequate for all pipes. After having realized that the problem required a fundamental solution, it was decided to replace the stuffing-box design by a new design using steel bellows and O-ring gaskets (Fig. 2). The lower part of each unit of steel and aluminum tube was cut in two steps using a compass saw and a milling cutter device. The radioactive corrosion products were removed from the gaps and new flanges were welded to the steel tubes and new nozzles to the aluminum pipes. Tritium release during welding was almost totally avoided by heating the aluminum material used before welding.
The new design represents an improvement of the plant since all the aluminum pipework is now enclosed by stainless steel and the sliding seal has been replaced by a static one.

3. Upgrading.

3.1 Earthquake Analysis and Improvements.

A systematic approach was chosen for the required earthquake analysis and improvements. The components and systems were grouped into three classes in accordance with their significance for the safety of the plant. Class I contains all components and systems needed for safe shutdown, afterheat removal and enclosure of radioactive substances. For them, it had to be shown that in the case of a design-basis (safety) earthquake stresses and strains remain within the linear elastic range and that the stability and safety function are maintained.

Very important class I components of the FRJ-2 are the reactor block with the primary circuit beneath and the reactor hall, an airtight cylindrical steel shell with a steel dome. Steel pillars are welded to the cylindrical shell supporting the track of the polar crane and the experimental floor which surrounds (Fig. 3) the reactor block. The experimental floor only rests on the pillar cantilevers but is not attached to them. The first dynamic analysis for the reactor shell with its interior revealed a relative movement of the reactor block of 70 mm compared with the basement in the case of a design-basis earthquake. Although the strain of the block pillars remained mainly in the elastic range it was decided to couple the block, via the experimental floor, to the pillars of the shell by buffers in order to reduce the block movement. This would have meant that the shell had to be surrounded by a steel collar at the height of the experimental floor. The license had already been applied for, when a strong earthquake occurred on 13th April 1992 with its epicenter about 50 km from the research center. The evaluation of this earthquake resulted in an alteration of the acceleration-response spectrum for the design-basis earthquake at the site. When the new spectrum was applied the deflection of the reactor block was reduced to 35 mm. This was deemed acceptable so that no modification with respect to the connection of the experimental floor to the shell and its pillars was necessary.

The strain and stress analysis of the primary circuit on the basis of the calculated block movement resulted in minor modifications of the supports of some components. The main modifications are related to the flanges. In order to guaranty a definitive distance between the flanges, each pair of flanges was equipped with an individually adapted ring as a spacer. This was necessary to prevent the gaskets lying in series with the flanges from being squeezed, which had resulted in leakages in the past. In order to make sure that the flanges would not twist against each other in case of the design-basis earthquake, it proved to be necessary to replace the screws by new screws of greater strength and to tighten them with a torque wrench. This had to be done in the presence of a TÜV expert.

The earthquake analysis for the secondary circuit were restricted to the pipework inside the reactor hall taking credit from the fact that an auxiliary cooling system is available for after heat removal. The latter feeds water from the fire extinguishing system onto the shell side of the heat exchangers and from there into the waste water sump from where it is pumped into the waste water tanks outside the reactor hall. Of course, for all components of the auxiliary cooling system it had to be shown that they meet the earthquake requirements. This meant that a lot of components had to be replaced. Although the system already existed, a special license was necessary for this modification.

For buildings not belonging to class I components but accommodating the latter, it had to be proven that their collapse would not impair the function of those components, which is in general very difficult to prove, or else that their stability is maintained. The second approach was taken in case of the FRJ-2, which meant that a lot of brick walls had to be reinforced by steel frames and supports.

3.2 Fire Protection.

The measures for the improvement of fire protection also required a special license which was granted in autumn 1994. The measures were mainly related to the electrical part of the plant and they included the coating of cables, the insulation of cable trays, the separation of electrical busses and many other improvements. Fortunately, some of them were not required to be realized before restarting of the reactor. The latter include the replacement of wooden air ducts in the reactor hall by steel ducts, the installation of a new fire alarm facility and the installation of a CO_2 fire extinguishing facility for the relay room. The supervisory authority expects that most of the outstanding measures will be realized within 100 days of operation.

4. Emergency Handbook.

The required emergency handbook, which describes the regulations and procedures in the case of beyond-design-basis accidents, consists of three parts. Part I with general information such as the definition of terms and the criteria for the different degrees of alarm and part II with the organizational emergency regulations were put into force before restarting the reactor. Part III with the accident management measures has been discussed with the supervisory authority and the technical expert involved. It will be put into force soon.

The accident management procedures are based on the current technical status of the plant. However, in order to facilitate some procedures, modifications will be necessary and will be carried out in the near future. For instance, in the case of a large primary coolant leak with a late failure of both emergency cooling pumps, light water can be injected into the reactor tank. However, the reactor hall is filled up within days to a level at which the design pressure of 3 m water column is exceeded due to the flow rate needed for the emergency cooling of the core. Therefore, an interruption of emergency cooling and a recirculation of the water by a tank lorry is planned after one day of light water injection. Of course, this can be achieved much more easily and without the necessity of interrupting core cooling by a recirculation pump which must be installed in the reactor hall. Additionally, it proved helpful to install remote control of the light water injection system so that it can be operated from the shielded emergency control room. It is then possible to operate it in the case of a core meltdown accident when the level of direct radiation from the reactor hall is very high. The advantage of this would be that the molten core would be cooled and that radiologically significant fission products would be washed out of the atmosphere.

When investigating the efficiency of possible accident management procedures it was discovered that the loss of forced secondary cooling would probably not result in the loss of afterheat removal from the primary circuit. Natural convection in a closed loop, including a small part of the total secondary system, seems to remove enough heat to the environment so that the coolant temperature in the reactor tank would not exceed the boiling point, as can be seen from Fig. 4. This will be demonstrated by a reactor experiment using the primary cooling pumps as the heat source which will be of the order of the decay heat after about one hour.

5. Outlook.

Upgrading is a permanent task for the thirty-year old plant. It is necessary in order to obtain and maintain reasonable availability. Most components are as old as the plant and it is practically impossible to get spare parts for them. Thus, it is necessary to replace them by new components as has already occurred in the case of the emergency cooling pumps.

In the past, one weak point of the plant proved to be the main primary coolant pumps. Many outages were caused by the failure of one pump. Therefore, it was decided a year ago to replace the pumps by new ones. In this connection, it has been suggested that one of the new pumps should be supplied with electrical power from a machine composition equipped with a fly wheel in order to maintain forced flow for about 100 seconds in the case of a loss of offsite power. After that time, natural convection cooling of the core is adequate so that the safety of the plant no longer depends on starting a shutdown pump .

The results of an aging evaluation program did not reveal significant aging/damaging effects on nonreplaceable parts of FRJ-2. Taking into account the various modifications carried out or to be carried out in the near future in order to meet modern German safety standards it is realistic to assume that FRJ-2 can be operated at least for about 5 to 7 more years. This assumption is supported and confirmed by the final conclusion of the TÜV which performed the aging evaluation analysis. It reads /3/: Due to the results of the inspections and tests carried out for FRJ-2 aging and operation-related damage critical from a safety engineering point of view are not expected for a period of 10 years.

6. References.

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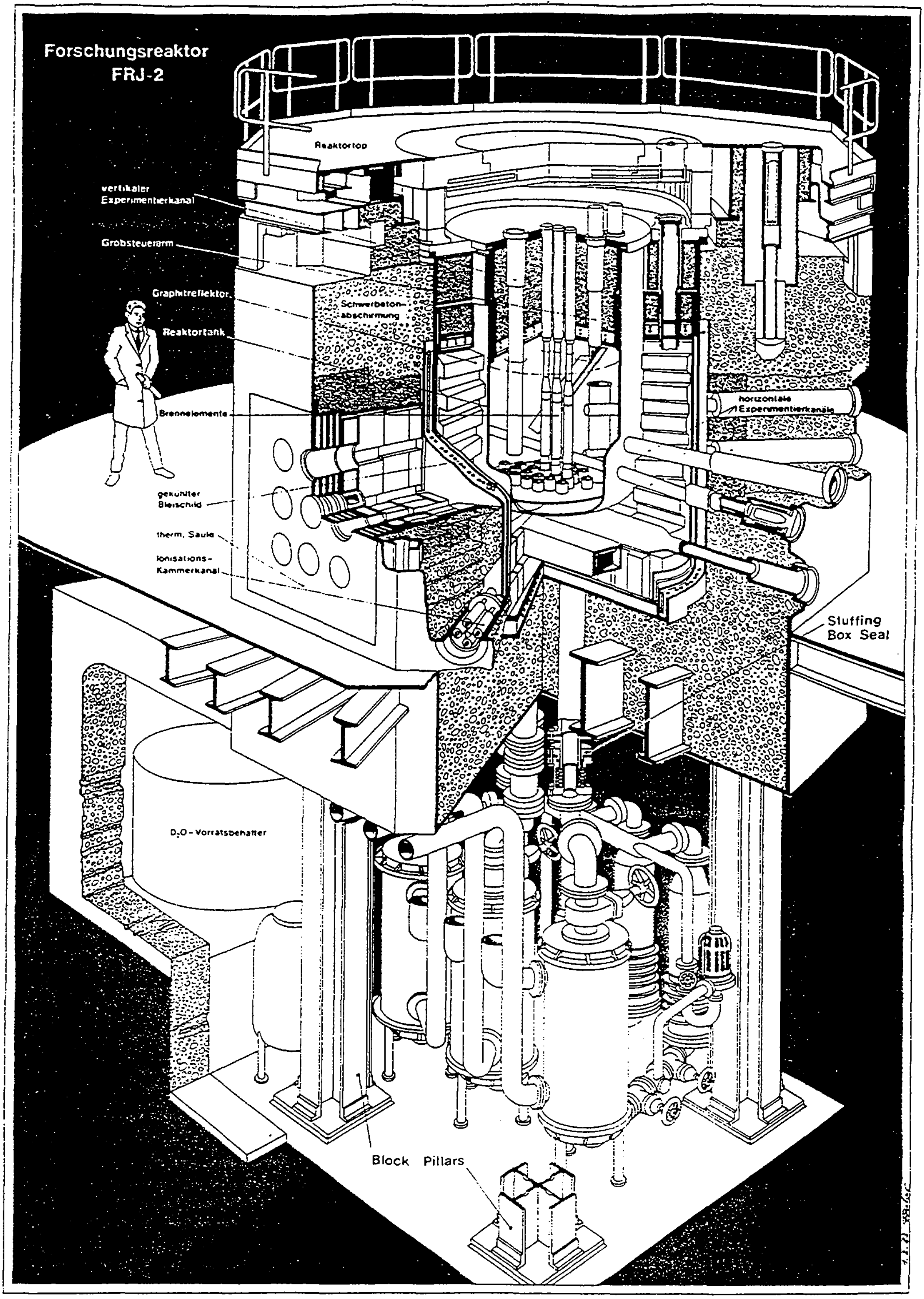
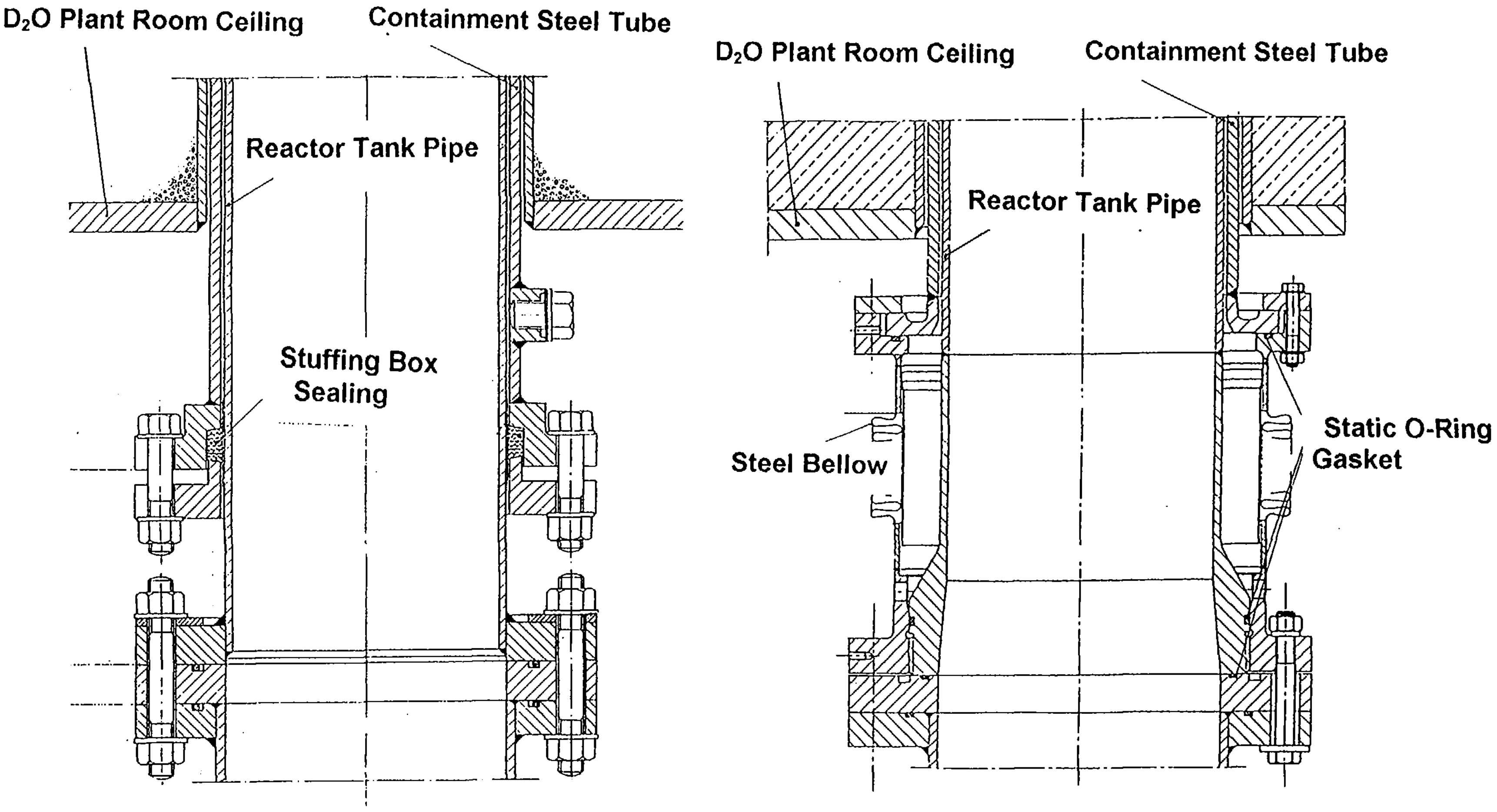


Fig. 1: Perspective View of the Reactor Block and the Primary Circuit of the FRJ-2



Former Design

New Design

Fig. 2: Sealing between the Reactor Tank Pipe and its Containment Steel Tube at the Outside of the Biological Shield

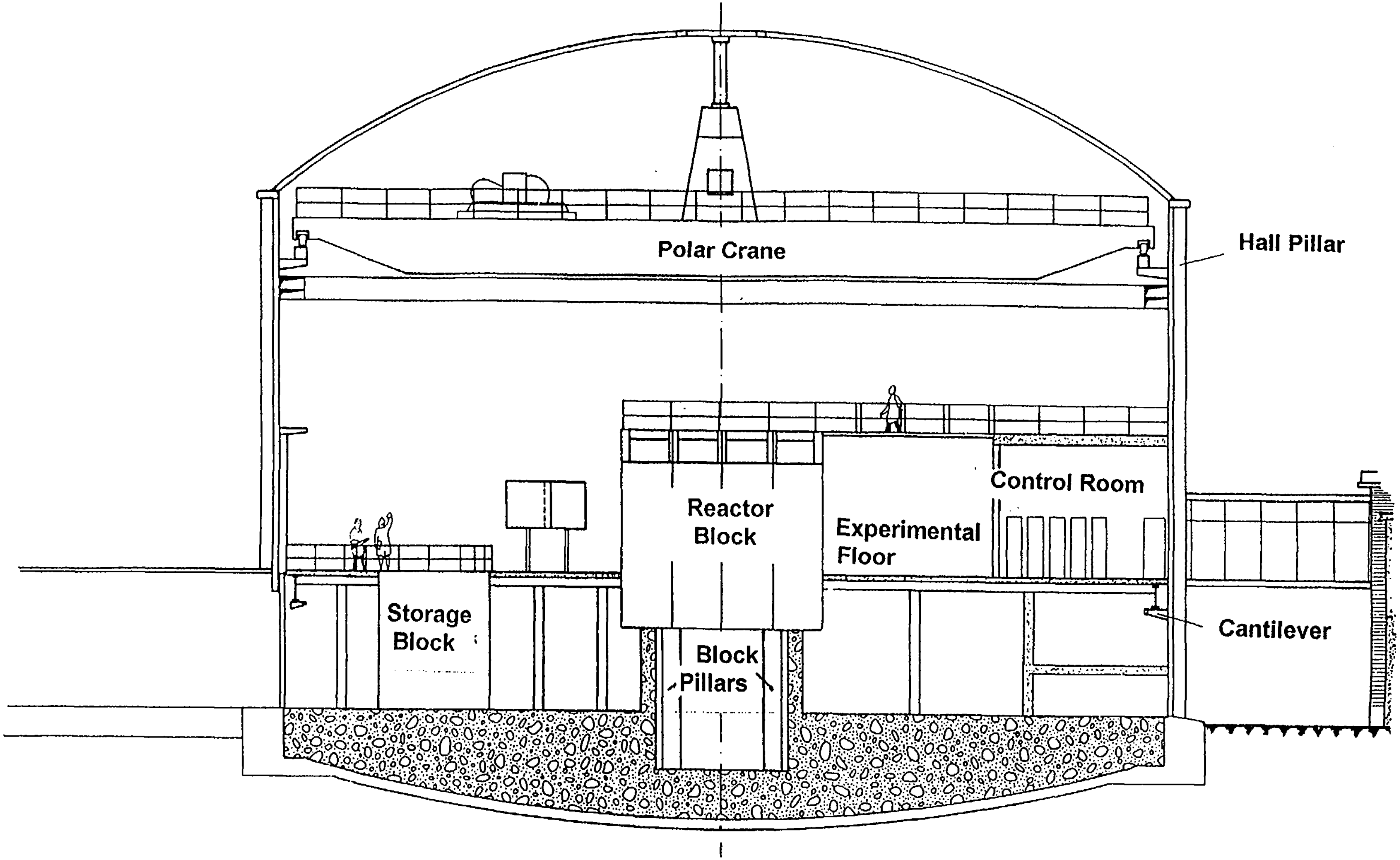


Fig. 3: Sectional View of the Reactor Hall and its Interior

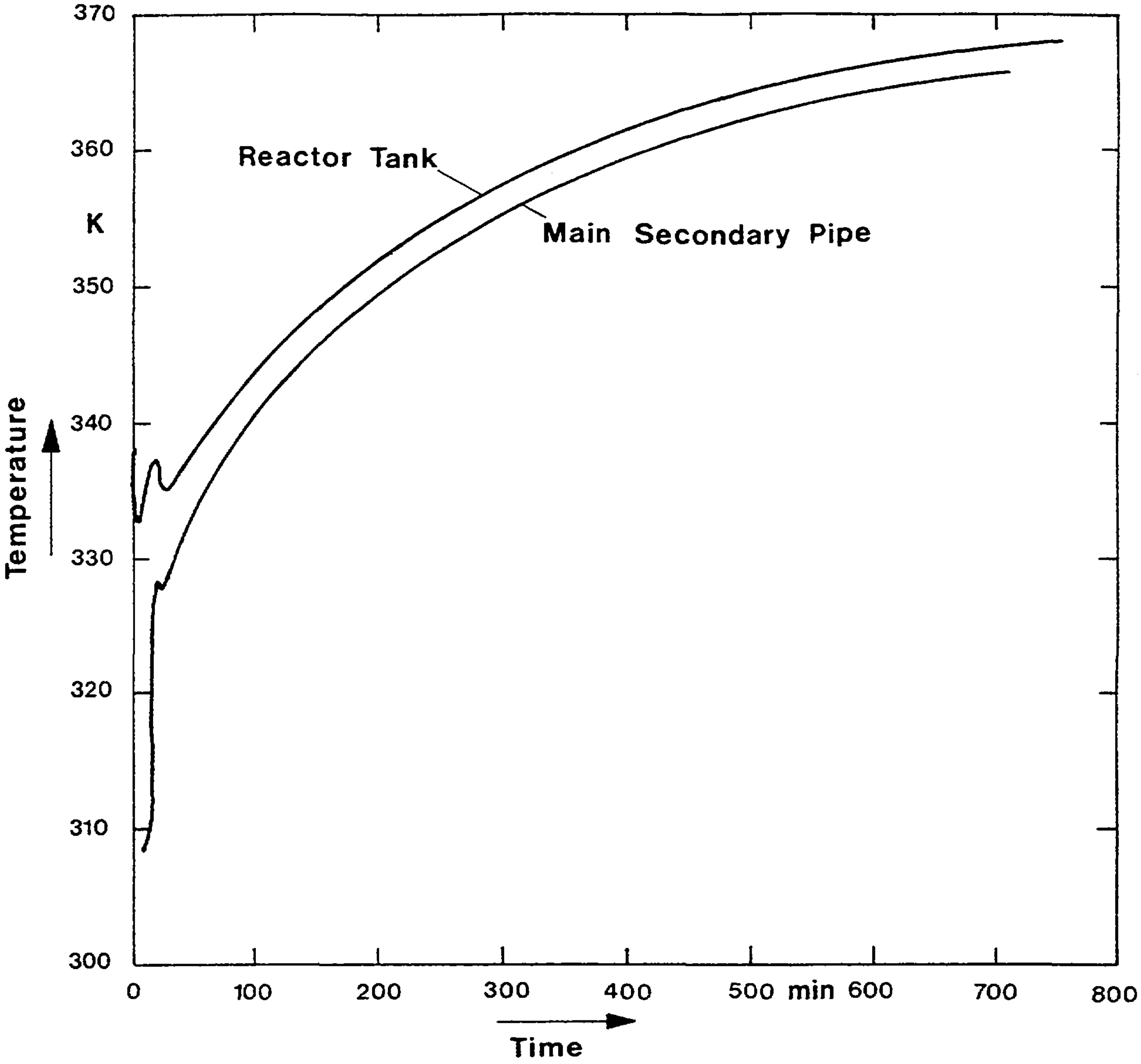


Fig 4: Time Dependent Temperature of the Water in the Reactor Tank and in the Secondary Manifold in Front of the Primary-Secondary Heat Exchanger in the Case of Secondary Cooling by Natural Convection