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Document Title

HTR-N1

TEMPERATURE COEFFICIENTS EVALUATION IN THE HTTR

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INTRODUCTION

Until now, HTTR and HTR-10 calculations done in the **HTR-N's WP1**, have been performed at room temperature. It was planed, that additional calculations on the HTTR carried out in the **HTR-N1's WP1** had to take into account temperature feedback effects. Indeed, HTTR core configurations obtained during homogenous raised temperature might be available in a near future. They represent a succession of critical state during which feedback effects have to take place with more and more importance.

Before modeling these HTTR core configurations at different reactor power levels taking into account these temperature feedback effects, firstly, control rod modeling related problems must be solved and then, a good accordance has to be achieved between the partners on the evaluation of the obtained reactivity worth for an homogeneous temperature variation in the reactor at a hot zero power (*isothermal temperature coefficient*). The latter constituted the basis of the present **Task 1**: estimation of the isothermal temperature coefficients on the fully loaded core configuration at hot zero power and with fixed control rod position (HTTR-TC benchmark).

Isothermal temperature coefficients (HTTR-TC) for a fully loaded core between temperatures 280K to 480K (in six steps) had to be calculated. Therefore, the effective multiplication factors should be calculated for the following temperatures:

- 280K, 300K, 340K, 380K, 420K, 460K, and 480K.

Then, the isothermal temperature coefficients should be deduced at:

- 290K, 320K, 360K, 400K, 440K, and 470K

1. DESCRIPTION OF THE DIFFERENT HTTR CORE MODELS

The different core models developed with the various European calculational tools used in the present study, are similar to those built up during the studies of the HTR-N contract. A detailed description of the calculation schemes and their associated assumptions is given in [1] and its support documents. However, additional informations are given below.

1.1. THE KENO MODEL

3D multigroup transport calculations have been performed on the basis of the Monte Carlo method. The Monte-Carlo code KENO-Va (V4.3) was selected for the analysis of the specified problems, detailed geometry of the reactor is adjusted for the corresponding reactor core design given in [2 & 3]. The calculations of the second phase of the benchmark problems scheduled as follows:

- Generate cross sections for KENO taking into account of the impurities, all enrichments of the fissile materials and requested temperatures (Seven different temperatures of the benchmark phase 2).
- Change of geometry for the KENO model of the fully loaded core in connection with control rod settings and evaluate k_{eff} for *Scram* and *Temp. Coeff.* cases. Also calculation of insertion depth of C, R1, R2 at T = 480K for a critical system where R3 is full out.
- Comparison with previous calculations and preparation for the benchmark request.

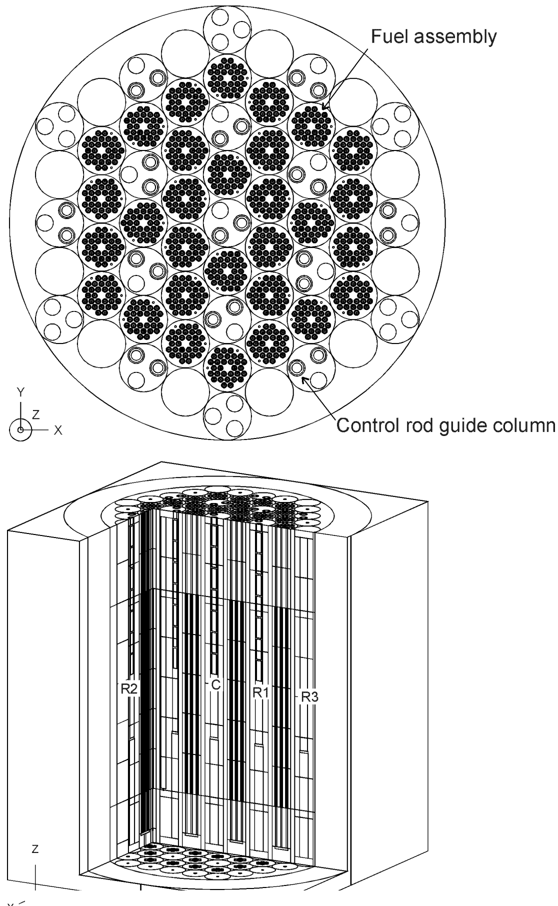


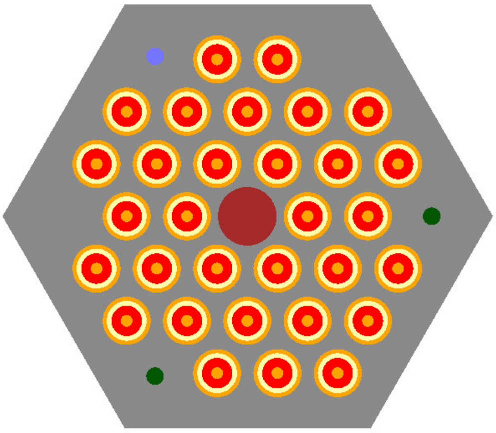
Figure 1 : 3D core model with KENO

New cross sections are prepared for seven different temperatures using the INAS code system (IRI-NJOY-AMPX-SCALE) with the JEF-2.2 evaluated nuclear data files. The resulting cross section libraries contain data for 172 neutron energy groups used in KENO.

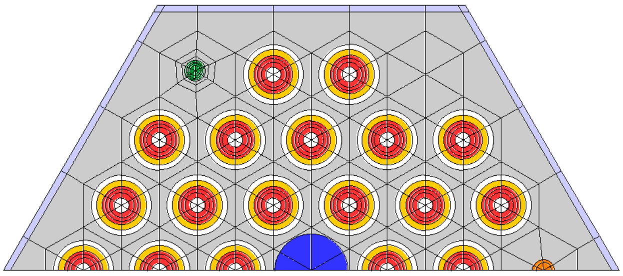
The geometry description of the HTTR in the original benchmark documentation [1] served as a guide for the development of a detailed KENO model. In this model practically all reactor components could be modelled explicitly, only for new control rod settings the model is adjusted explicitly.

1.2. THE CRONOS MODEL

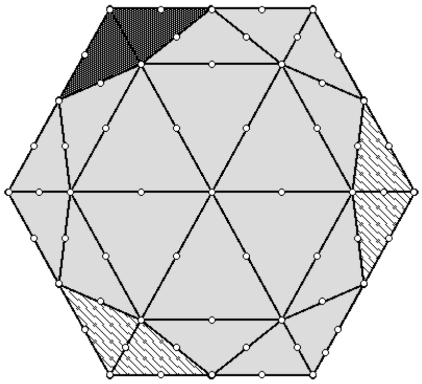
The general methods and assumptions used to model the fuel block elements and to generate the cross sections (APOLLO2 code) for the core diffusion calculations (CRONOS2 code) are given in [1 and 4]. New finite elements recently implemented in CRONOS-2 have been used. They allow taking into account the exact position of the burnable poison in the fuel blocks and the fuel element orientation in the core, as depicted in Figure 2.



Fuel element geometry



Fuel element description
in transport calculations (APOLLO2)



Fuel element description
in diffusion calculations (CRONOS2)

Figure 2. Fuel element modelling in the improved Transport – Diffusion calculation scheme

1.3. THE CITATION MODEL

To perform the transport calculations on the fuel cell we used an improved version of WIMS-D/5B code (namely WIMS-D/5B-P1) for cell calculation and a new nuclear library (172 energy groups) based on JEF2.2 dataset developed by IAEA in the frame of Wims Library Update Project (WLUP). The 3D whole core calculations (Figure 3) were performed with CITATION code (diffusion method and finite differences) with the hypothesis of 7 energy groups.

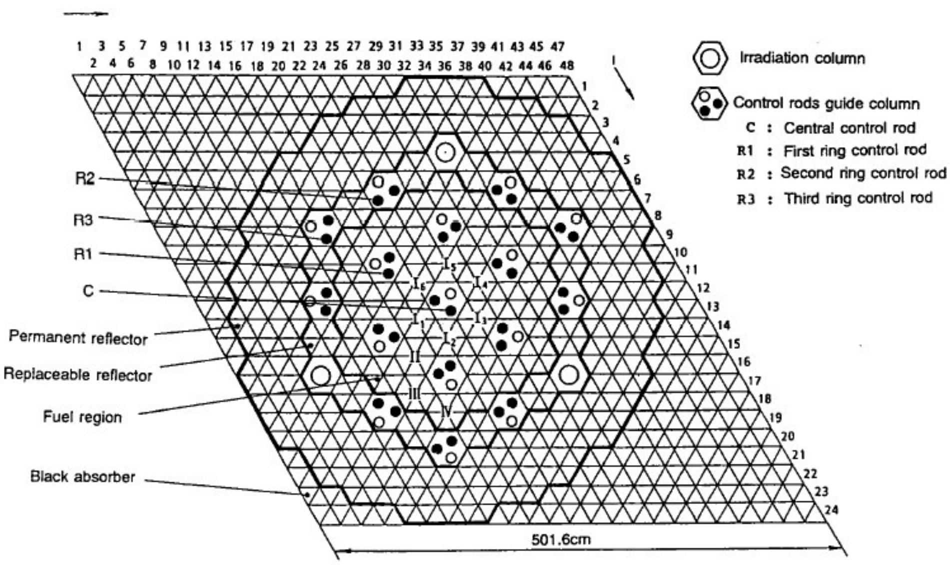


Figure 3: Hexagonal plane of core calculation

2. RESULTS

Isothermal temperature coefficients (HTTR-TC) had to be estimated for a fully loaded core between temperatures 280K to 480K (in six steps) where control rod positions C, R1, and R2 are slightly different setting due to temperature elevation (13 mm). Therefore, the temperature coefficients have actually been calculated with the help of several codes for 6 temperatures varying from 280 K to 480 K :

- 280K, 300K, 340K, 380K, 420K, 460K, and 480K.

Then, the isothermal temperature coefficients should be calculated at:

- 290K, 320K, 360K, 400K, 440K, and 470K.

These temperature coefficients have then been evaluated from the following expression:

$$\rho_{12} = \frac{k_{T_1} - k_{T_2}}{k_{T_1} \times k_{T_2}} \cdot \frac{1}{(T_1 - T_2)}$$

ρ_{12} Temperature coefficient between T_1 and T_2 (Δk/k/K)
T_n Core temperature at n^{th} measurement (K)
K_1 Effective multiplication factor at T_1
K_2 Effective multiplication factor at T_2

The insertion depth of C, R1, R2 are at same level (1776 mm) and R3 is fully withdrawn. Also critical control position at 480K (C, R1 and R2 (mm), R3 is full out) is requested for the benchmark.

2.1. EXAMPLE OF RESULTS OBTAINED WITH KENO

The core reactivity and associated temperature coefficients estimated from k_{eff} of 3D core transport and diffusion calculations are presented in Table 1 at different temperatures.

Table 1: k_{eff} and T coeff. as function of the temperature

Items	*Calculated values*
Effective multiplication factor for different temperatures#	
k_{280}	1.0096±0.0002*
k_{300}	1.0082±0.0002*
k_{340}	1.0019±0.0006
k_{380}	0.9965±0.0005
k_{420}	0.9905±0.0005
k_{460}	0.9844±0.0002*
k_{480}	0.9820±0.0002*
Temperature coefficients(Δk/k/K)	
ρ_{290}	- 6.88 E-5
ρ_{320}	-15.59 E-5
ρ_{360}	-13.52 E-5
ρ_{400}	-15.20 E-5
ρ_{440}	-15.64 E-5
ρ_{470}	-12.64 E-5

Critical control rod position at 480K k_{eff} =0.9998±0.0005, C, R1 and R2 1920 (mm) and R3 Full out

Isothermal temperature coefficients can be estimated between 280K and 440K. On the average between 320K and 440K, the value is: -14.7 pcm/K. The calculated critical control rod position at

480 K by KENO is 1879 mm. Besides, the PANTHER value of the isothermal coefficient averaged between the same range of temperature, is -15.2 pcm/K. The calculated critical control rod position at 480 K by PANTHER is 1934 mm

2.2. THE CRONOS2 RESULTS

The temperature coefficients have been estimated from k_{eff} of 3D core diffusion calculations performed at different temperatures. The Table 2 and 3 below give the k_{eff} and deduced temperature coefficients obtained with CRONOS2.

Table 2: k_{eff} as function of the temperature

Temperature [K]	APOLLO2 – CRONOS2
300	1,00395
340	0,99724
380	0,99088
420	0,98455
460	0,97823
480	0,97525

Table 3: Isothermal temperature coefficients

Temperature coefficients [pcm/°K]	APOLLO2 – CRONOS2
ρ_{320}	– 16,75
ρ_{360}	– 16,09
ρ_{400}	– 16,22
ρ_{440}	– 16,40
ρ_{470}	– 15,62

It should be noticed that according to the results gathered here, the temperature coefficients range from - 15 to - 16 pcm/°K between 300 K and 480 K respectively.

3. CONCLUDING REMARKS

In order to have a comparison between the different code systems, the evaluation of the temperature coefficient at 400 K is given below (Table 4). It is noteworthy that the results are in relatively good accordance with the experiment where the values are comprised between - 13 and - 14 pcm/K at the same temperatures. One can conclude that compare to the experimental measurement the calculated temperature coefficients are overestimated by about 10 % in average by the different codes.

Table 4: Isothermal temperature coefficients for the HTTR[#]

	KENO (IRI)	PANTHER (NRG)	CRONOS (CEA)	CITATION (UNIPI)
Core at 400 K	**- 14.7 pcm/K**	**- 15.2 pcm/K**	**- 16.2 pcm/K**	**- 17.2 pcm/K**

[#] CR group C, R1 and R2 inserted (178.9 cm)

4. SUPPORT DOCUMENTS

All the documents available on the Web SINTER site and related to the works that have been performed in this WP1 are listed below:

- HTR-N1-02/12-S-1.1.1-1_1
- HTR-N1-03/06-S-1.1.3-1_1

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[7] IAEA-TECDOC-1382, Volume 1 – *Evaluation of high temperature gas cooled reactor performance: Benchmark analysis related to initial testing of the HTTR and HTR-10* -. CRP-5, Nov. 2003