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FAST NEUTRON DOSE IN HIGH-TEMPERATURE GAS-COOLED REACTORS
- COMPARISON OF MEASURED AND CALCULATED FAST FLUXES -

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An der Kritischen Anlage KAHTER wurden Benchmark-Experimente zur Bestimmung der schnellen Neutronenflußdichte durchgeführt und mit theoretischen Ergebnissen verglichen, die mit dem Programmsystem GAMTEREX erzeugt wurden.
Rhodiumfolien wurden in verschiedenen radialen und axialen Meßkanälen bestrahlt. Die Messungen zeigen im Core-Bereich gute Übereinstimmung mit den berechneten Flüssen, aber im Reflektorbereich liegen die Rechenwerte um mehr als 10% zu hoch. Da die inelastische Neutronenstreuung an ^{103}Rh eine ähnliche Schwelle wie die Graphitschädigung hat, scheint daher auch die Strahlenschädigung des HTR-Reflektors niedriger zu sein als bisher theoretisch berechnet.

At the critical facility of the High Temperature Reactor (KAHTER) Benchmark Experiments were performed to determine the fast neutron flux. The experimental results were compared with theoretical ones, which are calculated using the computer code system GAMTEREX.
Foils of Rhodium (^{103}Rh) were irradiated in several radial and axial channels. The measurements show a quite good agreement with the calculated fluxes in the core region, but in the reflector the calculations overestimate the flux in the range of 10%. Since the inelastic neutron scattering of ^{103}Rh has a similar threshold as the graphite damage, the radiation damage of the HTR-reflector seems to be less high than predicted by the calculations.

1. INTRODUCTION

For pebble-bed HTGR it is essential to know exactly the fast neutron dose of the graphite reflectors. This fast dose changes mechanical properties of graphite, especially of the inner reflector regions. Therefore, in the critical facility KAHTER /1/ benchmark experiments for estimating fast neutron fluxes and doses were performed. These investigations include an accurate prediction and evaluation of the fast neutron fluxes with the HTGR-computer code system GAMTEREX normalized to the KAHTER-power.

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 thick graphite and circumferentially by 40 cm thick graphite. 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 400 up to 1500. Nine rods (eight in the radial reflector and one central rod) control or shut down the reactor system. As neutron absorbing material in the rods B_4C was chosen.
The experiments which are described in the following pages were carried out in a core with OTTO-loading /2/. To simulate this load scheme the core was filled up from the bottom first with a mixture of boron and graphite elements, then with a zone of fuel elements of Type-THTR (1g ^{235}U, 10g ^{232}Th) and with fuel elements of Type-AVR (1 g ^{235}U, 5 g Th). Finally a top reflector of 50 cm height was installed.

Figure 2 shows the flux distribution in the KAHTER facility with OTTO-loading. In a pebble bed HTGR the fuel elements slowly travel downwards, fresh ones are added at the top of the core, and those depleted by burn up are removed at the bottom. Due to increasing fuel depletion, the flux density distribution is pregnantly tilted towards the bottom.

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. THEORETICAL MODEL

Standard codes, which are generally applicable to HTGR calculations, were used for estimating power, flux, and fast reaction rates. Cell calculations were done with the GAM-I /3/ and THERMOS-JÜL /4/ codes or with the Mupo /5/ code. The ^{232}Th and ^{238}U resonance absorption was determined using the ZUT-DGL /6/ code. The resulting resonance absorption, the GAM, and the THERMOS cross sections have been collapsed by the GAM and the THERMOS spectral codes into 7-energy-group cross sections (Table I).

TABLE I

Boundary energies of 7 macroscopic energy groups

Group no.	upper energy eV	lower energy eV	Code	
1	$1 \cdot 10^7$	$1.35 \cdot 10^6$		
2	$1.35 \cdot 10^6$	$2.35 \cdot 10^5$	GAM-I	
3	$2.35 \cdot 10^5$	130		
4	130	1.86		MUPO
5	1.86	0.6		
6	0.6	0.1	THERMOS	
7	0.1	$3.9 \cdot 10^{-3}$		

Condensed 7 energy-group cross sections from spectral codes have been used in the EXTERMINATOR-2 /7/ diffusion code for k_{eff}-calculation, for estimation of power and of 7 energy group flux.

4. DETERMINATION OF REACTOR POWER

The experimental determination of the absolute power is performed with measurements of relative fission rates, which were normalized at some positions by absolute fission rate measurements. To determine absolute fission rates weighted quantities of UO_2 were irradiated on some fixed positions in the core.

The absolute fission rate R_{abs} was determined taking into account:

a) the fission yield of ^{140}Ba
b) the time-dependence of build up and decay of ^{140}La
c) the probability of emission of the 1,596 MeV gamma line of ^{140}La
d) the efficiency of the counter
e) the measured counting rate (activity) of the La-Peak

Reproduced measurements at different positions give a mean power of 58 J/s.
Systematical and statistical errors are estimated and give a total error of 10% maximum.
Diffusion calculation normalized to the same power of 58 J/s gave reaction rates, which agreed within ± 2% with the measured values.

5. MEASUREMENT OF FAST FLUXES AND THEORETICAL RESULTS

For the experimental determination of fast neutron flux the activation analysis of irradiated ^{103}Rh-foils has been used. This method is based on the following inelastic scattering:

$$^{103}Rh(n,n')\ ^{103}Rh^{*}\ \xrightarrow{T\frac{1}{2} = 57\ min}\ ^{103}Rh$$

Rhodium has a fast threshold inelastic scattering cross section of about 1 barn /8,9/ at 0.1 MeV. This reaction has a similar threshold as the lattice displacements of graphite by the fast neutron flux. So it is reasonable to calculate this lattice defects production, if theoretically and experimentally determined fast fluxes agree.

The decay of $^{103}Rh^*$ is accompanied by a 40 keV γ ray, with a 0.157 internal conversion coefficient /10/ to 20 keV X-ray. In the literature different values for the conversion of the 40 keV level had been obtained. KONDAIAH /11/ reports a value of 0.2, DRABKIN et al. /10/ a vlaue of 0.157, GRUNDITZ /12/ a value of 0.116, and BRESESTI et al. /13/ a value of 0.0986. In this work the result of DRABKIN et al., which is about a mean value is used.

Complications arise in the use of ^{103}Rh as detector material for the following reasons:

a) the X-ray is of low energy,
b) the half life is fairly short (57 min),
c) the activation cross section is rather small (~1b),
d) there is thermally induced background.

The low energy X-ray makes is necessary to employ thin window detectors to maintain counting efficiency. In these experiments a Be window NaJ detector /14/ had been applied in near 4 π geometry to measure the 20 keV X-ray. By means of a ^{103}Ru γ-source the detector efficiency has been determined to 0.050 ± 0.001. Thin foils (d=0.1 mm) were used, and a correction for the self shielding was made of the form

$S = S_o \exp(-\mu d)$ where S = fraction of X-rays emitted
S_o = total number of X-ray
μ = attenuation coefficient
d = foil thickness

The value of μ has been determined experimentally to 1,703, which delivers a self shielding factor of 0.48 ± 0.042.

To supress the thermally induced background the ^{103}Rh foils had been covered by 1 mm thick Cd boxes.

Rhodium foils had been irradiated in three radial and in two axial channels. Many reproduced measurements gave same results within 1 to 2%. Fig. 3 shows the radially measured values which are compared with theoretical curves, calculated with the above mentioned computer code system GAMTEREX. The calculated curves have been normalized to a power of 58 Joule/sec.

The overall correspondence between measurements and calculation is quite good. In the center of the core there obviously is a greater deviation of 8% maximum, which is supposed to be due to the guide tube of the central absorber rod. In the radial reflector there seems to be a tendency to overestimate in the calculation the fast flux. Figure 4 shows the axial distribution of the fast flux. In the top reflector region the calculation overestimates the fast flux evidently. Statistical and systematical errors sum up to 10% maximum in the final result of the fast flux. Taking into account these errors, it comes out that the calculation overestimates the fast flux in HTGR-reflector by at least 11%.

6. CONCLUSIONS

The applied inelastic neutron scattering reaction of ^{103}Rh has a similar threshold as the grpahite damage. Therefore, if the experimentally determined fast flux in the energy region beyond this threshold agrees with the calculated one, it is possible to use the calculated fluxes to estimate the graphite damage rate. As the discussed measurements have shown, a good agreement with the calculated fluxes in the core region has been obtained, but in the reflector region the measured fast flux is overestimated by calculation. So, the radiation damage of HTGR reflector seems to be less high than predicted.

7. REFERENCES

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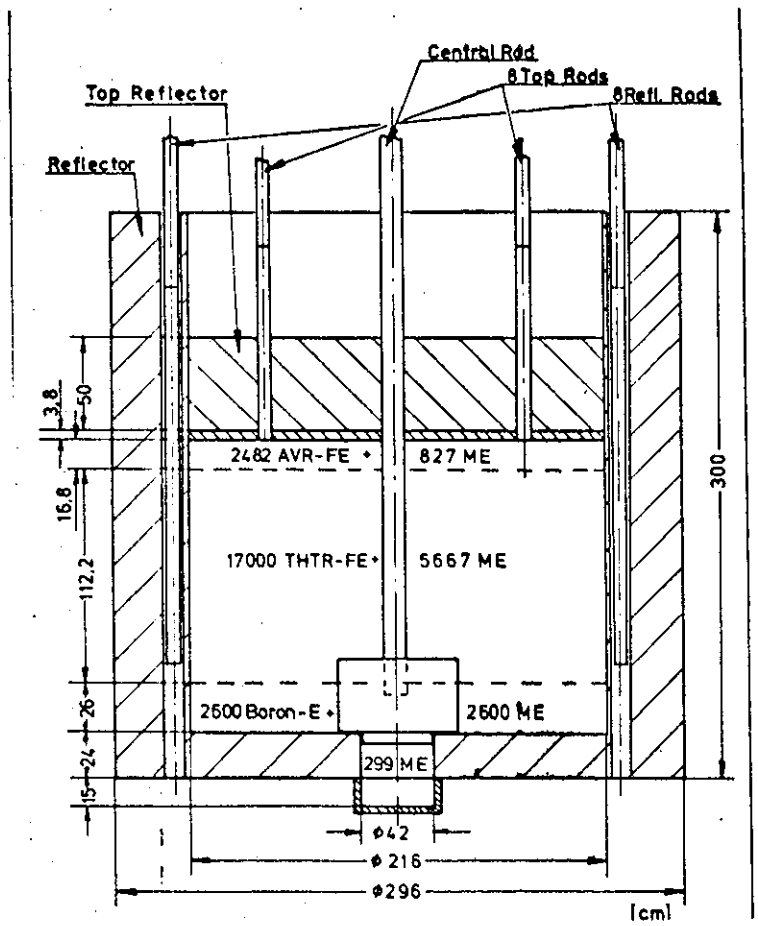

Figure 1: The critical facility KAHTER Core OTTO 0/5

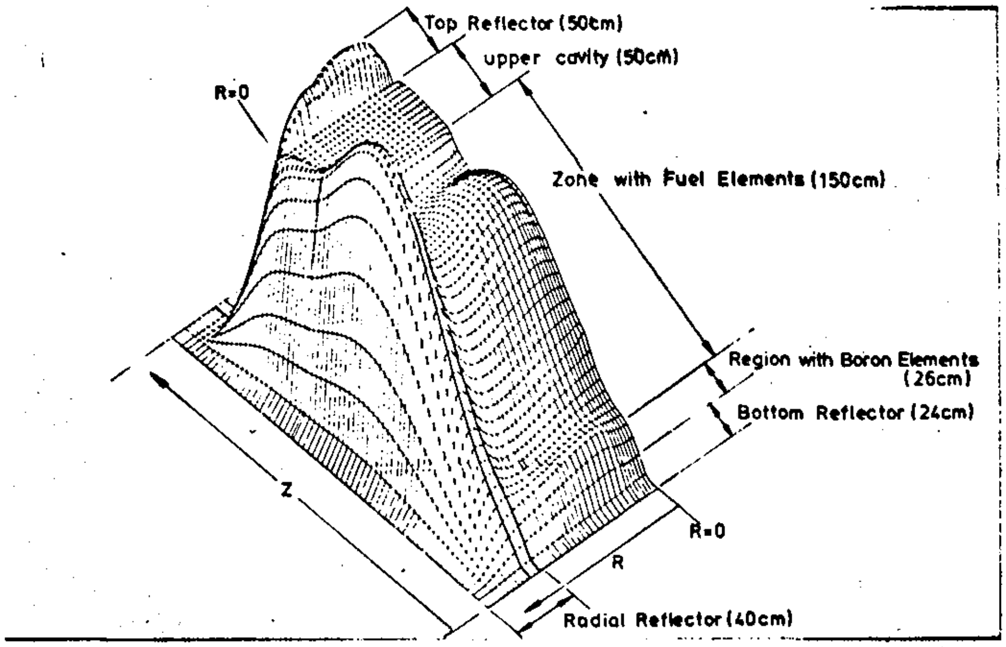

Figure 2: KAHTER: Core OTTO 5/5 thermal flux

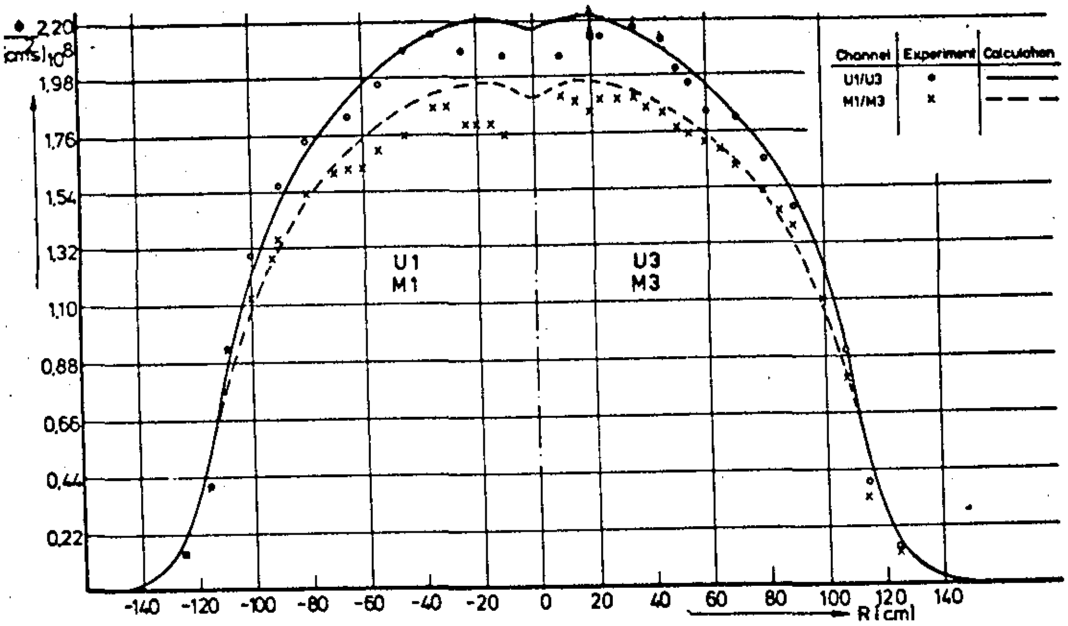

Figure 3: Fast flux (E>0.1 MeV) in radial channels U and M -
(h = 110,160 cm)

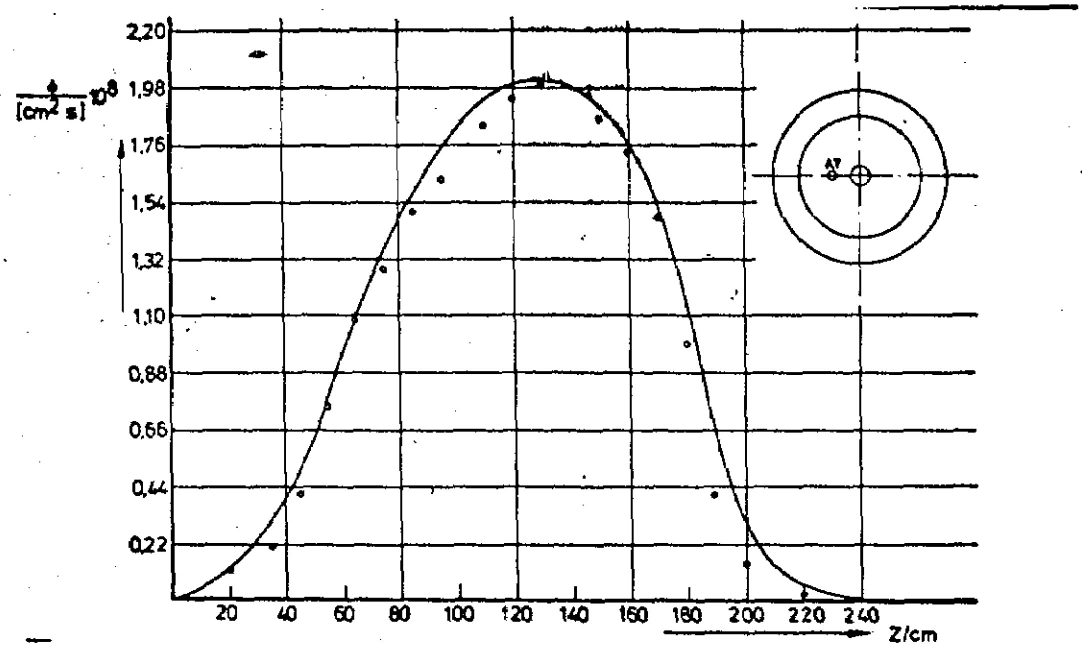

Figure 4: Fast flux (E>0.1 MeV) in axial channel A7 (r = 54.0 cm)