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THTR 300 MWe Prototype Reactor – Safety Assessment

1. Main design features

- primary circuit

– reactor core	pebble bed consisting of 675000 spherical fuel elements with a diameter of 6 cm (0,96 g high-enriched uranium 235 and 10,2 g thorium 232)
– coolant	helium at a pressure of 39 bar is heated from 250 °C to 750 °C and transported by means of six circulators
– control and shut down systems	for power control and reactor scram 36 absorber rods are inserted or dropped in by effect of gravity into borings in the side reflector (reflector rods), for long term shut down 42 absorber rods with pneumatic drives are inserted directly into the pebble bed (incore rods)
– reactor pressure vessel	pre-stressed concrete reactor vessel with a wall-thickness of 5 m, a diameter of 25 m and a height of 29 m using a steel liner.
• secondary circuit	largely conventional type with steam–feedwater–circuit at a maximum of 535 °C
• beginning of construction	1971
• commissioning	16. Nov. 1985 (first electricity generation)
• beginning of decommissioning	1. Sept. 1989

2. Experience during construction and licensing

A main problem when beginning construction in 1971 was the missing of reliable technical rules and guidelines for the THTR-specific components and for the THTR-specific reactor concept. Therefore the necessary rules and guidelines had to be developed by project accompanying programmes.

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The BMI[1] Safety Criteria for nuclear power plants did not come into force until 1977. They were valid for all reactor types, specially for the light water reactor, but they did not take into consideration the specific characteristics of an HTR. For the THTR 300 therefore in 1978 the so called "THTR-planning basis" (THTR-Planungsgrundlagen) were established, which got the agreement of the responsible licensing authority MWMT[2] in 1978. These planning bases were a reactor specific interpretation of the German BMI-Safety criteria from 1977. The safety criteria for HTR, which were developed under contract of BMI by RWTÜV, made the technical requirements on the HTR more precise in 1980.

In consequence some new or more detailed requirements came into force during the construction phase of the THTR:

- external impact (e. g. aircraft crash, pressure wave, earthquake)
- internal impact (e. g. pipe whipping, pressure vessel damage)
- new radiation protection requirements (e. g. reduction of the radiation exposure of the personnel).

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[1] BMI – German Federal Ministry of the Interior (the responsibility for nuclear safety was later changed to the Federal Ministry for Environmental Protection)
[2] MWMT – Ministry for Economy, Trade and Technology of the State of North Rhine Westphalia

3. Operational history

The electric power output during the operation time of the THTR 300 reached a total of 2.891.068 MWh. The plant was in operation over 16.410 h and had a time utilization factor of 61 %.

The time history shows a lot of power changes and several prolonged plant shut down times (see fig.):

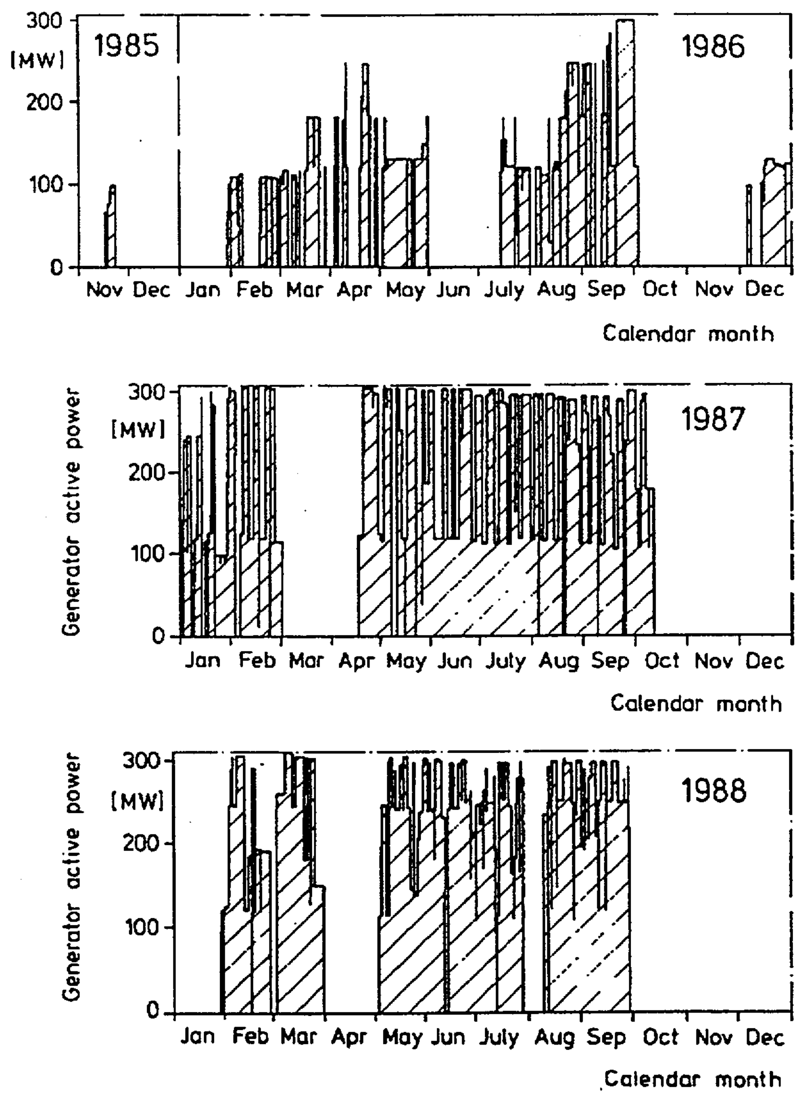

Fig. **THTR 300, electric power output during operating phase between 16 Nov 1985 and 31 Dec 1988.**

These plant shut times had different causes, which are explained in section 5. Experiences during construction and licensing have been detailed in /1/ to /3/.

4. Main positive experiences

There were a lot of positive experiences from the early phase of the commissioning tests to the actual operation phase:

- The first criticality was reached with a load of 198.180 spherical elements. That means a deviation of only 4.500 elements from the design value and showed a good correspondence between theoretical calculations and real loading.
- All reactivity measurements during the commissioning phases with the different core cooling media air, nitrogen and helium have confirmed the precalculations.
- There were no problems with the core power control in any level between 40 and 100 % power.
- The two independent shutdown systems (reflector rods and incore rods) ensured sufficient subcriticality in all cases, in the short-term shut down as well as in the long-term shut down.
- The two shut down procedures, which were planned for the THTR 300, were repeatedly triggered by the plant protection system. Experience showed that the systems had sufficient availability and functional capability. (For the reasons of the multitude of unplanned triggering see 5.)
- The design data of the primary and secondary system could be confirmed during operation e.g.:
  - The special THTR-components such as the fuel, reflector and incore rods, helium circulators, steam generators and the concrete reactor pressure vessel and even the dry cooling tower were tested in a nuclear plant with full success.
  - The in service inspection of primary components could be performed at low radiation exposure of the plant personnel.
  - The radiation of the plant personnel was generally at low values.
  - The spherical fuel elements showed the planned good retaining of the fission products, although some of the elements were broken into pieces caused by the insert of the incore control rods. But this was never a problem of increased radiation.

5. Main incidents and problems

The operation of the THTR 300 showed some incidents and problems:

- Difficulties with the refuelling system, because the withdrawal of the spherical fuel elements was only possible with reduced helium-mass-flow; this problem was solved in 1987 by a complex repair operation (Further openings were cut by means of spark erosion in the region of the flow cross section near the singularizer disc. That was only possible under the depressurised primary circuit.)
- Damage of spherical fuel elements caused by frequent and deep insertion of the incore control rods during the commissioning phase; the share of damaged elements in the total amount of the withdrawn elements decreased from 1,5 % in the beginning to 0,6 % towards the later periods of operation.
  Due to the higher share of damaged elements the casks for broken elements had to be changed earlier than planned. (Never saw elevated radiation)
- Damage of some bolts (35 of 2.600 bolts) of the thermal insulation in the hot-gas-ducts[1],which were discovered during the routine inspection in 1988. The analysis of this event by RWTÜV showed, that the insulation was still sufficiently safe fixed; and furthermore there were enough possibilities and means to detect a loosening of the metallic insulation by the operational monitoring.
- The measurements of the primary system data showed that the core outlet temperature was locally higher and lead locally to higher fuel element temperatures, which however remained below the design values of the fuels and the other materials. It may have been caused by a higher bypass of the helium mass flow than expected. 7% predicted vs 18% actual bypass...
- Graphite dust mass in the primary circuit was higher than expected. This was found during in service inspection. The reasons for this could not been cleared during the operation time.

[1] This construction is specific to the THTR design inside the prestressed pressure vessel

6. Overall performance and safety features

In the above sections of this report, we explained, that the THTR has fully reached its operational target and confirmed the feasibility and safe operability of a high temperature reactor (HTR) based on the pebble bed principle.

In detail:

- the performance for full power operation was demonstrated;
- the principle of continuous reactor refuelling with new elements without operation interruption was demonstrated;
- the inherent safety characteristics of the reactor were proven;
- it was shown that the maintenance and the in service inspection of this type of reactor was possible under low radiation conditions for the personnel and the surroundings.

The relatively long time from the beginning of construction in 1971 until the first electric power generation in 1985 was caused by:

- the prototype character of the THTR 300,
- the requirements of the German law ("Atomgesetz") to bring the technical concept up to the status of science and technology and
- the missing HTR-specific rules, which still had to be created.

Some of the technical requirements, which had great consequences on the plant concept and therefore on the time schedule of the plant construction are as follows:

- the redundance of decay heat removal system
- constructional requirements due to earthquake load (particularly the additional consideration of a vertical component of the earthquake)
- external impact particularly aircraft crash
- internal impact due to a conventional pressure vessel damage
- assumption of pipe fractures up to 2 F-breaks and their consideration in the course of plant construction
- experimental proof of leak before break concept in order to minimize the number of safety mechanisms against pipe whipping
- optimise the accessibility for plant maintenance (e. g. in service inspections)

The main difficulties due to the prototype character of the reactor are discussed above. They hade a great contribution to the delays during construction, commissioning and operation.

After the discovery of the damages of some insulation bolts of the hot-gas-ducts in 1988 extensive investigations were done by the constructor and by the independent expert - RWTÜV. The result was – also confirmed by the authority -, that there were no technical objections against further operation.

There were no technical and safety reasons for finishing the operation in 1989. The reasons were financial and economical considerations.

/1/ Bäumer, R.; Kalinowski, I.: Construction and operating experience with the 300-MW THTR Nuclear Power Plant. Nuclear Engineering and Design 121 (1990) 155-166

/2/ Kahlert, W.; Glahe, E.: Erste Betriebserfahrungen des THTR 300 und Folgerungen der Zukunft. VGB-Kraftwerkstechnik, 66 (1986) 11, 1021-1028.

/3/ Barnert, H.; Haag, G.; Kugeler, K. & Scherer, W.: Die Entwicklung des Hochtemperaturreaktors – Zum Tode von Prof. Dr. rer. nat. Dr. Ing. E.h. Rudolf Schulten. atw 41 (1996) 8/9, 552-556.