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Appendix

Know-how on the Pebble Bed HTR owned by FZJ being of Relevance for the PBMR-Project of ESKOM

Contributions of the Research Centre Jülich to the PBMR-Project of ESKOM

PBMR = Pebble Bed Modular Reactor
ESKOM = a Utility of Republic of South Africa

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D-16

Know-how on the Pebble Bed HTR owned by the FZJ

Introduction

The Forschungszentrum Jülich GmbH, FZJ, (Research Center Jülich) is in its Research Programme for „Safety Research and Reactor Technology" performing fundamental research work on safety aspects of innovative future reactor systems. The objective of the work is to contribute to solutions for the realization of a catastrophe-free nuclear energy technology. The Amended Atomic Energy Act of Germany requires that, even for events which can be practically excluded, the consequences remain confined to the plant so that, for example, evacuation is not necessary. Advanced reactor concepts therefore should satisfy three basic requirements for all cases of accidents:

- Self-acting limitation of nuclear power and fuel element temperatures,
- self-acting removal of afterheat from the reactor system, and
- self-acting maintenance of fission product barriers, mainly in the fuel element.

The background for this research work is that the Research Centre, Jülich, has been the research leader in the German Development Programme of the Pebble Bed High Temperature Reactor, HTR, for more than three decades. This Research and Development Work on the Pebble Bed HTR was done in co-operation with various German industrial companies. It is in this area of research and development that the Research Centre Jülich owns know-how in a number of fields of the technology of the HTR.

The R & D work was performed in the following institutes of the Research Centre Jülich:

Institute for Reactor Development,

Institute for Reactor Components,

Institute for Reactor Materials, including Hot Cells, and

Institute for Nuclear Chemical Technology, as well as

Institute for Nuclear Safety Research

with assistance of Central Institutes of Applied Mathematics, Electronics and Technology. Over the many years the R & D work was concentrated on the following projects:

Project: "High Temperature Reactor Fuel Cycle" (HTR- Brennstoffkreislauf, HBK), with the Fuel Pebble Mass Test Programme for THTR fuel (BISO fuel) and TRISO fuel at AVR and with the „JUPITER" (= Jülich Pilot Plant for the Thorium Extraction Reprocessing) and its operation demonstration at Research Centre Jülich.

Project: "AVR" (AVR = Arbeitsgemeinschaft Versuchsreaktor, Joint Working Group Experimental Reactor) financed via the Research Centre Jülich with the Mass Test of fuel spheres and the Experimental Program at AVR on a

large number of topics, e.g. self-acting safety characteristics and operational behaviour of fuel and of the plant.

Project: "THTR-300" (THTR-300 = Thorium High Temperature Reactor 300 Mega Watt$_e$) with contributions to the technology and the licensing, in particular via fuel qualification by post irradiation examination work.

Project: "High Temperature Helium Turbine, HHT", with High Temperature Experimental Turbine Pilot Plant, HHV, 50 MWe input, and its operation demonstration.

Project: "Prototype Plant Nuclear Process Heat, PNP" (= Prototypanlage Nukleare Prozeßwärme) including the processes Hydrogen Gasification of Lignite and Steam Gasification of Hard Coal for the production of Substitute Natural Gas and Synthesis Gas, including HTR, design work for high temperature heat production with temperatures up to 1000 °C and the High Temperature Metallic Materials Programme.

Project: "Nuclear Long Distance Energy" for the medium distance transportation of high temperature heat from the HTR via the chemically reacting system $CH_4 + H_20 = 3H_2 + C0$, including the 10 MW scale Pilot Plant EVA/ADAM II:

Project: "High Temperature Reactor MODULE", with fundamental work to the qualification of TRISO coated particle fuel and to the licensing of the plant.

Project: "High Temperature Reactor Plants (HTR-Anlagen, HTA)", with R & D contributions reactor components, primary loop components, safety, including fission product behaviour, materials development, fuel elements, graphite, and final disposal.

Project: "AVR II" for the demonstration of HTR process heat application at temperatures of up to 950 °C with the Methane-Steam-Reforming process with a small HTR-Module (not realized).

Project: "AVR-Reconstruction" for the demonstration of HTR process heat application at temperature of up to 950 °C with the Methan-Steam-Reforming process using 50 % of the hot helium (950 °C) of the operating AVR beside ist electricity production (not realized).

Project: "Pre-Stressed Cast Steel Vessel Experimental Plant" 2.5 m outer diameter, 3 m outer height, 60 bar helium pressure for the demonstration of the pre-stressed vessel technology at Institute of Safety Research and Reactor Technology (former Institute for Reactor Development) of the Research Centre Jülich.

The above summarizes the R & D work on the Pebble Bed HTR done in the Research Centre Jülich in a broad overview. Therefore this summary is not complete and special topics may be addressed later and than be added.

The co-operation between the Research Centre Jülich GmbH and the industrial partners was ensured via Working Circles with representatives from participating parties.

List on Topics of Know-how on Pebble Bed HTR Technology owned by the Research Centre Jülich

1) Installations

The Research Centre Jülich operates a material test reactor, hot cells, intermediate spent fuel storage facilities, and low active waste storage facilities.

2) Safety and Licensing

The Research Centre owns know-how in the field of safety of nuclear plants due to the participation of heads of institutes in the German Reactor Safety Commission and due to review work, dialogue and work for license authorities and other governmental bodies as well as the public in general via parties and other similar institutions and by public information courses. Special know-how has been developed by contributions to the licensing procedures of the THTR-300, of the HTR-Modul and other HTR projects. Special experiences have been gained in the project "AVR Reconstruction for Process Heat Applications Demonstration" with heat in the form of hot helium of 950 °C with the result of a positive recommendation for licensing, given by an Advisory Council, consisting of member of the Reactor Safety Commission, established by the Federal Minister of the Interior of the Federal Republic of Germany.

3) HTR Plant Concept Realization

The Research Centre has developed and owns know-how on the development of concepts for the HTR under the headlines of electricity production via steam cycle, breeding, using the thorium fuel cycle, high temperature heat production for electricity production using a direct gas turbine cycle and for process heat applications. A good proof for that was the successful increasement of the mean outlet temperature of the AVR to 950 °C in 1974 and the successful demonstration of the high efficient product retention capability of TRISO fuel for gas turbine and process heat applications.

4) HTR fuel development and Operational Behaviour

The Research Centre Jülich was involved in the development of pebble type fuel elements for the HTR concept, together with German Industrial Companies, and owns know-how in particular in the "hot qualification" by post-irradiation examination experimental research and development work, as well as in the processes of kernel fabrication, and coating of coated particles. The objective of the respective research and development work was to increase the retention capability of the coated particles and to be able to operate the fuel fabrication under remote conditions. The base for the high quality of the fuel pebbles were the fuel mass test program on BISO fuel for THTR and on TRISO fuel for advanced applications in the AVR. Additional know-how was collected by the R & D work for and the operation of the JUPITER plant (= Jülich Pilot Plant for the Thorium extraction reprocessing), intended for reprocessing of THTR fuel, but not long-term applied (political reason).

5) AVR operational and experimental results

The Research Centre owns the results and the respective know-how of the 21 years of operation and of the experimental programme performed all that time. Of particular importance is the know-how from the 21 experimental programs performed in the last 3 years of operation to finalize the experiments at AVR with international participation. The topics in that program were:

- Stationary and dynamical reactor physics,
- hot temperature coefficient of the reactivity,
- production of plutonium in selected fuel pebbles,
- loss of coolant accident,
- release of fission products by depressurization (not finished to end of 1988),
- neutron and gamma fields,
- maximum outlet temperature of core,
- combined thermoelement and noise thermometer,
- instruments back fitting, hot gas sampling VAMPYR I, and
- plate-out-loop VAMPYR II; dust production and remobilization,
- selective filtering for tritium,
- tritium measurements,
- gas cleaning by gettering,
- input specific impurities, as well as
- mass tests of fuel elements for THTR for highly enriched TRISO coated $(ThU)O_2$-particle fuel pebbles, and for low enriched TRISO coated UO_2-particle fuel pebbles.

6) Reactor Ceramic Materials

The Research Centre Jülich has performed Research and Development Work in the field of ceramic high temperature materials for the production of high temperature heat in the form of hot helium with temperatures up to 1 000 °C as there is the oxide fuel with uranium as well as thorium, the coatings of the coated particles, that is the pyrolytic carbon layers, and the silicon carbide layer, as well as buffle layers. In addition there is the core structural high temperature ceramic material, namely graphite in the various qualities. The base for the developed know-how on that materials was the fact that all post-irradiation examination and hot qualification research and development work was done in the Research Centre Jülich.

7) Reactor High Temperature Metallic Materials

The Research Centre Jülich has performed Research and Development Work on high temperature metallic materials for the application of high temperature heat in the form of high temperature helium with temperatures up to 950 °C. Topics were to meet conditions of HTR-helium, and for a number of metallic materials meeting at the same time additionally process

gas conditions on the other side of a wall structure. Topics were: helium corrosion, process gas corrosion, reduction of permeation of hydrogen and tritium, a large number of experimental proof tests on structural characteristics, as e.g. low cycle fatigue. Examples of materials are:

X10NiCrAlTi3220 (Alloy 800),

NiCr22Mo (Nimonic86),

NiCr22Fe18Mo (Hastelloy X), and

NiCr22Co12Mo (Inconel 617), as well as

AC66 for the steam coal gasification process helium heat exchanger.

8) Reactor Components

The Research Centre Jülich owns know-how from R & D work on reactor components. Examples are:

Pebble bed configuration: Pebble flow mechanics, hydrogenamics, natural convection of gases in pebble beds,

Small absorber sphere systems: Flow behaviour, also inside the pebble bed, with respect to different limiters.

Heat transfer conditions: As for the pebble bed, and also for different heat exchangers, produced by the operation of a close to 1:1 scale gas loop inclusive circulators,

High temperature insulation material: Fibres and ceramics, including natural convection, depressurisation effects on insulations with demonstrated limiting pressure transients, e.g. 5 bar /s for PNP and 10 bar/s for HHT,

Pebble bed and fuel sphere accident simulation: Water ingress and air ingress causing corrosion

Concrete vessel heat-up accident simulation: Behaviour of the concrete and the included metallic material as well as the insulation, including cooling water refill procedures,

and so on.

9) Proof Test Experiments

The Research Centre has performed and is still performing proof test experiments in close to scale 1:1 facilities, to examine the feasibility of a future catastrophe-free nuclear energy technology, to demonstrate fundamental self-acting safety characteristics of the HTR concept, to use the experimental results for the validation of computer code systems and to facilitate future licensing procedures with the experimental proof test results. The proof test facilities are :

SARA : Self- Acting Removal of Afterheat,
NACOC : Natural Convection in the Core with Corrosion
SEAD : Self-Acting Separation of Droplets of Water, and
GRANIC : Granulate Injection into Core.

10) Nuclear Waste Management

The Research Centre has performed and is still performing Research Work on Nuclear Waste Management. The work focuses on

characterizing radioactive wastes,

treatment and storage of radioactive substances, scale 1:1 experiments,

radiochemical studies on waste partitioning for isotope transmutation, and

development of methods for quality assurance of the wastes to be disposed.

In addition to that know-how has been gained by the licensing of an experimental final disposal of HTR spent fuel spheres in a saltmine.