RESEARCH AND DEVELOPMENT PROGRAM FOR PRESTRESSED CAST IRON PRESSURE VESSELS (PCIV) FOR HIGH TEMPERATURE REACTORS

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SUMMARY

Based on the Siempelkamp activities in the field of the development of prestressed cast iron pressure vessels, a cooperation contract concerning the development of the Prestressed Cast Iron Pressure Vessel (PCIV) for high temperature reactors (HTR) has been signed between: Gesellschaft für Hochtemperatur Reaktortechnik mbH (GHT), Hochtemperatur Reaktorbau GmbH (HRB), Steinmüller, and Siempelkamp. The research and development program for this type of PCIV is sponsored by the Ministry for Economics and Transportation of the state of Northrhine-Westphalia. The program has a total value equal to 10 Million US Dollars and runs for 4.5 years. Thus two reactor-engineering companies: Hochtemperatur Reaktorbau GmbH and Gesellschaft für Hochtemperatur Reaktor Technik mbH, and two suppliers of heavy components: L.+C. Steinmüller GmbH and Siempelkamp Giesserei KG, which are able to manufacture the complete pressure vessel are cooperating in the design and construction of this vessel.

The Materials Testing Institute of the state of Northrhine-Westpfalia (MPA–Dortmund) is in charge of the materials testing program.

Before the R & D program could be started at the end of 1975 preliminary work in the PCIV field had been done by Siempelkamp. This included: *1969-71.* Design and construction of a PCIV model at a scale of 1 : 7.5 with respect to the PCIV of the THTR. *1972-73.* Erection of the model and pressure tests up to 90 atm. (2.3-times the operating pressure of the THTR). *1973-74.* Based on designs by Siempelkamp for the PCIV, the Battelle-Institute in Frankfurt performed two feasibility studies orderded by the Ministry for Economics and Transportation of the state of Northrhine-Westphalia. The results of both were positive. *1975.* Order for a first "conventional PCIV" as helium storage tank for the THTR; service pressure 230 bar. The Ministry for Economics and Transportation starts to support the development of a PCIV.

The objects of the R & D program are:

— Fully worked out construction plans,
— Demonstration of the decisive economic advantages of this new type of vessel.
— Plans designed to meet the requirements of licenzing authorities.
— A preliminary safety report.

The development program has been subdivided into three phases.

During phase I at least 4 vessel geometries, e.g. cylindrical cavern with 2 diameters, pod boiler, and satellite type will be analysed. The object of phase I is to select the most advantageous type of vessel and to determine the data for phase II. Phase I will end in March of 1977. The object of phase II is to produce detailed construction plans and analyses as well as to provide the basis for phase III. The duration of phase II is set at 15 months and it will end in May of 1978. Phase III comprises the detailed construction and tests of a model with scale of 1 : 3 or 1 : 5 and the writing of a safety report.

1. Introduction

The research and development programme "Prestressed cast iron pressure vessel for high-temperature reactors" has the aim of developing the concept of the prestressed cast iron pressure vessel to the state of maturity for application for helium-cooled graphite-moderated high-temperature reactors up to the state of readiness for manufacture. In this procedure both the possibility of application of the prestressed cast iron pressure vessel for power production and for process heat lines is investigated.

The government, in this case the Ministry of Economics, Commerce and Transport of Northrhine-Westphalia, was only prepared to support the development of prestressed cast iron pressure vessels after the manufacturer had carried out extensive development work which was able to prove feasibility of this vessel concept and after these development results had been judged positively by indepentent experts (scientists of the Battelle Institute of Frankfurt). In order to make the following explanations easier to unterstand, the priciple of the prestressed cast iron pressure vessels should be described in short:

The vessel consists essentially of 3 components, the vessel body consisting of heat-resistant grey cast iron (which corresponds to concrete part of the prestressed concrete vessel), these cast iron walls are not, however, made of monolite as in the case of the prestressed concrete vessel, but consist in the lid and bottom region as well as in the cylindrical part of prefabricated individual parts. (refer to fig. 1)

The blocks are mechanically worked in the positions where they contact adjacent blocks and are provided with shearing wedges.

The 2nd component is the circumferential and axial tensioning system which is made of high-strength prestressed steel, holds the block pack together and charges it with compressive stress by means of the effect of prestress forces.

The 3rd major component is the gas-tight liner with the appertaining armoured pipes and lid covers, the liner covering the entire inside surface of the vessel.

2. Fundamental operations prior to starting the development programme

In 1966 a special grey cast iron - works designation: SKM-U84 - was developed which can be ultrasonically checked in all wall thicknesses and has a guaranteed minimum tensile strength even in thicker parts of at least 20 kp/mm^2 and a guaranteed minimum compressive strength of 80 kp/mm^2. This special cast iron is, just like cast iron in general, excellently suited for use in hot-operated construktions of up to approx. 400 ^oC.

The ultrasonic checkability had to be achieved in order to fullfil the increased quality and safety requirements of reactor building.

It was this SKM-U84 material which was used in 1966/67 for the primary shielding system of the German nuclear ship "Otto-Hahn". This shielding system consists of cast iron pieces of up to 30 tons of weight each, which are arranged round the reactor core in the fully demineralised water of the primary cycle.

Following these operations, parts of up to 45 tons per piece were used in nuclear power station construction and in the construction of hot cells as shielding structures. During the years 1968/69 the first research work about the feasibility of a prestressed reactor pressure vessels made of individual blocks was done in conjunction with the engineering work for the thermal shields of the THTR 300 at Schmehausen. The task arose from the question why one would use concrete as protective material for a prestressed vessel when concrete has a comparatively low compressive strength compared to cast iron (compressive strength of concrete: 4,5 kp/mm^2 - compressive strength of cast iron : approx. 100 kp/mm^2). The result of these initial investigations was that a vessel from machine-worked cast iron parts was makeable in general and that production costs and building time savings seemed favourable in comparison with prestressed concrete vessels.

The next step in the development was characterised by the design and calculation of a model for a prestressed cast iron pressure vessel, scaled 1 : 7.5, for the prestressed concrete vessel of the THTR 300. (fig. 2, fig. 3)

In 1972 this PCIV model was built, equipped with instruments and tested in Pressure tests with up to 2.3 times the operating pressure of the THTR, which is about 90 bar. Fig. 4 shows the assembly of the vessel bottom. Figs. 5 and 6 show the essential test results and their comparison with the finite element calculations on the model. The test results showed very good conformity with the results of the finite element calculation. The possibility of producing the vessel, incl. mechanical treatment and assembly, was proved.

In 1972 the Ministry for Econimics, Commerce and Transport decided to have this research work examined and judged by the Battelle Institute in two studies. The first study examined the applicability of a prestressed cast iron pressure vessel using is as an example of a construction for the THTR 300 MWe, and carried out a comparison with the prestressed concrete vessel of the same reactor. The result of this study was: The PCIV concept is technically an economicly interesting and promises consinderable advantages over the prestressed concrete vessel. The comparison with the prestressed concrete vessel was carried out on the basis of PCIV design documentation which still has a cold-operated liner and internal insulation.

The 2nd part of the study was concerned with the economic and technical feasibility of PCIV's specially for high-temperature reactors with capacities of 1000 - 1200 MWe and the applicability of the PCIV for water-colled reactors and burst protection structures for steel pressure vessels.

The result was that these types of vessels are also technically and economicly feasible. Government subsidies were recommended.

In 1974 an application was submitted to the Ministry for Economics, Commerce and Transport of Nothrhine-Westphalia with regard to a development programme "Prestressed cast iron pressure vessel for high-temperature reactors". This application was approved in November 1975.

In the meantime the thermal shields (bottom, side and lid shields) for the THTR had been supplied in SKM-U84 quality. These constructions were, just like the vessel construction, divided into individual parts which are machine-worked at their contact surfaces. The application temperature lies at 260°C.

In 1975 a first commercial order was placed for the supply of a smaller prestressed cast iron pressure vessel with 230 bar operating pressure as helium reservoir for the high-speed shut-off system of the THTR 300. This vessel will be delivered in October this year.

In addition, engineering studies about the application of PCIV's as reactor pressure vessel for boiling-water reactors, process heat reactors as well as burst protection constructions were carried out.

3. The PCIV-HTR development programme

The development programme PCIV-HTR is a cooperation of the following companies:
Hochtmeperatur Reaktorbau GmbH (HRB),
Gesellschaft für Hochtemperatur Reaktortechnik mbH (GHT),
L.+C. Steinmüller GmbH and
Siempelkamp Giesserei GmbH + Co.

Examination of the materials is carried out at the Material Testing Authority of Northrhine-Westphalia in Dortmund (MPA). This way, the two German high-temperature reactor building firms and two supply companies, which are able to supply a complete prestressed vessel, are combined in a group venture.

The research programm will run over 4.5 years. Work started in January 1976. The funds required for the development programme amount to 10 million US Dollars.

Targets of the PCIV development programme:
- Proof of achieved maturity to be built
- Proof of qualification for approval
- Proof of profitability
- Preparation of a temporary safety report for the approval procedure
- Investigations on the basis of a reference vessel.

4. Classification of the PCIV-HTR development programme

The PCIV-HTR development programme is divided into 3 phases. The duration of these pases, their essential investigation contents as well as their tragets are listed as follows:

Phase I - System study :
Examination of 4 versions; priciple examination liner concept; heat protection system; vessl covers; cast iron blocks; tensioning system; examination of materials;
Targets: Selection of the most favourable version; data description for pahse II // 1. July 75 - 31 March 77 = 21 months.

Phase II - System development:
Further reatment and detailing of vessel version from phase I; partial model

tests; calculation and design of large-scale vessel model; first safety analyses; continuation of material tests;
Targets: Preparation of detailed design and calculation documentation; Foundation for phase III // 1 Apr.77- 31 May 78 = 14 months.
Phase III - Detailed design and large-scale testing:
Preparation of building documentation; test regulations; specifications; Assembly large-scale model and test; temporary safety report;
Target: Proving maturity for being built and creation of prerequisites for approval procedure // 1 June 78 - 31 March 80 = 22 months

From a material point of view the programme is divided into 9 subunits. This division was chosen in order to be able to introduce already at this stage a classification in the development programme which can be transferred to a building project. The subunits are numbered :

Subunits 100 Cast iron support system
200 Tensioning system
300 Liner, vessel covers and heat protection system
400 Operating and supervising system
500 Material checks and subunit tests
600 Large-scale model
700 Test plant
800 Project management
900 Preparatory work for approval procedure.

5. Organisation of the PCIV-HTR development programme

The organisation of the PCIV-HTR development programme is shown in fig.7. As an explanation it should be mentioned that the companies Siempelkamp and Steinmüller have founded a joint subsidiary, the Siempelkamp + SteinmüllerGmbH which becomes the legal successor to the subsidy recipient Siempelkamp Giesserei KG.

The four industrial companies GHT, HRB, Siempelkamp and Steinmüller, who participate in this development programme, are connected with each other by a group contract for this project.

The MPA (Material Testing Authority) is not included in this group contract on account of this special position as an Authority.

6. Changes in the programme

It was as early as during stage of agreeing on the development application among the participating firms that the possibility of building the PCIV as hot-operated vessel with floating liner was realised. This presents a deviation from the operations carried out up to then. The foundation for these considerations was the fact that the cast iron material can be employed very well and without any reduction of its strength properties up to 400°C. Thus internal insulation and a liner colling system were no longer required in contrast to the prestressed concrete vessel.
The entire development programme was shortly changed over to this hot-operated vessel type. Cold-operated vessels were only abserved at the beginning of the

programme and then for comparative tests between pod boiler, single underground hydro-electric vessels and satellite vessels of PCIV design.

The structure and the design principle of this hot-operated vessel type for power production and process heat lines, which is now the basis of the development programme, will be explained in detail in the following lectures.

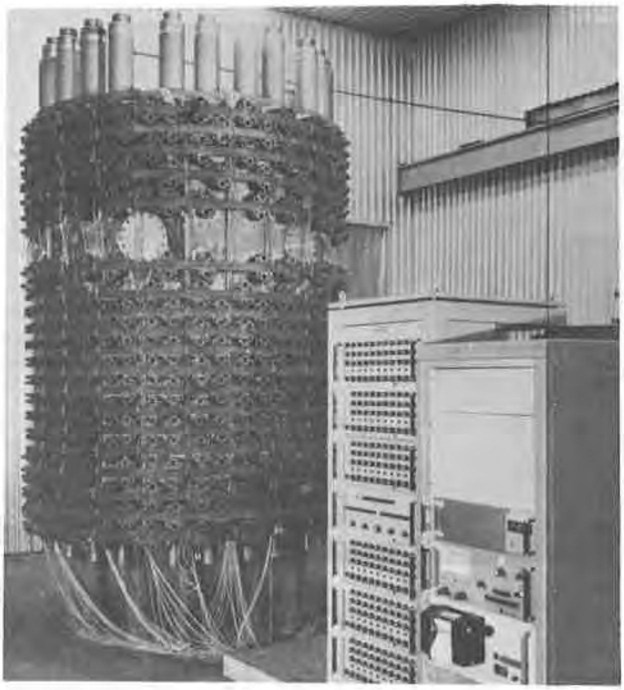


Fig. 1: View and longitudinal section of PCIV conceptual design for THTR 300 MWe (dimension in mm)

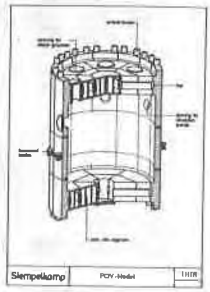
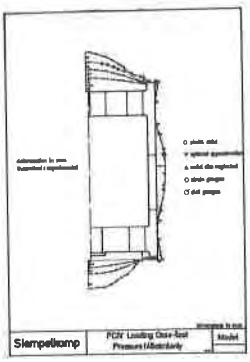
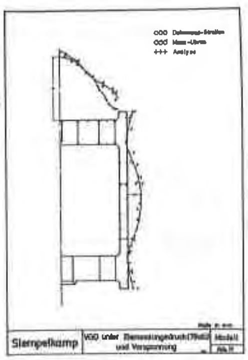


Fig. 2: PCIV model structure

Fig. 3: PCIV model

Fig. 4: Assembly of bottom slab of PCIV model





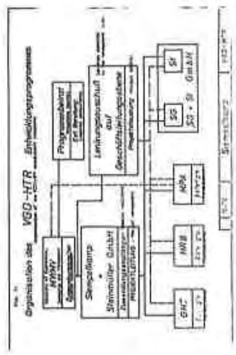


Fig. 5 + 6: Test results and their comparison with finite-element-calculations.

Fig. 7: Organisation plan of PCIV-HTR development programme