# The Situation of the THTR in October 1989

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# The Situation of the THTR in October 1989

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**By R. Bäumer***

In October 1989, it is now certain that the THTR will not be returned to service. This is the outcome of several years of difficult rounds of negotiations followed at the end by a frightening tightrope walk by HKG at the brink of bankruptcy.

During all the months of contract negotiations, the THTR plant, which had been shut down as scheduled in September 1988 for the annual overhaul outage, was technically intact, was kept operational and could have been returned to service any time within three days. The decision for the immediate decommissioning without phase-out operation to consume the manufactured fuel elements is only understandable because at the end of the negotiations this was the only way to prevent the impending bankruptcy of the operating company HKG with all its unforeseeable consequences for the energy industry and national economy as a whole.

The reasons for the decommissioning are therefore by no means technical.

The reasons for the decommissioning are rather amongst others the complex structure of the project, the limited financial resources of the HKG shareholders, the public sector and the electricity industry, the open-ended nuclear waste management costs and ultimately also the diverging political views on nuclear energy.

Following all this it is now time to take stock and to ask what results the THTR research project has produced, what financial problems prevented the continuation of the project and what findings remain to be gathered during the decommissioning. This is what I would like to do in the following subdividing my paper into three theses:

### 1st Thesis:

*By operating the THTR, HKG has made the high-temperature reactor technically and commercially viable*

The thorium high-temperature reactor represents the consistent continuation of the research and development of high-temperature reactors based on the AVR research project in Jülich and the related research and development work which has been done in the nuclear research centre in Jülich since the fifties with funds from the Federal Government and the Land of North Rhine-Westphalia. Between the research and the commercial implementation, the THTR constitutes the link to a fully developed plant ready for the market.

Therefore, the project was and is aimed at demonstrating the technological feasibility of the large-scale high-temperature reactor. The computer models used for the first time in the planning and construction of the THTR were to be verified by means of the measured values of the plant; the operation in the interconnected electricity transmission grid and the controllability of the plant in line with the requirements defined by the load dispatcher were to be demonstrated. When judging whether this aim has been achieved, it must not be ignored that the THTR-300 represents a brave step forward beyond the AVR (15 MW electric output) both technologically and in capacity terms. The planning base of the AVR was left in many respects and new concepts had to be developed, such as the prestressed concrete pressure vessel, the shutdown rods inserted into the pebble bed, the parallel arrangement of steam generators alongside the core with downward evaporation and reheating, the use of hot gas channels.

In the following, the operation of the THTR prototype plant will be evaluated on the basis of figures and diagrams:

The operating results achieved from mid-1986 until today are represented in Table 1. On the whole, the THTR has supplied 2 891 000 MWh of electrical energy. The reactor plant was in operation for 16 000 hours. In 1987, the time availability was 61.7 %, in 1988 52.4 %; in 1989, the plant remained out of service as a result of the difficult financing negotiations. According to HKG is could have been restarted on April 26, 1989, at the latest following the evaluation by the Reactor Safety Commission. At this time, the Reactor Safety Commission had come to the conclusion that the damage detected at the hot gas channel was not safety-relevant and that the THTR could resume operation with a few conditions imposed.

The following positive operating experience has been gathered:

- The favourable inherent safety characteristics have been proven.

  The positive safety characteristics manifest themselves by the fact that the control response of the reactor core has always been stable. Never were there any variations of the power distribution. The temperature coefficient of the THTR is negative in all power ranges. The expected slow progression of reactivity processes could be demonstrated in experiments. The operational reliability and the safety engineering design of the THTR have meanwhile also been confirmed as corresponding in principle to the current state of the art by safety reviews conducted by the Federal Minister of the Environment as well as the Minister of Economics and Technology in North Rhine-Westphalia.
- 100 % design power has been reached.
- Thermodynamic primary system data have been confirmed.

  As a result, the design models for high-temperature reactors have now been verified, and the capacities for the planning of follow-up plants are available.
- The radiation exposure of the personnel is extremely low.
- Extension and repair work at the primary system can be performed.

*Table 1. Operating results.*

| operating results | | |
|---|---|---|
| — generated electricity | MWh | 2 891 068.0 |
| — hours of reactor operation | h | 16 410.0 |
| — availability time ratio 1987 | % | 61.7 |
| 1988 | % | 52.4 |
| **favourable operating experience** | | |
| — the inherent safety characteristics have been proven | | |
| — 100 % design power has been reached | | |
| — the thermodynamic primary system data have been confirmed | | |
| — the radiation exposure of the personnel is extremely low | | |
| — extension work at the primary system can be performed | | |

The individual dose between 1987 and 1988 is represented in Figure 1. During normal operation the exposures remain below 10 mSv; for inspection and overhaul outages the values rise to 40 mSv. In this context, it must be taken into account that in the past all overhaul outages included repairs or investigations performed at the open primary circuit. At the end of 1987, flow cross-section were cut at the fuel sphere discharge system; at the end of 1988, investigations were performed at all six hot gas channels. The extremely low total individual dose absorbed during these investigations demonstrates the high retention capacity of the fuel elements and the excellent shielding effect of the prestressed concrete.

A position should also be given here on the critical remarks expressed in the media in recent months with regard to the technical condition of the plant. The operational reliability of the THTR was called into question, in other words the availability was described as being too low.

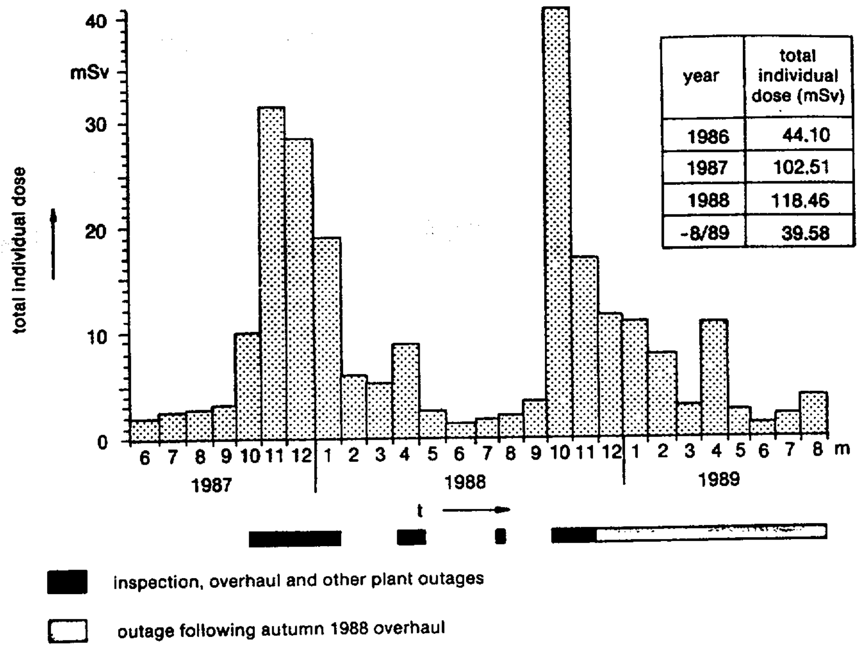


*Fig. 1. Monthly accumulated total individual dose.*

Figure 2 shows the mean annual load factor in the first years of operation for various reactor types. These figures have been taken from the nuclear engineering journal "Atomwirtschaft/Atomtechnik" and represent an average for all reactors world-wide. The availability of the gas-cooled reactors is lower than that of the water reactors. This is certainly because gas-cooled reactors have not yet seen their breakthrough on world-wide markets either. However, the availability increases as the operation of the individual plants continues. This also goes to show that all plants required further development work after commissioning.

In this overall picture, the THTR occupies a respectable position indeed and could certainly have attained availabilities of more than 70 or 80 % if the operation had continued, especially because the problems of the fuel circulating system restricting the availability during the first years of operation could meanwhile be eliminated. The repair of the fuel discharge system should be mentioned in this context. Furthermore, the unscheduled shutdowns could be substantially reduced through optimization of limit adjustments and an improved control response.

It was furthermore maintained that the operation of the plant was substantially handicapped by damaged fuel spheres. During the past operating period, HKG could establish the connection between rigorous shutdowns with a compacted pebble bed during the commissioning and the associated fuel sphere damage rate. This fuel sphere damage rate descreased towards the end of the power operation to 0.6 % of the discharged spheres. A further reduction of the damage rate could have been expected if the operation had continued and the shutdown regime had been changed accordingly. A connection between coolant gas activity and sphere rupture could not be found. The coolant gas activity is in the expected range. The damage rate is not safety-relevant. In terms of operation, HKG has learned how to handle damaged fuel spheres. This was not expected to result in any further unscheduled outages.

There was also the persistent assumption that the hot gas channel damage identified during the scheduled outage at the end of 1988 ruled out the continued operation of the reactor. Figure 3 provides a look into one out of altogether six hot gas channels.

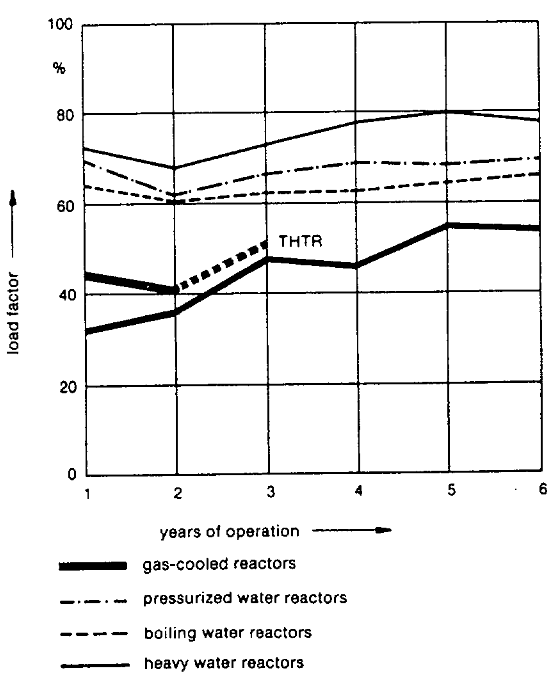


*Fig. 2. Mean annual load factor in the first years of operation.*

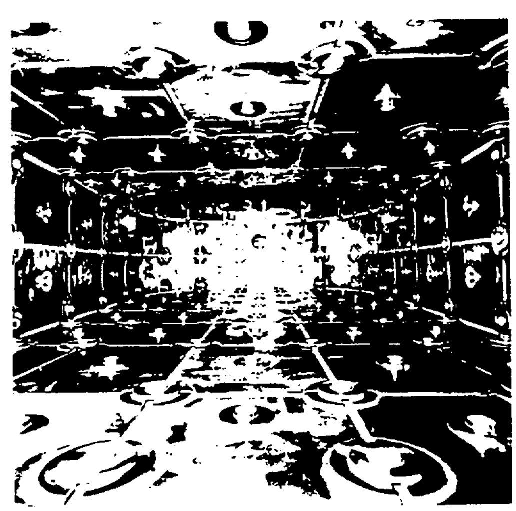

*Fig. 3. Hot gas channel.*

The picture shows the inside insulation consisting of sheet-metal packs covering 30 cm × 30 cm, each of which is secured by four corner bolts and one centre bolt. The internal inspection of all six channels revealed that out of about 2600 bolts a total of 33 centre bolt heads had popped off.

This is due on the one hand to decreased material ductility as a result of the irradiation with thermal neutrons and on the other hand to the loading of the bolt with secondary forces resulting from variations in the thermal expansion behaviour of the 18-layer insulation. Together, both effects are stronger than originally expected and result in rupture of the prestressed centre bolt.

Owing to their different design, the corner bolts can absorb the secondary forces.

The Technische Überwachungsverein (Authorized Inspection Agency), the Reactor Safety Commission as well as the regulatory authority under the Atomic Energy Law concluded that the existing damage warrants the continued operation of the THTR-300 from an engineering perspective. Since the damage is concentrated on the centre bolts, the inside insulation in the metal part of the hot gas channel is still secured by the corner bolts. This ensures the proper functioning of the inside insulation even under the present circumstances.

Moreover, there was reason to believe that the present extent of the damage had already been caused shortly after the commissioning and that the centre bolt failure would not spread over a wider area during continued operation.

In sum, our evaluation of the THTR operation is therefore clearly positive. Operation of the plant has never been restricted for safety-engineering reasons, nor has the plant suffered from any safety-relevant damage. The operation within the interconnected transmission grid has been without blemish or blame.

For follow-up plants, important knowledge has been gained to improve the accessibility of the core internals as well as the design of the hot gas channels and the fuel element handling.

Today we know how a follow-up plant should be designed. Therefore, the THTR has fully come up to expectations, advanced the development of the high-temperature reactor and has led this reactor line to technical and commercial viability. This is about all you can expect from a pilot plant.

The fact that the commissioning and operation of the THTR have produced extremely satisfactory results inevitably raises the question why the plant will be decommissioned. This will be explained by my

### 2nd Thesis:

*Decommissioning became necessary because adequate provisions in the balance sheet for the future decommissioning expenses and the financial cover for existing outage risks proved impossible. Nonetheless, the THTR experience has demonstrated that the operation of high-temperature reactors can be economically efficient.*

Up to this day, the THTR is a research project predominantly sponsored by the public sector. Its objective of demonstrating the technological feasibility of a high-temperature reactor primarily benefits industry policy and the national economy. This is also the reason for the high proportion of public funds both in the construction and in the risk sharing by the governments at Federal and Land level to provide cover for operating losses. The overriding maxim was that the operating company HKG should neither incur losses nor generate profits when implementing this research project exclusively benefitting the national economy.

Shares in HKG are held by:

| | shares |
|---|---|
| Gemeinschaftskraftwerk Weser GmbH, Porta-Westfalica | 26 % |
| ELLEKTROMARK Kommunales Elektrizitätswerk Mark AG, Hagen | 26 % |
| Vereinigte Elektrizitätswerke Westfalen AG, Dortmund | 31 % |
| Gemeinschaftswerk Hattingen GmbH, Hattingen | 12 % |
| Stadtwerke Aachen AG, Aachen | 5 % |

The operating company HKG could draw on the following funds for the operation:

— The revenue from the sale of electricity to the shareholders of HKG. The electricity prices were defined in contracts and determined to cover the costs on the basis of an assumed availability of about 70 % for a period of 20 years.

— The demand rate prepayments of the shareholders for the periods without electricity production, for overhauls and outages.

This revenue contrasts with current expenditures of HKG for the operation, in particular input materials, personnel, depreciation, interest, maintenance and provisions for decommissioning and waste management. Remaining losses are covered on the basis of

— the Risk Sharing Agreement (RSA) by the governments at Federal and Land level. During the first three years 90 % and in the subsequent years 70 % of an annual loss fall upon the Federal Government and the Land of North Rhine-Westphalia. The remaining difference to 100 % of an annual loss is settled by the shareholders.

The Risk Sharing Agreement is of crucial importance in the following. This agreement has been concluded between the Federal Government, the Land of North Rhine-Westphalia and HKG for potential losses which cannot be ruled out for a research plant. The volume of the agreement is limited to DM 450 million.

F i g u r e 4 provides a long-term representation of the projected development of operating results and the financial use of the RSA over a period of twenty years. Assuming an availability of 70 % from 1990, the

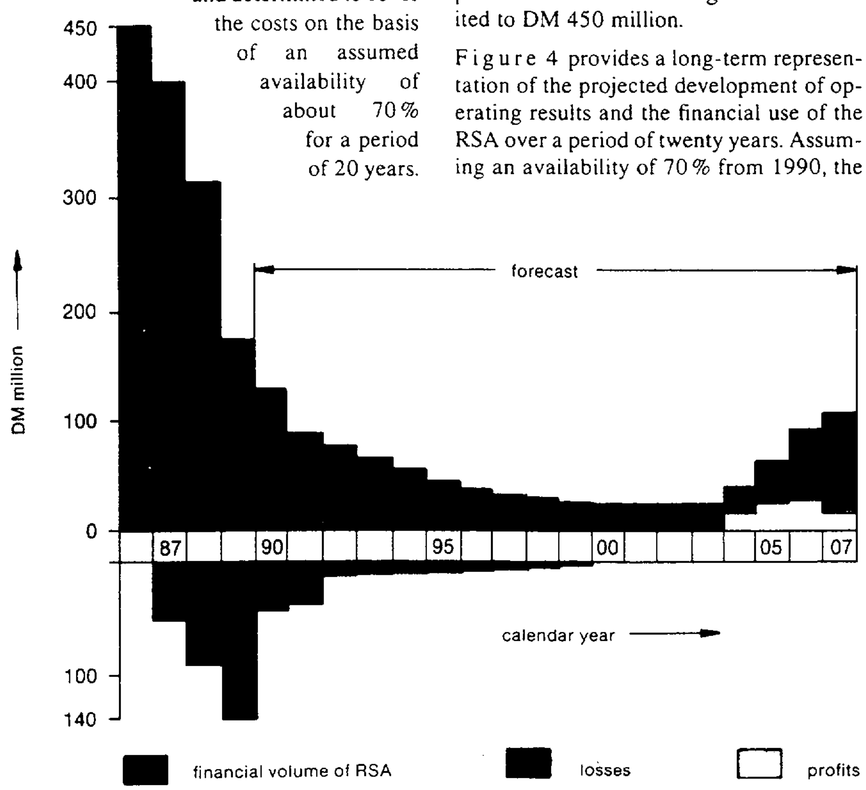


*Fig. 4. Use of the RSA for continued operation of the THTR.*

operating result of the plant would remain negative until the year 2000. This is mainly attributable to the high debt servicing charges in the initial years. After the year 2000, a positive operating result can be expected. Another important conclusion to be drawn from this diagram is that on the assumption of routine operation without any licensing and political risks the uncalled liability of DM 450 million provided for in the RSA would have been adequate.

The blue graph represents the respective financial reserve in the RSA fund. The main burden of the RSA occurs in the first three years of operation when high losses were incurred because the energy availability fell short of the 70 % target.

And this already highlights the problem. The profit and loss account is largely determined by the energy availability and hence the generated kilowatt hours. High losses are the immediate result at least in the first years even if the target of 70 % is only slightly missed. This predicament is exacerbated when analysing the external risks HKG would have been confronted with up until 1992.

The financial risks for the short-term period look completely different from the idealized expectations of a long-term operation over a period of twenty years. For the period up to 1992, additional risks would have been in store for the THTR that could have resulted in extended plant outages and hence loss of revenue. These risks have been summarized in Table 2. They are the following:

*Table 2. Risks for continued operation external influence.*

- fuel element supply
- transport pick-up hall
- Ahaus intermediate storage facility
- further operating licence

*1. Fuel element supply*

At the end of 1988, NUKEM stopped the production of fuel elements. Although the fuel element production was intended to be resumed by the Siemens/ABB industrial group, the smooth transition could not be guaranteed for the operation of the THTR. For this reason, HKG had to take into account an outage of the plant for about one year, especially because also the financing of a new production facility could not be settled.

*2. The partial operating licence limited to 1100 full-load days and the waste management precautions*

The valid operating licence is limited to 1100 full-load days and would have expired in 1992. This valid operating licence specifies that at the time of 600 full-load days HKG has to furnish proof of an available operating licence for the transport pick-up hall for the storage of low-level waste according to section 3 of the Radiation Protection Ordinance. Furthermore, the operator had to demonstrate that the external interim storage of spent fuel elements was secured. As far as the granting of a continuing permanent operating licence was concerned, HKG foresaw again licensing as well as political problems which could also have resulted in a plant outage of one year.

Up to this day, the required proof of waste management precautions cannot be regarded as furnished. HKG considered this to be another outage risk for the plant of about six months.

*3. Precautions for decommissioning*

For premature decommissioning, the Risk Sharing Agreement provides for funds which have to be reserved and should, together with the allocated decommissioning provisions, be adequate any time to safely and permanently enclose or dismantle the THTR plant. The amount of funds needed for decommissioning was determined by expert opinions prepared by engineering companies experienced in this field. It increased from DM 180 million in 1984 to DM 415 million in 1988.

All these risks have been evaluated and would have resulted in the described cumulative financial burden for the RSA (Figure 5) in the event of continued operation.

- Represented in red are the expected losses arising from normal operation with 70 % availability.
- Yellow is the financing risk through an outage of about six months to furnish proof of waste management capacities.
- Green stands for the outage risk resulting from delayed follow-up manufacture of fuel elements.
- Marked in blue is the loss of HKG incurred between April 1989 and October 1989 as a result of the financing negotiations when the plant had to be kept ready for start-up all the time.

Of central and decisive importance, however, are the precautions which have to be financed for the future decommissioning of the power station. This expenditure could not be covered with the existing funds of the RSA. Since the provisions are allocated continuously over the expected operating period of twenty years, the uncovered amount is of course very high during the first years. Together with the increased losses during the initial phase of operation the risk sum of the RSA therefore turned out to be far too low. Figure 5 reveals that it was exceeded in 1988 already.

These problems which HKG recognized back in April 1987 and indicated to the government authorities could not be resolved among the contracting parties of the RSA. Against this backdrop, the management felt compelled at the end of 1988 to lodge as a precaution an application for decommissioning in accordance with sec-

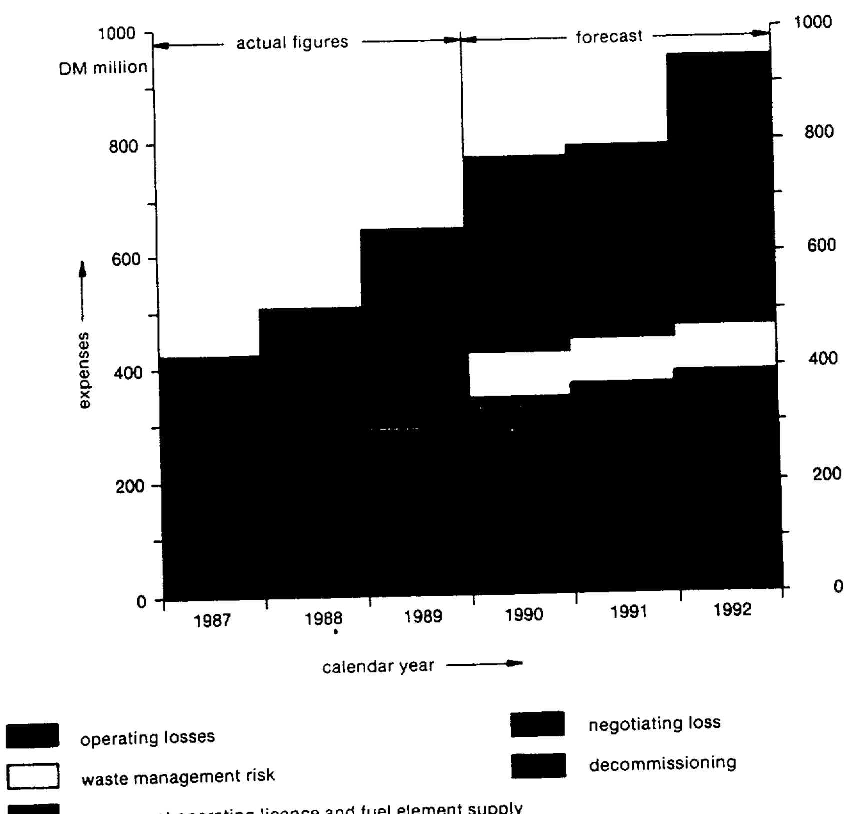


*Fig. 5. Cumulative use of funds from the RSA.*

tion 11 of the RSA, in the positive anticipation, however, that the parties to the project would now at last jointly find a solution at the negotiating table for the precarious financial situation.

The development that followed is now chronologically described in brief. Starting in November 1988, HKG and the partners of the THTR project (Federal Government and the Land of North Rhine-Westphalia) negotiated for ten months to find a way of putting the continued operation on a secure financial basis and to increase in RSA sum. During the talks, the following positions of the individual partners emerged very soon:

- The Land of North Rhine-Westphalia declared that more funds would not be provided for the continued operation.
- The shareholders of HKG were prepared to contribute further payments to the research project if they were not involved in the political and licensing risk.
- The Minister of Research and Technology was prepared in principle to support the continued operation, but could not make the promise requested by the HKG shareholders with respect to political and licensing risks, nor could he commit himself to providing the funds for an increase of the RSA sum alone.

The compromise proposal finally put forward in the negotiations provided for a phase-out operation of the THTR-300 ending on December 31, 1992, to consume the present supply of fuel elements. The situation was aggravated by the fact that owing to the open outcome of the negotiations the regulatory authority was doubtful about the economic reliability of the operator HKG according to section 7, subsection 2 No. 1 of the Atomic Energy Law and made the restart permit contingent on the proof of adequate financial resources of HKG.

This proof could have been furnished if HKG had signed a draft contract of the Federal Government and the Land in which some financial risks were still left open. Since the HKG management was not authorized by its shareholders and their supervisory bodies to assume open project risks unilaterally, the immediate decommissioning of the plant without phase-out operation turned out to be the only solution at the end of the negotiations. Otherwise HKG would have had to file for bankruptcy immediately in the event of a failure of the negotiations.

For the national economy this is not an efficient solution to the THTR problem. Whereas the HKG shareholders asked the partners (the Federal Government and the Land) to provide cover for uncertain financial risks which would not yet have entailed direct payments, the contributors of subsidies now have to make substantial payments immediately as a result of the existing agreements.

However, the evaluation of the financial situation also requires a description of how the operating losses of HKG were made up: These charges are represented in Figure 6 for a month in 1989. Depreciation and interest account for more than half the charges, about 15 % are personnel expenses and another 15 % or so are made up by the pure costs of servicing and maintenance.

This goes to show quite clearly that the operation of the power plant itself has contributed little to the losses. The operating result is decisively determined by the items interest, depreciation, provisions; it is precisely these items that increased substantially in the past: Rising costs for decommissioning and waste management should be mentioned here in particular. Minimum energy availabilities of 70 % were needed to cover this high share of fixed costs in the long term. Today we know that at least during the first years of operation a pilot plant, such as the THTR, cannot fulfil this prerequisite.

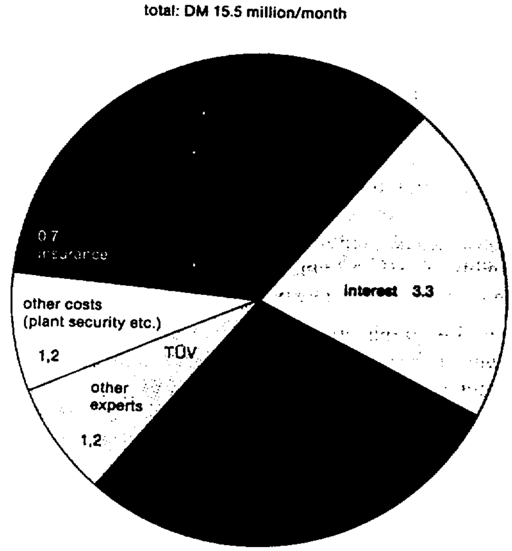


*Fig. 6. Average fixed costs per month (in million DM).*

### 3rd Thesis:

*By means of the decommissioning procedure HKG will demonstrate that high-temperature reactors can be safely enclosed under the outline conditions of the applicable Atomic Energy Law*

A high-temperature reactor will be safely enclosed for the first time, and the successful dismantling of this large-scale plant will in the final analysis also demonstrate the industrial maturity of this reactor line. The detailed safe enclosure will be performed in various steps. The reactor has been shut down since September 29, 1988, and the residual heat to be removed therefore amounts to just a few kW (Figure 7). In a first step it is intended to stop the residual heat removal via the steam generators and to remove the decay heat exclusively via the liner cooling system.

Figure 8 shows the decommissioning of systems. The secondary system has already been taken out of service. The following systems will remain in service for the outage operation and core unloading: Residual

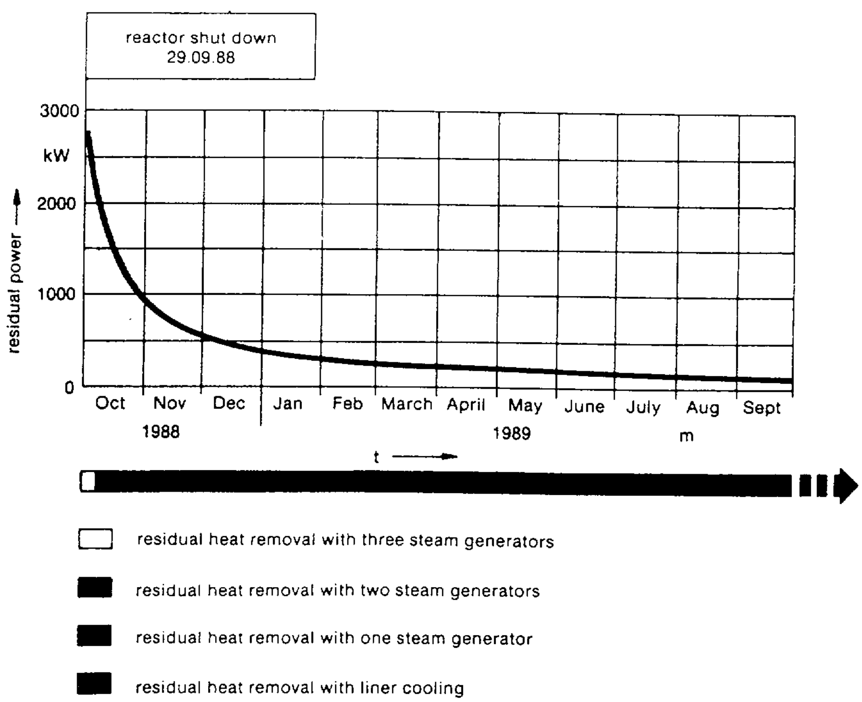


*Fig. 7. Residual heat removal during the outage phase.*

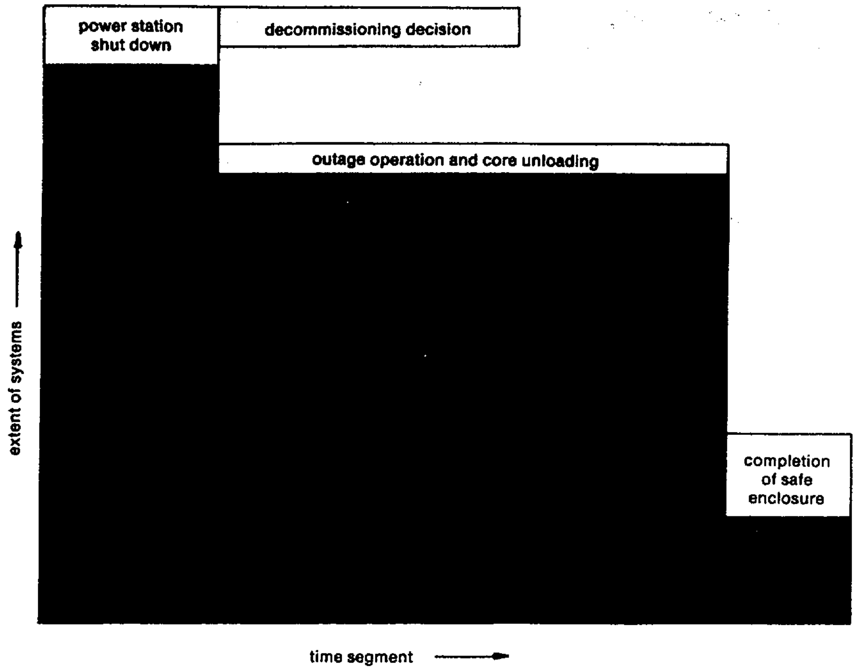


*Fig. 8. Decommissioning of systems.*

heat removal (liner cooling), gas purification system, fuel element discharge facility and ventilation systems. Upon completion of the safe enclosure, only the ventilation and monitoring systems will remain in operation.

On closer inspection, the core unloading turns out to be a very complex operation. The pebble-bed core consists of fresh and spent fuel elements arranged in layers (Figure 9). In order to maintain a balanced power density distribution, the fresh fuel elements (red) are added at the outside and the spent spheres (yellow) are inside. Elements of average burn-up are blue. When the reactor core is being unloaded via the fuel sphere discharge system, a discharge funnel will gradually form in the pebble bed (steps 1 to 4 in Figure 9) and the fresh fuel elements at the outside will roll to the inside thus enriching the centre of the reactor core with fissile material (red/yellow). This phase of enriching the core centre with fissile material has to be mathematically examined very carefully with accompanying sphere flow experiments in order to prevent local criticality. In this case it is planned to add absorber spheres in the centre of the pebble bed. The actual discharge operation is a time-consuming process and will take about 18 months. The foregoing makes it clear that especially the core unloading is a prototype task too.

After core unloading the safe enclosure can be carried out.

Figures 10 and 11 show where the bounds of the safe enclosure could be placed according to the present planning. Since waste management facilities for highly active plant components are currently not available, the gas purification plant, the fuel circulating system and the prestressed concrete vessel are to be included in the safe enclosure. This results in a very compact arrangement of the safe enclosure which could perhaps be monitored with a separate small ventilation system (red-rimmed).

There is no reason to question the technical feasibility of the safe enclosure over a period of twenty to thirty years and of the subsequent dismantling of the plant.

During the work for the safe enclosure all data obtained from the THTR are to documented, and new findings are to be added by internal inspections, material investigations and the removal of components.

## Conclusions

Between 1972 and 1986, the THTR went through a difficult and time-consuming construction phase. A prototype licensing procedure was conducted. Until today, the plant could always be adapted to the current state of the art; This reflects the in

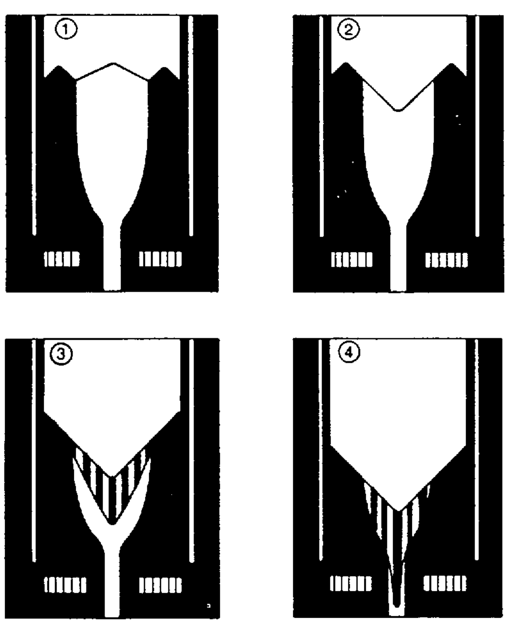


*Fig. 9. Assumed fuel sphere flow behaviour during core unloading.*

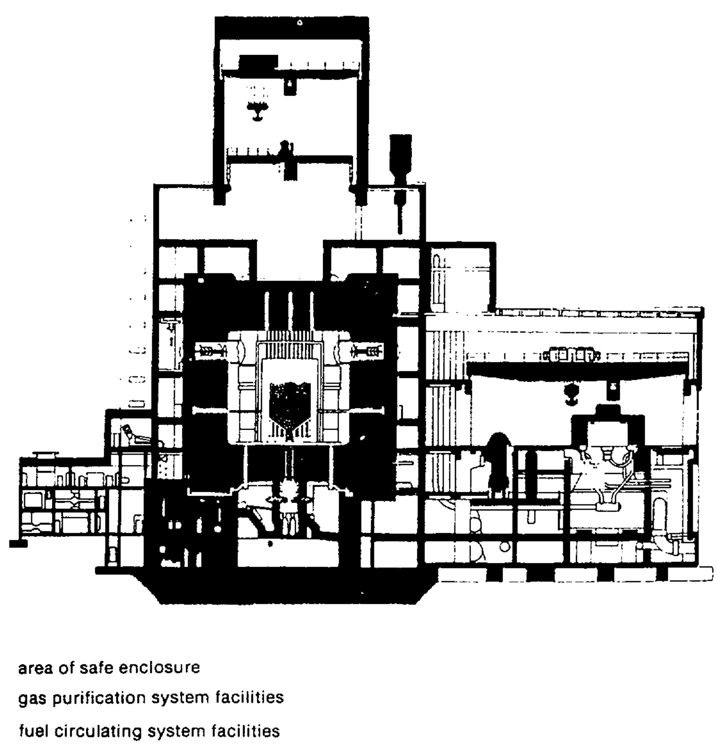


*Fig. 10. Safe enclosure concept.*

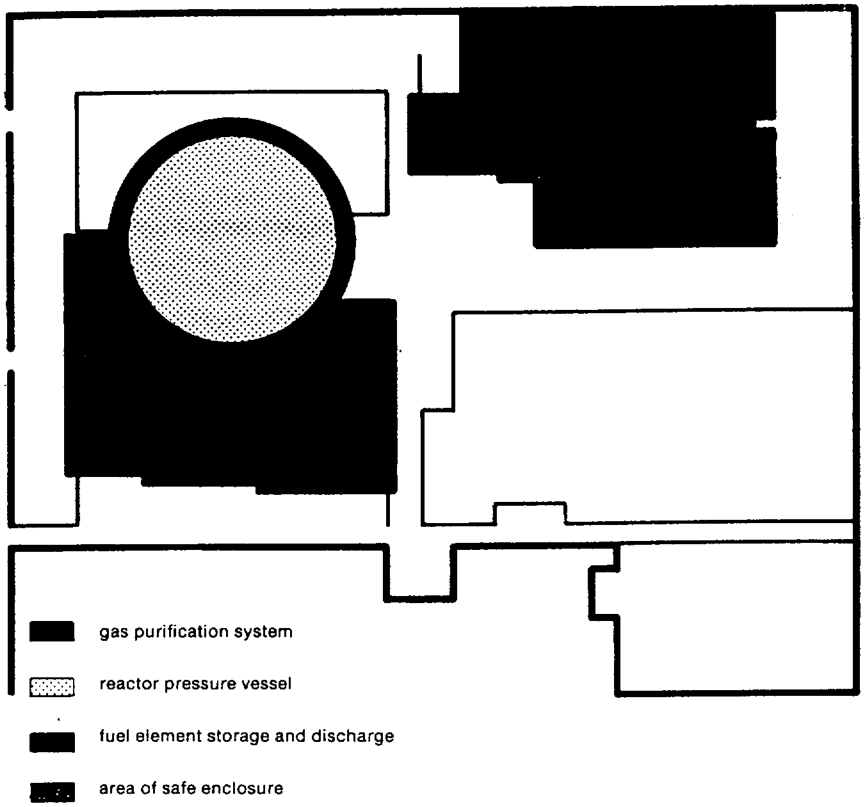


*Fig. 11. Safe enclosure concept — ground plan of reactor building.*

herent high flexibility of the high-temperature technology. Alongside the construction, the infrastructure for the manufacture of fuel elements could be built up with the help of HKG. We have learned from the construction that for follow-up plants the prime objective must be to have the licensing procedure complete before starting the erection. This is the only way of ensuring calculable construction times.

The short period of operation between 1986 and 1988 proved the THTR concept. Possible optimizations for follow-up plants were pointed out. The high-temperature reactor is commercially viable.

**For the large number of committed engineers who were involved in this project in the past, the operating period ends with the painful realization that in the existing environment for nuclear energy in the Federal Republic of Germany, the financial strength of individual energy utilities or even of the manufacturing industry will by far not be sufficient to render the continued operation of the THTR possible.**

**The engineers of HKG and with them many international experts remain convinced of the high-temperature reactor concept.**

**The technological potential of the high-temperature reactor line remains technically and scientifically undisputed, be it for the generation of hydrogen or the solution of the $CO_2$ problem. The symbiosis of nuclear and fossil energy via the high-temperature reactor, as conceived in several studies, is an option for an environmentally compatible energy supply in the future.**

It will all depend on whether the know-how gained by competent engineers in the research centres, by the operator and manufacturer during the construction and operation of the THTR can be kept up over a period of several years that will be a hard time for the use of the HTR technology. Several years of decommissioning will be a first step in that direction and do not mean the end for the high-temperature reactor line, but should, once all the data obtained from the THTR operation have been evaluated, provide a basis for a fresh international start towards the successful implementation of this promising and forward-looking technology.