EUROPEAN COMMISSION

Community Research

SEVENTH FRAMEWORK PROGRAMME

ARCHER

Collaborative Project (CP)

Co-funded by the European Commission under the Euratom Research and Training Programme on Nuclear Energy within the Seventh Framework Programme

Grant Agreement Number : 269892

Start date : 01/02/2011 Duration : 48 Months

www.archer-project.eu

Archer

Advanced Reactor for Cogeneration of Heat & Electricity-R&D

Gap Analysis

Authors : WIECHERS Bernhard (WESTINGHOUSE) , Markus Esch, Felix Sassen

ARCHER - Contract Number: 269892
Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D
EC Scientific Officer: Dr. Panagiotis Manolatos

Document title	Gap Analysis
Author(s)	WIECHERS Bernhard , Markus Esch, Felix Sassen
Number of pages	35
Document type	Deliverable
Work Package	WP 12
Document number	D12.11
Issued by	WESTINGHOUSE
Date of completion	07/11/2014
Dissemination level	Confidential, only for members of the consortium (including the Commission Services).

Summary

This report consitutes the Westinghouse contribution to the Work Package 1.2 (Technology Gap and SWOT Analsysis), Task 1.2.1 (Gap Analysis) of the European research Project. The report provides input regarding available technology specific for nuclear systems of the HTR. The input is based on experience, documentation and know-how form the AVR, THTR-300, PNP and other HTR projects. Gaps identified in the past will be re-evaluated and new gaps resulzting from new requirements will be identified and analysed.

Approval

Date	By
09/12/2014	Michael FUTTERER
09/12/2014	Ferry ROELOFS
10/12/2014	Steven KNOL

Distribution list

Name	Organisation	Comments
P. Manolatos	EC DG RTD	Through the EC participant portal
All beneficiaries	ARCHER	Through the private online workspace

Westinghouse Proprietary Class 2R

European Commission
EE-11-3052
ARCHER - EU

Work Package 1.2. / Task 1.1.2 - Westinghouse Contribution âĂŞ Gap Analysis

Technical Report

GBRA164541 Rev. -

Total Pages: 33

EXPORTKONTROLLE

AL/ECCN, Origin Company: 0E001 i. V. m. 0A001

Prepared:	2014-07-29 15:41	IG	Knoche, Dietrich
Reviewed:	2014-07-29 15:46	PEO	Esch, Markus
Approved:	2014-07-29 16:21	PEA	Sassen, Felix Philipp

Electronically approved records are authenticated in the document management system CIN2013 and transferred into EDMS.

Westinghouse

Document Category

Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D – ARCHER

Project Number	AP	UA	Document Ident No	Index	Page No.	No. of Pages
EE-11-3052	3000	BL	GBRA 164 541	-	1	32

Title

Work Package 1.2. / Task 1.1.2
Westinghouse Contribution – Gap Analysis

Origin:	Replaced by:	Replacement for:	Format	Language	Department responsible / Ref.	
			A4	E	PEA – FS	

Plant Designation

ARCHER

Mark of Approval, Stamp

Prepared by (Date / Signature):	Checked by (Date / Signature):	Approved by (Date / Signature):
25.07.2014	25.07.2014	25.07.2014
ISG/ Dr. Dietrich Knoche	PEO / Markus Esch	PEA / Dr. Felix Sassen
(Dept./Name)	(Dept./Name)	(Dept./Name)

HTR

Westinghouse Electric Germany GmbH

Changes

Revision Index	Date of Revision	Description of Revision
-	28.07.2014	Created

Contents

Contents

Abbreviations

ALARA	As Low as Reasonable Achievable
ARCHER	Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D
AVR	Arbeitsgemeinschaft Versuchsreaktor
CSC	Core Structure Ceramics
DHR	Decay Heat Removal System
FE	Fuel Element
FHSS	Fuel Handling and Storage System
FOAK	First of a Kind
HRB	Hochtemperatur Reaktorbau GmbH
HTR	High Temperature Reactor
I&C	Instrumentation & Control
LOI	Letter of Intent
LWR	Light Water Reactor
HX	Heat Exchanger
PBMR	Pebble Bed Modular Reactor
PNP	Prototype for Nuclear Process Heat
RCS	Reactivity Control System
R&D	Research & Development
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
SG	Steam Generator
THTR	Thorium High Temperature Reactor
TTA	Tieftemperatur-Anlage

WEG	Westinghouse Electric Germany GmbH

Index of Figures

Index of Tables

1 Introduction

This report constitutes the Westinghouse contribution to Work Package 1.2 (Technology Gap and SWOT Analyses), Task 1.2.1 (Gap Analysis) of the European research project “Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D” (ARCHER). Westinghouse has the lead for Task 1.2.1.

This report provides input regarding available technology specific for the nuclear systems of the HTR. The input is based on experience, documentation and know-how from the AVR, THTR-300, PNP (Prototype for Nuclear Process Heat) and other HTR-Projects such as HTR- 500. Gaps identified in the past will be re-evaluated and new gaps resulting from new requirements will be identified and analysed. This report is based on the Westinghouse contribution to Work Package 11 (Coupled System Specification), Task 1.1.3 (Elaboration of Schematics and Case Studies) to the ARCHER project.

A nuclear heat source was described based on a Pebble Bed High Temperature Reactor (HTR) taking into account the boundary conditions from Task 1.1.1 and the Key Performance Indicators defined in Task 1.1.2 /1/.

An HTR is a universal heat source which can be applied for electricity generation as well as for process heat supply or co-generation of both. The German pebble bed HTR technology was developed and realized by the Hochtemperatur Reaktorbau GmbH (HRB) in the frame of the AVR and Thorium High Temperature Reactor (THTR-300) projects in the 1960s and 1980s, respectively. Westinghouse Electric Germany GmbH (WEG) is the legal successor of the HRB.

This type of nuclear reactor is characterised by high thermal efficiency, low waste heat, easy operation, continuous re-fuelling during power operation, low radiation dose to operating personnel, low radioactive releases to the environment, inherent safety as well as sustainable and flexible fuel cycle. Due to the high helium outlet temperature of about 700 °C and steam temperature of about 530 °C a large range of process heat applications can be covered by an HTR.

Table 1-1 shows process heat application where some can immediately be covered by the existing HTR technology.

Table 1-1: Overview of Potential Process Heat Applications for an HTR

Product / Industrial Process	Application	Required Process Temperature
De-salination of sea water		120 °C
Optimized oil production		300 – 500 °C
Processes for coal refinement:		
Coal gasification with steam	Production of Substitute Natural Gas (SNG)	700 – 750 °C
Hydro gasification	Production of Substitute Natural Gas (SNG)	~ 920 °C
Hydrogen production:		
Methane splitting	Hydrogen production	750 - 850 °C
Coal gasification with steam	Hydrogen production	800 - 900 °C
Process steam for chemical plants (examples):		
Isopropyl benzene	Basis for phenol and acetone	250 °C
Polyamide production (e. g. nylon)		288 °C
Phenyl ethane		90 - 420 °C
Ammonia synthesis		400 - 500 °C
Process steam for refineries (examples):		
Atmospheric distillation	Liquid gas, light petrol, crude oil, Diesel oil, heavy oil	350 °C
Vacuum distillation	Vacuum gas oils, bitumen	350 °C
Thermal cracking	Hydrogen, methane, ethene, propylene, petroleum coke	450 - 800 °C
Reforming	Aromatic hydro carbons	500 °C

2 HTR Technology Basis: THTR-300

2.1 Technological and Commercial Demonstrator

The design of the THTR-300 started already in 1963. In 1970 a Letter of Intent (LOI) was issued followed by the order for a turnkey erection in 1971. First criticality was reached in 1983. As a technological and commercial demonstrator the THTR-300 was equipped with extended measurement instrumentation. The instrumentation was used during the extensive commissioning program to validate the design assumptions. The commissioning program for the THTR-300 was for a FOAK plant, later series plants would be commissioned in a much shorter timeframe. The commissioning program was divided into three phases:

- 1 year of component and functional system testing
- 1 year of 0-40 % power functional testing
- 1 year of 40-100 % power functional testing

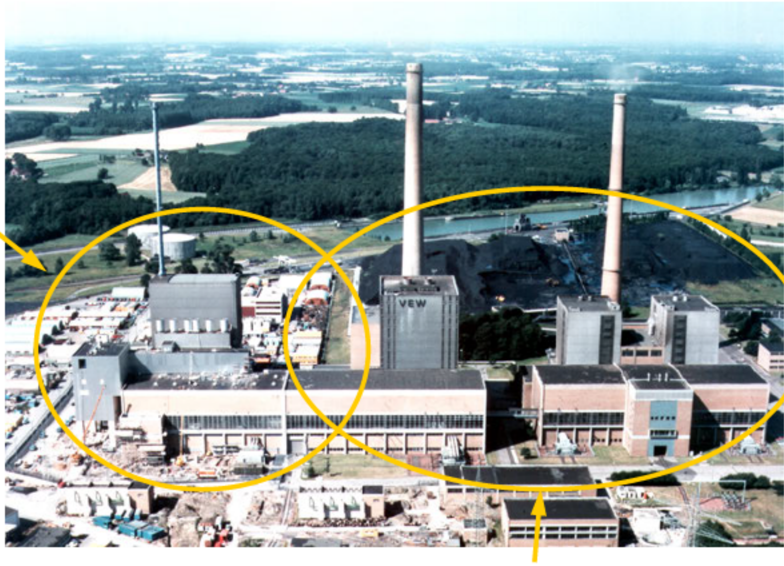


Figure 2-1: Kraftwerk Westfalen (RWE) and THTR-300.

In 1985 the plant was synchronised to the grid, full power operation started in 1986. The turn over to the utility followed in 1987. The THTR-300 was built on the same site together with a conventional coal fired plant (see Figure 2-1). The intention was to profit as much as possible from synergies by using a common infrastructure. The synergies decreased over the project duration mainly due to increased regulatory requirements especially in the area of plant security.

The THTR-300 demonstrator was defined as design basis and common technology platform for all future plants, for the whole power range and all applications. This requires a common design concept for the primary components and structures as well as a standardization of components, elements and qualified materials. Such a design requires a careful analytic and systematic approach with a considerable engineering effort and a comprehensive R&D program. The THTR-300 thus represents proven HTR state of the art technology. For future plants, technical and commercial risks were minimised. The objective of a prototype plant was to provide proof of a new technology to the customer to be safe, reliable and economic. This was successfully achieved by the THTR-300 project.

Due to the experiences gained during the planning, erection and commissioning of the THTR-300 demonstrator minor modifications are necessary for the series manufacturing. By this way, the engineering and licensing effort can be minimised. However, project and construction site management has to be done for each commercial plant separately.

Besides the engineering effort, a large R&D program was executed which was running before or parallel to the design phase, whereby the investigation starts with materials and ends with prototype tests under all operation and accident conditions and full lifetime including fabrication and construction methods. For the THTR-300 project a complementary R&D program was developed.

2.1.1 Main Design Data

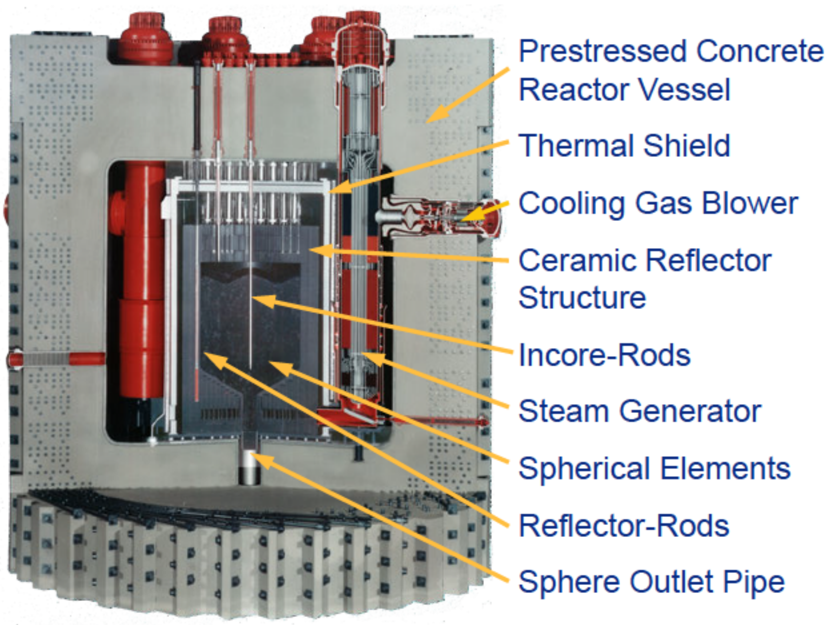


Figure 2-2: Cross section of the THTR-300.

In Table 2-1 the main Design Data of the THTR-300 is given and in Figure 2-2 a cross section of the THTR-300 is shown. It must be mentioned that the THTR-300 had restrictive contractual conditions and potential penalties for e.g. the net power output, the heat consumption of the secondary system, the ability of power control to follow load changes (40 %-100 %), frequency backup control and availability. These requirements were successfully achieved by the THTR-300.

Table 2-1: THTR-300 Main Design Data

Total Plant		
Thermal power	MW	750
Electric power	MW	296
Efficiency	%	39.5
He inlet temperature	°C	250
He outlet temperature	°C	750
Primary helium pressure	bar	39
Power density	MW/m^3	6
Steam conditions	bar / °C	177 / 530
Availability and Lifetime		
Service life	a	30
Attainable temporal availability	%	80

2.1.2 R&D – Basic Program

The research program for the THTR-300 covered among others the following aspects (which lead to the fact that on these topics no major gaps were identified):

- Materials:
  - High temperature steel, Ceramic materials, Pre-stressed Concrete, Insulation
- Properties:
  - Physical and Chemical Properties, Fracture Mechanics, Irradiation Behaviour, Corrosion, Tritium Permeation
- Helium Technology Aspects:

- Friction, Wear, Bearing, Welding, Coating, Sealing
- Pebble bed Mechanics
- Earth quake Behaviour
- Fabrication and Construction Methods

2.1.3 Operation Performance

In Figure 2-3 the power history of the THTR-300 from 1985 till 1988 is shown. 1985 is characterised by the start of the power functional testing and first electricity generation in November 1985 with a power between 80 and 110MW. In 1986 mainly power functional testing with 40 %, 60 %, 80 % and 100 % was performed. The optimisation of and adjustment of different control values required frequent power reductions and shut downs during this time period. The commissioning phase was impacted also by the reactor accident in Chernobyl where operation restrictions were imposed by the regulator.

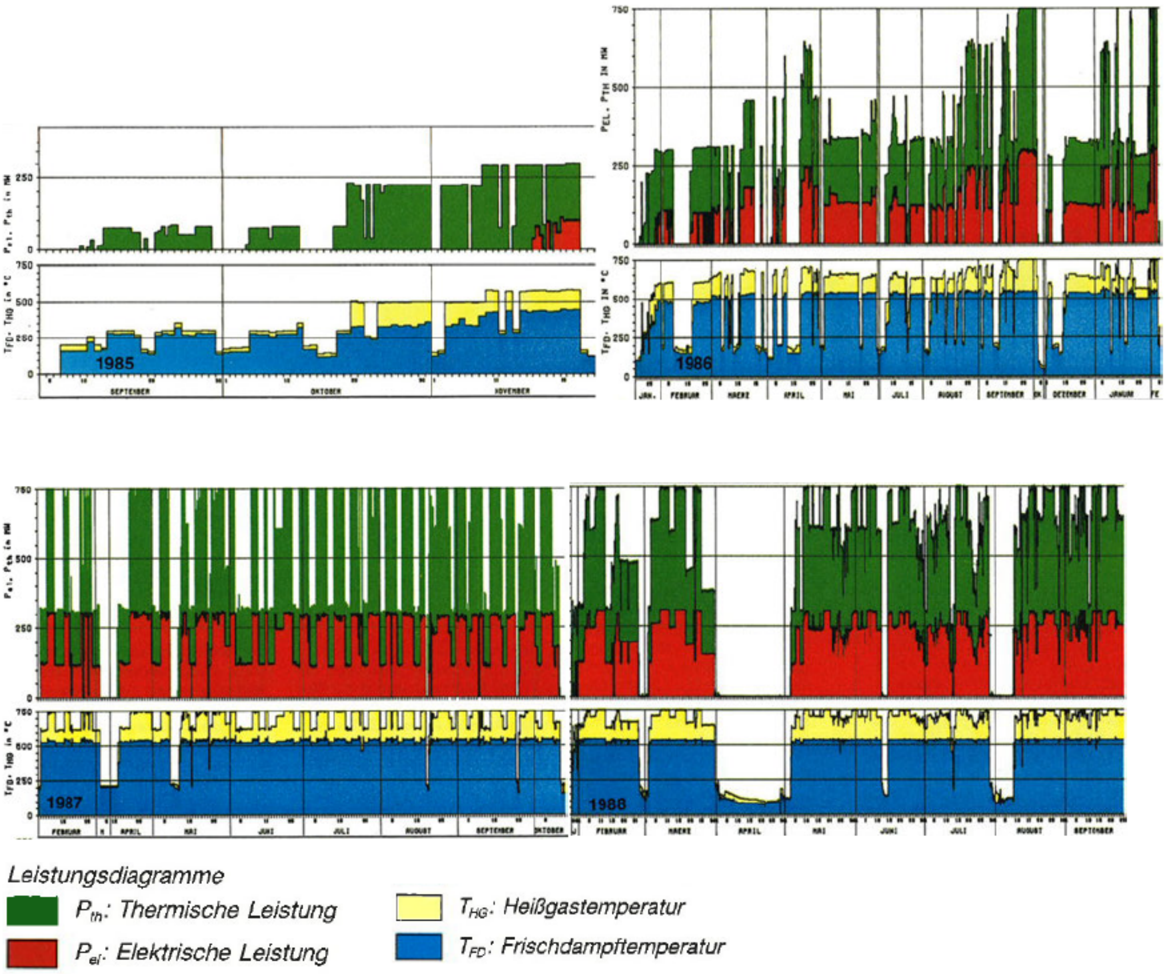


Figure 2-3: Power History of the THTR-300 from 1985 till 1988.

where: P_{th}: thermal power P_{el}: electrical power
T_{HG}: hot gas temperature T_{FD}: life steam

2.2 Gap Analysis: Technological Base Line

As shown in the preceding sections HTR technology is a mature technology which in the time of the THTR-300 prototype was ready for commercial application with minimal technological and economic risk for potential investors and customers. Any future HTR project shall be as close as possible to this technology baseline.

This baseline also applies to the HTR-100 which is described in /1/ as the technology is based on a modular approach. Nevertheless after the termination of the German HTR program items that are subject for optimisation were identified based on the THTR-300 experiences. In the following chapter the state of the art will be described and gaps if identified will be addressed.

3 State of the Art and Gap Analysis

3.1 Pre-stressed Concrete Pressure Vessel

With the THTR-300 in Germany for the first time a RPV was built as a pre-stressed concrete vessel. The RPV design is based on the experiences of decades of internationally driven developments and is considered to be a mature design. Figure 3-1 shows the THTR-300 pre-stressed concrete vessel during construction.

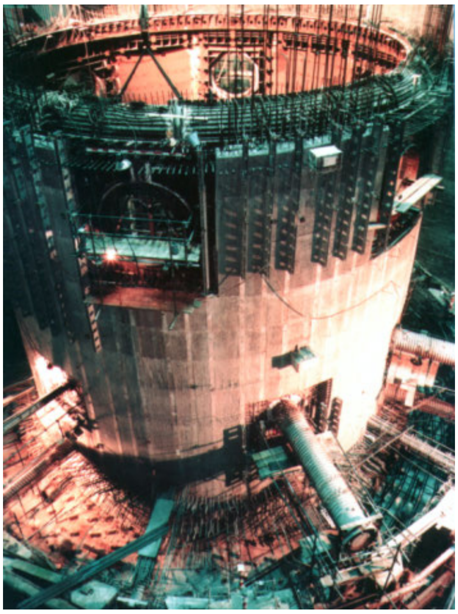


Figure 3-1: Construction of the THR-300 pre-stressed concrete vessel.

The need to build a Concrete Vessel comes from the large container dimensions of Gas-Cooled Reactors with a fully integrated primary circuit. With these dimensions, a conventional steel RPV can technically and economically not be realized. This concept, born out of necessity, ideally meets all requirements from the power plant and provides economic, safety and operational benefits.

For the pre-stressed concrete RPV a comprehensive experimental program was carried out that besides the demonstration of the feasibility was intended to optimise the vessel design. The focus of this research and development program was:

- Improvement of the material properties
- Deepening of knowledge of materials
- Commit realistic design conditions
- Creation of realistic calculation procedure

Remarkable results were achieved using concrete types containing quartz or basalt aggregates. In addition to the high strength (~ 75 N/mm^2) at operating temperatures only a relatively small decrease in strength was measured (about 25 % at 250 °C). The key parameter is the maximum temperature; the exposure time as well as the temperature cycles had only marginal impact.

With these development results, a technically optimized and safe design can be economically obtained.

3.1.1 Gaps

No gaps were identified.

3.1.2 Supply Chain Information

No supply chain information available.

3.2 Steam Generator and DHR HX

The steam generator of the THTR-300 is the basis for the design and construction of the follow up steam generator (SG) projects. Requirements regarding periodic inspections as well as experience in the manufacture and operation of the THTR-300 are considered for the follow-up SG design. Figure 3-2 shows a THTR-300 HX helical tube bundle during manufacturing.

Figure 3-2: Manufacturing of a THR-300 HX helical tube bundle.

For In-service inspection and potential plugging the tubes are brought together on tube sheets for follow up projects. The inner diameter of the SG tubes for simplification is limited to a max. of 3 different diameters.

The side spacing of the tubes was enlarged to maintain a predetermined gap between the tube bundle and the helium guide jacket inside the SG to limit the complexity of the fabrication. All heating surface tubes are designed to approximately the same length to minimize disadvantageous temperature distributions during rapid load changes. The geometry of the tube bundles was optimised to minimise as build tolerances in the heat transfer surface.

For the follow up projects of the THTR-300 for the preheating section finned tubes are foreseen to minimise the overall height of the SG.

In the THTR-300 no separate DHR HX (Decay Heat Removal System Heat Exchanger) was foreseen inside the RPV. For the HTR-500 a separate DHR HX has been developed with helix-shaped tube bundles like in the SG. The technical remarks for the SG apply in the same way for the DHR HX.

3.2.1 Gaps

The following gaps were identified:

- Graphite and dust deposition on fin tubes and resulting degradation of the heat transfer properties needs to be investigated.
- The SG tubes for helix shape tube bundles are much longer than tubes in conventional LWR. Existing LWR tube In-service Inspection equipment does not provide sufficient length for inspection. The In-service Inspection in the HTR R&D program were realised up to 90 m (2 x 45 m). Further increase range would be necessary to guarantee 100 % SG tube inspection.
- Tube sheets were not part of the THTR-300 design but are part of the design improvements for follow-up projects. The mechanical integrity and the qualification of this design shall be investigated.

3.2.2 Supply Chain Information

The following companies were suppliers for the THTR-300 SG or SG components:

- Gebr. Sulzer AG, Winterthur, Schweiz
- Balcke-Dürr, Ratingen, Germany

3.3 Core Structure Ceramics

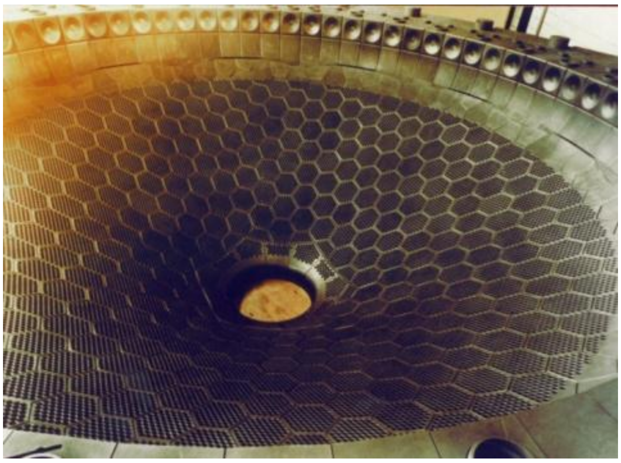


Figure 3-3: CSC: THTR-300 Bottom reflector during installation on site.

The design of the Core Structure Ceramics (CSC) is essentially based on the THTR-300 design principle. For the smaller or larger HTR with different power the design has been optimized. Figure 3-3 shows the THTR-300 CSC bottom reflector during the installation on site.

For all HTR the core structure forming graphite and/or carbon blocks are arranged to block columns and positioned by dowels and wedges. In conjunction with the metallic support and the support component, the core structure is flexible that on the one hand thermal expansions do not cause excessive compression in the structure and on the other hand are stable enough that the occurring mechanical and seismic loads are absorbed by the structure.

The design principle of the AVR core structure was different and does not fulfil today's seismic and mechanical requirements on CSC.

3.3.1 Gaps

The following gaps were identified:

- The raw material that was used during the German HTR program is not available anymore as the mine which served a source was shut down. On the basis of raw material characterisation material of equivalent quality is available. Final qualification of new graphite materials requires further irradiation and corrosion tests.
- Since the CSC due to function, design and tolerances contain gaps and on the other hand pressure gradients occur in the cooling circuit, helium by-pass

flows will be inevitable. The determination and minimisation of the following known by-pass flows can be further optimized:

- Radial gapflows through the sealing or gas channels in the side reflector.
- Gapflows between core and rod channels.
- Vertical gapflows through the side reflector.
- By-pass flows in the outer zone of the fluidised bed- due to the lower pebble bed density at the edge.

The limitation of the by-pass flow shall be obtained by design optimisation.

3.3.2 Supply Chain Information

The following companies were suppliers or manufactures for the THTR-300 CSC:

- SIGRI GmbH (Germany)
- Pechiney Sers, France

3.4 Helium Blower

Design basis for the helium blower shall be:

Export Control relevant content

[redacted]

Design Criteria:

Export Control relevant content

[redacted]

Figure 3-4 shows a THTR-300 helium blower during the installation process.

Figure 3-4: Installation of a THR-300 helium blower.

3.4.1 Gaps

The following gaps were identified:

- Magnetic bearing control system (availability analysis - continuous operation of a prototype) especially for the DHR blower.
- Alternative design: vertical shaft and oil lubrication: complete system test (blower system) for qualification. To be investigated: seal gas supply, oil cooling and oil ingress into primary circuit and oil change with reactor under pressure.

3.4.2 Supply Chain Information

The following companies were suppliers for the THTR-300 blower or its componets:

- ABB, Mannheim, Germany
- Howden, Glasgow, Scotland
- GEC Alstom, France
- Société de Méchanique Magnétique, France

3.5 Fuel Handling System

The Fuel Handling and Storage System (FHSS) of the THTR-300 is the basis for design and construction of the FHSS for follow-up projects. Figure 3-5 shows a schematic diagram of the THTR-300 fuel handling system.

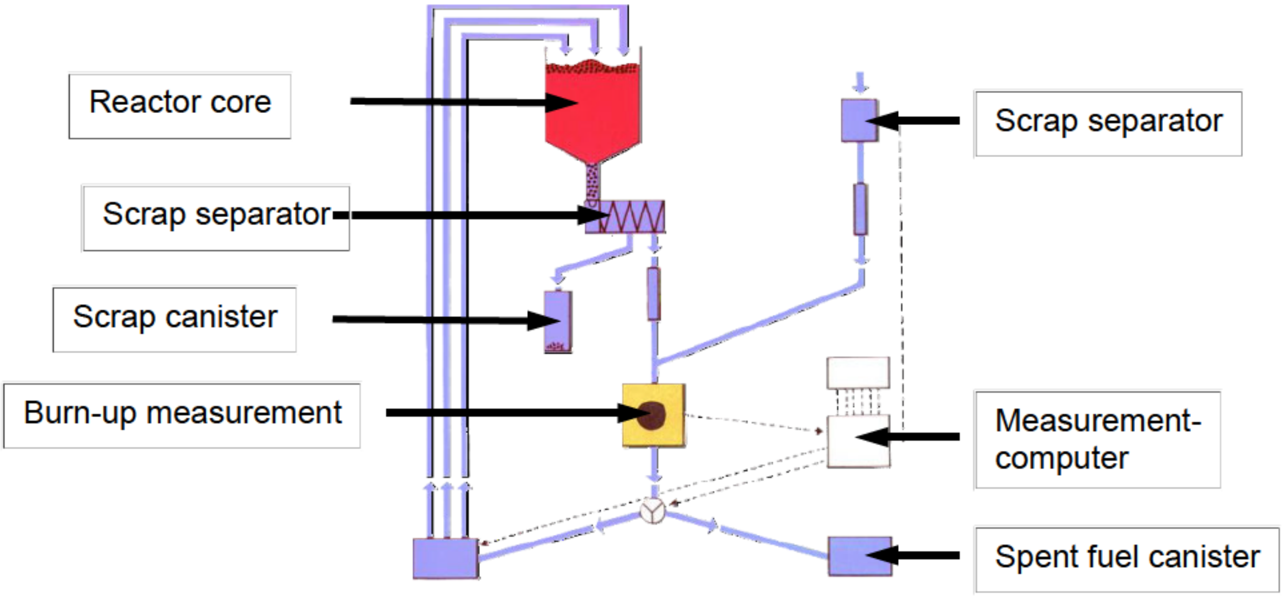
Compared with the THTR-300 FHSS following points shall be considered:

- Easier inspection and accessibility of the fuel element handling tubes (e. g. for removal of blockages etc.)

Export Control relevant content [redacted]

- Simplified Burn-up measurement system (Cs-137 method)

Based on the experience from the THTR-300 (1.3 million FE per year) a revised concept of the FHSS taking into account above mentioned improvements was al-ready developed.



<u>Figure 3-5:</u> Schematic diagram of the fuel handling system.

3.5.1 Gaps

The following gaps were identified:

Export Control relevant content

[redacted]

- Complete core unload and reload
- Burn-up measurement using Cs-137 method

3.5.2 Supply Chain Information

The following companies were suppliers for the THTR-300 FHSS or its components:

- Leybold-Herqeus, Hanau, Germany
- Krupp, Essen, Germany
- Thyssen-Henschel, Kassel, Germany
- Mannesmann Anlagenbau, Düsseldorf, Germany

3.6 Reactivity Control System (RCS)

The RCS for HTR depend on the power of the reactor design and is based on the THTR-300 RCSs. The THTR-300 was equipped with in-core and reflector rods for reactivity control. The in-core rods (Figure 3-6 shows the in-core control rods during the core loading of the THTR-300) were inserted from the top directly into the pebble bed, the reflector rods (Figure 3-7 shows schematically the main components of a HTR reflector rod) were inserted through vertical channels inside the CSC side-reflector. In literature often an increased damage rate due to the in-core rods is described.

Figure 3-6: In-core control rods during core loading of the THTR-300.

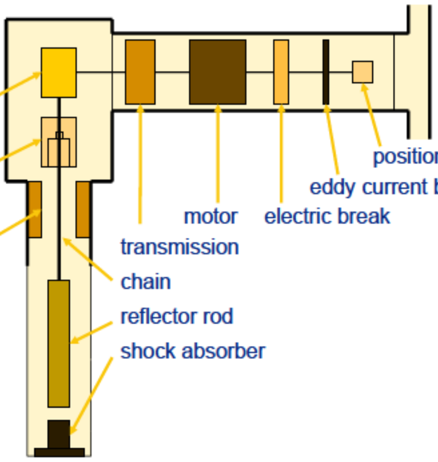


Figure 3-7: Main components of a HTR reflector rod.

It must be clarified that the damage rate of the fuel elements was due to the insertion of the in-core rod into an artificially compressed reactor core. Under normal operation and according to the specification the reactor core due to the FE circulation is not compressed. The compression of the reactor core was a consequence of intensive testing and commissioning of the in-core control rods. This has led to a high compression of the pebble bed and subsequently to a higher insertion forces for the in-core control rods and thus to a higher FE damage rate. During the later phase of normal operation this damage rate decreased to the specified design value. Nevertheless it was shown that even under the unfavourable conditions of a compressed pebble bed the in-core rods can still be inserted in a reliable manner.

In an HTR core with a diameter to about 3.0 m and an average power density of about 3 MW/m^3 the RCS will be arranged in the side reflector. In reactors with larger core diameters and/or higher power density (6 MW/m^3 in the THTR-300) in-core as well as reflector rod will be necessary to reach cold shut down (THTR-300 - principle).

3.6.1 Gaps

The following gaps were identified:

- In the HTR-500 the in-core rods due to the OTTO fuel loading philosophy besides the shutdown function have to adjust the power distribution in the upper part of the reactor core. This requires modification to the control rod drive mechanism.
- In the HTR-Modul the reflector control rods due to the RPV design will undergo a higher dose rate. This has impact on the reliability of the control rod drive mechanisms. Testing and qualification under these conditions are to be done.
- During start-up of the THTR-300 due to extensive testing the pebble bed was compacted which led to
    - increased scrap from FE. Improved testing procedures taking into account improved flow models for the pebble bed shall be put in place,
    - an early criticality when loading the core resulting in early insertion of the in-core rods. FE flow in the outer zone was reduced due to inserted in-core rods. The pebble flow, resulting compaction of the bed and impact on neutronic and thermo-hydraulic behaviour shall be further investigated and

  - higher insertion forces for the in-core rods. Additional instrumentation is recommended here to better control the rod insertion.

- NH_3 reduces friction between the pebble bed and the in-core control rods. The THTR-300 for this purpose had a NH_3 injection. The partial pressure of NH_3 increased slower than predicted which might be due to adsorption of NH_3 to the graphite. The following gaps need to be clarified:
  - Re-evaluation of the necessity of a NH_3 injection system.
  - Analysis of adsorption behaviour of NH_3 to graphite.
  - Interaction of NH_3 and some few primary circuit sealing materials were observed. Systematic compatibility check of used primary circuit materials with NH_3.

3.6.2 Supply Chain Information

The following companies were suppliers for the THTR-300 RCS and its components:

- ABB-KW, Germany
- NTG
- GAAA/CIT-Alcatel
- Fa. Berger / Fa. Kachelmann, Germany

3.7 Helium Purification System

The THTR-300 was like the AVR equipped with a low-temperature purification equipment (TTA for Tieftemperatur-Anlage) in the process stream (after deposition of H_2O and CO_2). In the TTA at temperatures of about 80 K

- Krypton and xenon (radioactive fission products)
- Argon (radioactive Ar-41 as a result of activation)
- Methane (contains radioactive tritium)
- Nitrogen (own radioactivity irrelevant, but is source of C-14 by neutron capture)

are adsorbed on activated charcoal. Argon and nitrogen for example originate from residual air after maintenance work on an open primary circuit or adjacent systems and components. The adsorpates must be eliminated at regular intervals (Regeneration) and after intermediate storage in an exhaust gas storage container be released through the chimney. Figure 3-8 shows a schematic diagram of the THTR-300 helium purification system.

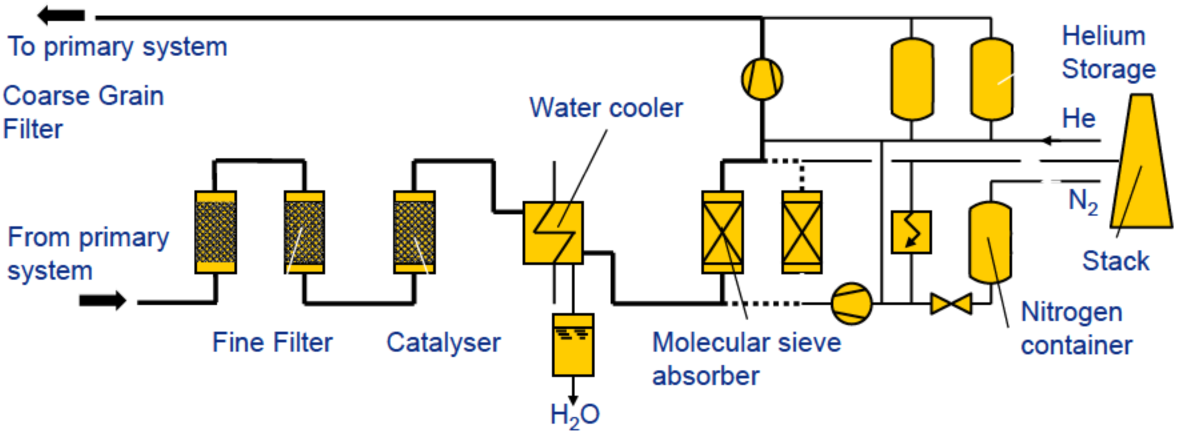


Figure 3-8: Schematic diagram of the helium purification system.

In the gas circuits of the THTR-300 low temperature applications like the molecular sieve (located in the process before the low temperature purification equipment) are part of the design. The molecular sieve is designed to retain H_2O and CO_2. The main component in this context is the "Ausgefriergegenströmer" in which the regenerants H_2O and CO_2 of the molecular sieve at temperatures of about 80 K are cold trapped. H_2O contains radioactive tritium, CO_2 and the radionuclide C-14. In a next process step fractionated thawing takes place, where CO_2 is checked at about 195 K in a gas storage, while H_2O as far as possible is discharged in liquid form, into a water container for long-term on-site storage of tritium containing desorbate (as well as condensate from the helium purification system).

The low temperature purification equipment was topic of many discussions. The operation experience of the THTR-300 has shown that with the realised technology the tritium release requirements for exhaust air can hardly be met. The primary cause of this is the underestimation of the methane contamination in the primary circuit in the design of theTHTR-300. Despite other intentions the low temperature purification equipment might be necessary.

3.7.1 Gaps

The following gaps were identified:

- Design improvements of the helium purification system under consideration of today's regulatory requirements

3.7.2 Supply Chain Information

No supply chain information available.

3.8 Thermo-hydraulic and Neutronic Core Design

Significant experience of the neutron-physical and thermo-hydraulic calculation of the THTR-300 core was gained and validated against measurements gained during commissioning and operation of the THTR-300. A large package of qualified and validated programs was thus available at that time.

Since that time the modelling capabilities changed drastically. Already during the PBMR project many of the old programs were used and updated and further developed.

3.8.1 Gaps

The following gaps were identified:

- Collection analysis of the old programs (see also ARCHER and NC2I-R).
- Investigation of later developments by PBMR, Research Centre Jülich and other research institutions.
- Investigation of state of the art modelling tools for core and thermo-hydraulic design under the aspect of applicability for the HTR.
- Development of an integral HTR modelling package.
- Validation through benchmarks (code to code and experimental, commissioning and operational data).

3.9 Graphite Dust

THTR-300 operation experience in the proximity of humidity sensors high local dose rates was measured due to radioactive graphite dust in the components. This had consequences for the accessibility and maintainability of the components. 40 % of the THTR-300 collective dose rates originated from the radioactive hotspots at measurement points. During maintenance work release of radioactive graphite contamination from the gas analysis, humidity sensor change and faulty operation of the FHSS caused problems and required countermeasures. First dismantling of the conveying gas blower of the FHSS showed that the contamination of equipment by radioactive Graphite dust caused difficulties when an external repair is required.

Contamination in the humidity sensors resulted in an elevated radiation background which influenced also monitoring systems of radioactive aerosols and radioactive noble gases. Impact on I&C equipment lifetime needed to be re-evaluated. Incorrect operation of valves in the gas circuits led to contamination carryover (e.g. behind the dust filter system of the helium purification system or into the clean gas storage).

Already during THTR-300 operation countermeasures were taken in order to reduce aerosol release during inspection, repair and maintenance as well as reduce graphite dust carry over into the FHSS. Installation of led shielding and additional aerosol filters was carried out.

3.9.1 Gaps

The following gaps were identified:

- Graphite dust generation was significant in the THTR-300
- Improvements of FE performance and / or efficient filter / flushing concepts are to be developed
- Development of a separation concept to minimise contamination carry over
- Development and application of a release model for scraped FE
- Development of simulation models for dust activation, transport and deposition in the primary circuit including remobilisation and release in case of a depressurisation event in the primary circuit

3.10 Regulatory Framework

During the design and construction of the THTR-300 regulatory requirements were defined as well as industrial standards identified that are applicable for the design, manufacturing, construction commissioning and operation of HTRs. Since the shutdown of the THTR-300 these activities were stopped in Europe. In the frame-work of the PBMR development in South Africa a regulatory framework was re-established.

3.10.1 Gaps

The following gaps were identified:

- Collection and analysis of the regulatory requirements and industrial standards used during the THTR-300 project and PBMR projects and defining state of the art European HTR requirements under consideration of today LWR regulatory requirements.

3.11 Commercial Impact and Gaps

Chapter 2 ‘HTR Technology Basis: THTR-300’ points out the historical HTR experience which shall be the technological baseline for future HTR developments. In the present chapter 3 ‘State of the Art and Gap Analysis’ an overview of the state of the art for the HTR technology is given and resulting gaps are identified.

The technology described and analysed here due to its modular design can be transferred to many different HTR concepts covering a whole portfolio of HTRs.

Figure 3-9 shows an example on how the existing technology baseline can be applied to a whole portfolio of HTRs.

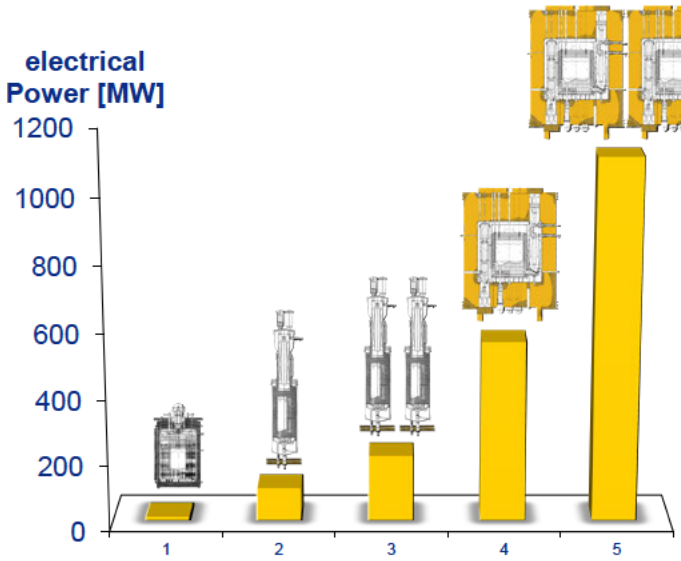


Figure 3-9: Example of HTR portfolio.

A HTR like any other reactor consists of a nuclear island, energy sink (e.g. turbine with generator or process heat consumer) and auxiliary systems. A control room, cooling tower, I&C and electrical distribution system, cooling loops for chiller machines etc., residual heat removal system (for investment protection) etc. are necessary like for any LWR. As a consequence, to be commercially competitive, also for the HTR, the investment divided by the power output will give the specific investment cost. As a consequence any HTR design, small or large, shall be optimised to the highest in the design possible power.

The THTR-300 is a concept with existing operation experience. Any design deviating from the proven demonstrator will result in an increase in risk.

3.11.1 Gaps

The following gaps were identified:

- Unclear end-user specification (e.g. power consumption).
- Commercial competitiveness not considered seriously in the early concept phase.

4 References

/1/ Work Package 1.1, Task 1.1.3: Westinghouse Contribution - Description of Nuclear Heat Source, GBRA 154 219, Mannheim 2013

/2/ HRB: HTR Know-How Sicherung, Mannheim 1995