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THE CRITICAL HTR-TEST FACILITY KAHTER

A PROGRAM FOR VERIFICATION OF THEORETICAL MODELS AND MINIMIZATION OF LAYOUT AND SAFETY MARGINS

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1. INTRODUCTION

Since more than a decade the gas cooled High Temperature Pebble Bed Reactor is being developed in the Federal Republic of Germany. The Federal Government sponsors several large-power plant projects such as the AVR, the THTR, the PNP and the HHT[1].

In parallel to the planning and construction of these reactors an extensive research and development program is performed with the pronounced participation of the KFA Jülich. In the frame of this program the critical facility KAHTER[2] has been established at the KFA's 'Institut für Reaktorentwicklung' (IRE) in order to test, compare and -if necessary- to correct the theoretical models, codes and data bases which are used for nuclear layout and safety analyses concerning the HTR pebble bed reactor.

KAHTER was first critical in summer 1973 and since then a detailed experimental and theoretical nuclear program takes place, especially taking into account questions of control rod efficiency, macroscopic and microscopic neutron flux distribution, graphite

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[1] AVR = Arbeitsgemeinschaft Versuchsreaktor; THTR = Thorium-Hochtemperatur-Reaktor, PNP = Prototypreaktor Nukleare Prozeßwärme, HHT = Hochtemperaturreaktor mit Helium-Turbine

[2] KAHTER = Kritische Anlage Hochtemperatur-Reaktor /1/

damage by fast neutrons and effects of diverse neutron poisons.

In all this, emphasis is laid on exact comparison between theory and experiment, to minimize layout error margins and to verify experimentally the prediction of the HTR's inherent safety aspects. The following gives a survey over the activities at KAHTER including results concerning the THTR-loading phase and the effects of axial inhomogeneous fuel loading simulating the principles of the OTTO-loading scheme /2/.

2. DESCRIPTION OF THE FACILITY

The core of the critical facility KAHTER (Fig. 1) has a diameter of 216 cm and a height of 276 cm maximum. It is reflected on the bottom by 24 cm -or 50 cm- thick graphite and circumferentially by 40 cm thick graphite. A top reflector of graphite with a height of 10 up to 50 cm may be installed. This core can be filled with up to 50 000 fuel elements of the pebble type (6 cm Ø). By mixing these fuel elements with graphite pebbles it is possible to vary the moderation ratio N_C/N_{HM} from 340 up to 1350. Nine control rods (eight in the radial reflector and one central rod) control or shut down the reactor system. In the core configurations with OTTO-loading (Fig. 2) eight experimental rods are available additionally and can be inserted in the top reflector and the upper cavity. As neutron absorbing material in all rods B_4C was chosen.

To measure reaction rates in the core small tubes of Al (Ø 1.6 cm) are positioned in radial and axial directions. For the same purpose boreholes exist in the reflectors.

3. EXPERIMENTAL PROGRAM

In the first part of the experimental program homogeneous core configurations were studied and compared with theoretical calculations. In these configurations critical masses were determined; reaction rates and power distributions were measured. Reactivity worth of the central rod and the reflector rods was investigated in several configurations using static and kinetic methods.
A second part was dedicated to special questions concerning loading and control of pebble bed power plants. In this phase the effects of statistically distributed absorber pebbles as used in the THTR initial core containing Boron and Hafnium were studied. Further unsymmetric power distributions were detected from outside the core.
The program's third part which is now under investigation deals with multizone-OTTO-cores. The aim here is to study the axial unsymmetric flux and power profile, the reactivity and flux flattening effect of the upper cavity, and the control rod efficiency in this cavity and the top reflector. Additionally investigations will be made in respect to the water ingress in the core and to the reactivity worth of small pebbles as second shut-down system.

4. THEORETICAL MODELS

In theoretical interpretation emphasis is laid on the verification of standard methods used in layout and safety analysis. Few group cross sections are generated in spectral calculations with the GAM and THERMOS /3/ or the MUPO /4/ codes. The nuclear data are based on the ENDF/B-II library and on previous KFA work. Resonance absorbers are normally treated using the ZUT-DGL /5/ code. Hafnium resonance cross section are generated with GAROL /6/. Spectral data for control rods and other strong absorbing materials are generated with the SN-code ANISN /7/ applying an improved method /8/ of equivalent cross-sections. Neutron streaming in experimental channels and especially between the fuel pebbles is taken into account by a modified Behrens theory /9/ which was developed at KFA during the KAHTER-program. Integral reactor data and flux distributions are then obtained from criticality calculations using diffusion codes, namely EXTERMINATOR-II-Jül /10/ in 2-D and CITATION /11/ in 2-D or 3-D geometry.

To check the validity of the diffusion models for special situations comparison with Monte Carlo /12/ methods is done.

The interpretation of dynamic experimental methods especially in evaluating rod efficiencies is somewhat more complex.

A detailed analysis led to a theoretical method correcting the space dependent detector signal of the different experimental methods to get uniform detector-material and -position independent reactivity values. Whereas for the inverskinetic method this tool is achieved using extensively exact perturbation theory /9/, the Simmons-King-Method and the diverse area methods can be improved by adjusting the experimental results solving a time integrated external source problem in diffusion approximation /13/.

A special method was developed to calculate the upper cavity which is incorporated in the third part of the KAHTER program /14/. Comparing the exact transport result for the neutron field inside the cavity with solutions of the diffusion equation in a fictitous material, cross-sections and diffusion constants can be obtained for that region even if control rods are inserted.

Using the described models made it possible to predict, recalculate and interprete the results of the experimental work.

5. RESULTS

Experimental and theoretical results of phase 1 critical experiments, i.e. 3 cores of different moderation ratio without top reflector are given in table I. The results for the B-cores with inserted central control rod are given in table II. All these core loadings are calculated with an error margin of far less than 1% which is inside the today tolerated limits. Another good test of calculation methods is the comparison of calculated and measured reaction rates. Figure 3 shows radial reaction rates of Dysprosium in Core IB, i.e. with central rod in core position. The agreement between experiment and calculation of Dysprosium reaction rates is good even near the central absorber rod and in the reflector region.

In phase 2 the reference core with THTR fuel elements as well as two boron poisoned cores containing 435 and 955 statistically distributed boron elements have been calculated as good as the cores of phase I with AVR fuel element loading (table III). To see whether hafnium poisoned cores like the initial THTR core can be calculated with the same accuracy three hafnium experiments were performed. To compensate geometrical effects the boron and hafnium absorption was equalized in equivalent cases by adjusting the poison content. As table III further shows the calculation for hafnium poisoned cores is of same good agreement with experiments as for the previous cores shown in tables I and II.

The question of reproducing a k_{eff} value by randomly distributed elements will be studied in near future by experiments.

For High Temperature Gascooled Reactors it is essential to know the fast neutron dose of the graphite reflectors. Therefore, in the ciritical facility KAHTER benchmark experiments for fast neutron fluxes and doses were performed including an accurate prediction and evaluation of the fast neutron fluxes. The inelastic neutron scattering reaction of ^{103}Rhodium has a similar threshold as the graphite damage. Therefore Rhodium can be used to test the accuracy of graphite damage rate. Measurements (figure 4) show a good agreement with the calculated fluxes in the core region, but in the reflector region the measured fast flux is overestimated by calculation. So the radiation damage of HTGR reflectors seems to be less high than predicted.

As in-core-instrumentations are not suitable, spatial flux irregularities in a pebble bed reactor have to be detected from the side reflector. A computational check was done for some measured flux profiles. Due to the experimental investigations theoretical models for flux mapping by a set of out-of-core detectors are developed and are checked for detection of Xenon induced flux oscillations.

Phase 3, i.e. cases with OTTO flux distribution which is axially asymmetric as shown in figure 5 is just started. As a reference core a first core without upper cavity between fuel elements and top reflector has been investigated. First results show that the accuracy of the theoretical model will be in the same order for this strongly heterogeneous core as for the homogeneous loading.

6. CONCLUSIONS AND SUMMARY

It has been shown how a critical facility can be used to verify and to adjust theoretical models describing the nuclear behaviour of HTR pebble bed reactors. Besides straight forward methods such as evaluating critical masses, flux mappings and reaction rate measurements, more sophisticated experimental and theoretical methods have been developed to get exact information and interpretation of control rod efficiency, power determination and fast neutron damage. A special model was developed to simulate large cavities in diffusion type calculations.

It has been found that in general there is quite good agreement between theoretical prediction and experimental results. There however some dynamic situations where comparisons are not possible in a direct way, because of different definitions of system parameters in both, theory and experiment. In such cases discrepancies can be diminished by trying to simulate the dynamic experimental methods in static calculations.

Future work at KAHTER will look detailed to the stabilizing effect of the OTTO-profile on large scale flux irregularities and to the nuclear data of U-233. Questions dealing with the medium enriched uranium fuel cycle according to the aspects of proliferation risk may be incorporated too.

It should be kept in mind, that there are some questions not cleared, because of the impossibility of heating up the KAHTER facility. Information of temperature effects to the doppler resonance broadening and to the graphite scattering matrix therefore have to and can be taken from other experiments or from the now more than 10 years experience with the AVR-power plant.

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Table I: Experimental and theoretical k_{eff} values of KAHTER phase 1 facilities

Core	FE : ME	NUMB.OF FUEL ELEM.	k_{eff} THEORY	Δ% CRIT.MASS
IA	3 : 1	16 414	1.0015	-0.4
IIA	1 : 1	12 892	1.0010	-0.2
IIIA	1 : 3	10 329	1.0004	-0.2

Table II: Critical loading of KAHTER-B Cores. A Comparison to KAHTER-A Cores

Core	NUMB.OF FUEL ELEM.	k_{eff} THEORY	Δ% CRIT.MASS	Δ%CRIT. MASS (B.A)
IB	17 455	1.0008	-0.2	0.2
IIB	13 950	0.9997	+0.06	0.3

Table III: k_{eff} values of KAHTER phase 2 facilities

CORE	FE : ME : AE	NUMB.OF FUEL ELEM.	$\frac{C-E}{E}$ %
REFERENCE	10 : 7 : 0	11 500	0,49
B1	36 : 24 : 1	15 660	0,21
B2	20 : 13 : 1	19 100	-0.13
H1	36 : 24 : 1	14 985	0.51
H2	27 : 18 : 1	16 578	0,48
H3	20 : 13 : 1	18 540	0,13

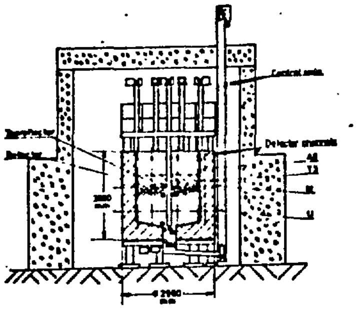

Fig. 1: The critical facility KAHTER

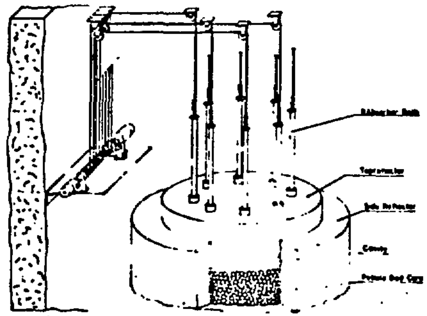

Fig. 2: Configuration with OTTO-loading
Upper part of the core

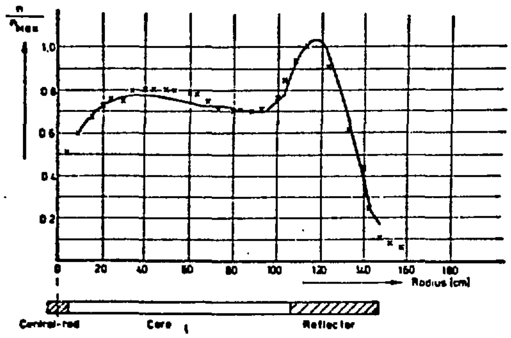

Fig. 3: Dysprosium-reaction rate in radial direction

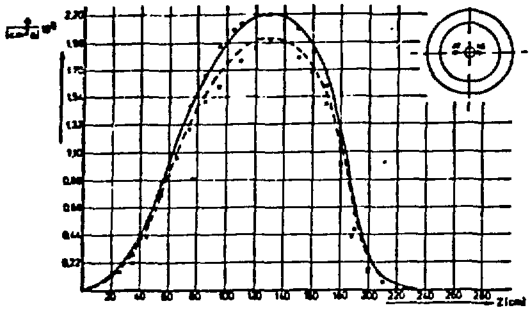

Fig. 4: Fast flux (E>0.1 MeV) in axial channels A6 (r=23,5 cm)

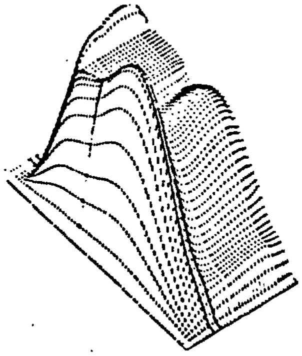

Fig. 5: OTTO flux distribution