EUROPEAN COMMISSION
5th EURATOM FRAMEWORK PROGRAMME 1998-2002
KEY ACTION : NUCLEAR FISSION

HTR-N

HTR-N & N1
High-Temperature Reactor Physics and Fuel Cycle Studies
(EC-funded Projects: FIKI-CT-2000-00020 & FIKI-CT-2001-00169)

Work Package: 1	**HTR-N1 project document No.:** HTR-N1-04/07-D-1.2.0-1_1				**Q.A. level: 1**
Task: 1.2	**Document type:** Deliverable				**Document status:** Final
Issued by: CEA	**original document No.:**	**Annex pg.** 0	**Rev.** 0	**Q.A. level** n/a	**Dissemination level:** CO

Document Title

HTR-N1

Control Rod Position at Criticality and Scram Reactivity in the HTTR

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Notes

Electronic filing: *SINTER*

Electronic file format: *PDF file*

Rev.	Date	Short Description	Prepared by	Partners' Review	Control WP Manager	Approval Project Manager
					[signature]	[signature]	[signature]
0	22-07-2004	first issue	CEA	NRG, IRI, UNIPI	CEA	FZJ

Chronology and history of revisions

Rev.	Date	Description
0	22-07-2004	First issue

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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 first items constituted the basis of the present **Task 2**: estimation of the control rod position at different core critical state and scram reactivity evaluation (HTTR-CR and HTTR-SC benchmarks). The Figure 1 depicted the control rods arrangement in the HTTR core gathered in several groups.

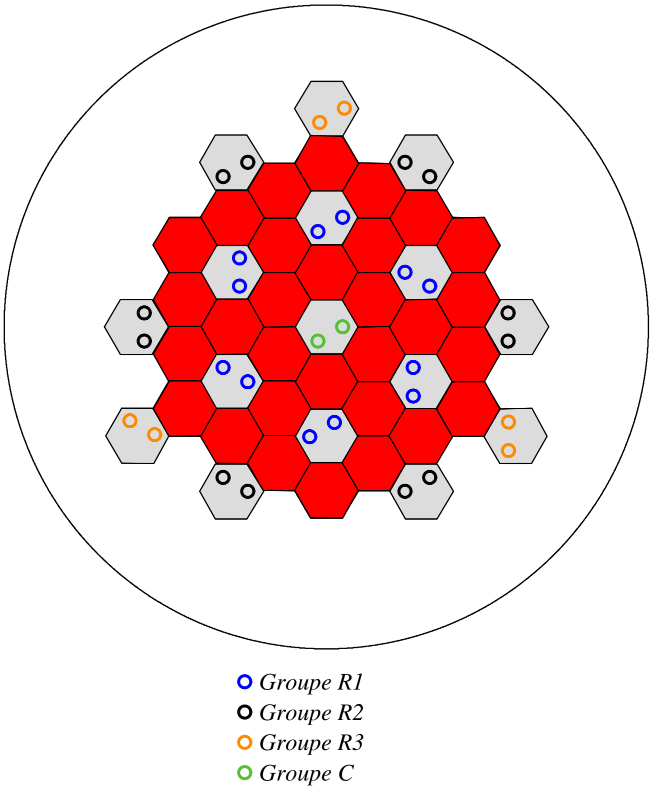

Figure 1. Control rods layout in the HTTR

1. DESCRIPTION OF THE PROBLEMS

The objective of the **Task 2** was the evaluation of the control rod worth for different core configurations at hot zero power condition. Many configurations were available: scram reactivity of all the control rods, and scram reactivity of the reflector control rods only. Therefore, there was a continuation with the work performed in the previous contract (HTR-N) where control rod modeling is tackled on one or several core configurations. The expected results were an improvement of the control rod modeling in the core calculations.

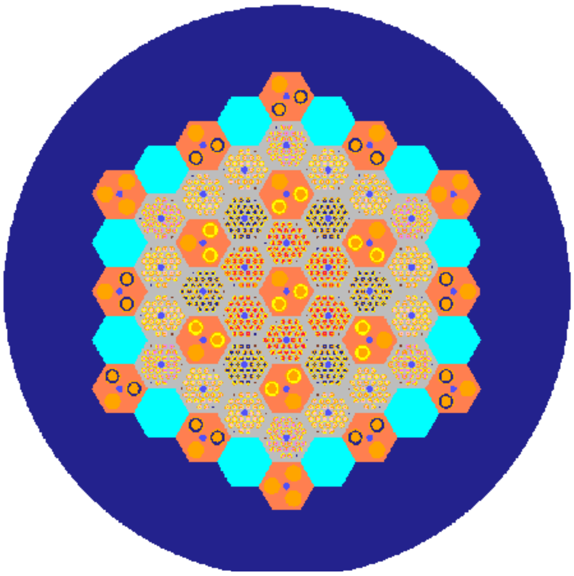

Figure 2: example of calculational geometry with the TRIPOLI4 code

The benchmark comprises two problems for a full core (30 fuel columns) of the HTTR at zero power:

- Evaluation of the core reactivity with the control rod at their critical position. That provides the initial state before inserting the control rods and calculated the corresponding scram.
- Scram reactivity (control rod worth) for control rod position before and after scram of reflector control rods (R2 and R3), the temperature of core being 300K. The R2 and R3 represent the all the scram of all control rod in the reflector.
- Then, the scram with all control rods (including rod groups C and R1) must also be calculated, the temperature of core being the same.

For the scram reactivity calculations, two different scram conditions as given in Table 1.

CR Group	Critical position (mm)	Position after reflector scram (mm)	Position after all CR scram (mm)
C	1789	1789	-41
R1	1789	1789	-41
R2	1789	-41	-41
R3	Full out	-41	-41

Table 1. Scram configurations

As an example, the Figure 3 shows the resulting thermal neutron flux distribution obtained in the fully loaded core when the control rod are inserted at their critical position (C, R1 & R2 at 178.9 cm). The six flux peaks correspond to the location in the reflector where no control rod is inserted (see Figure 1 - R3 is out). Besides, the Figure 4 underscores the axial perturbation of the neutron flux when the control rod are inserted at their critical position.

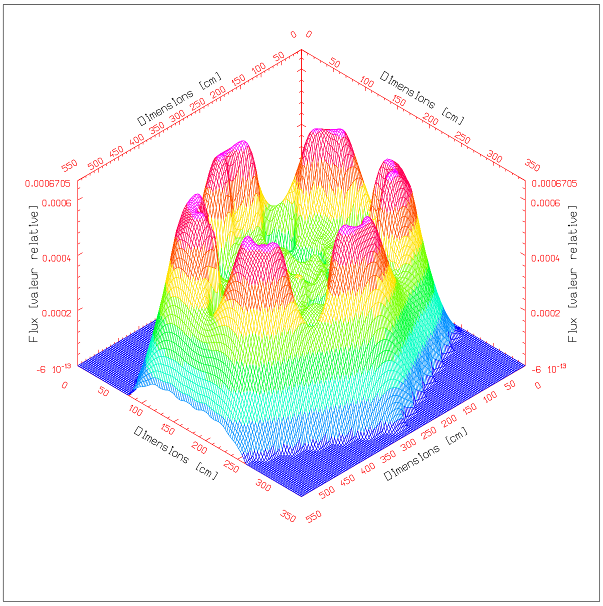

Figure 3: Neutron thermal flux for z = 320 cm - « full core » configuration Critical control rod position

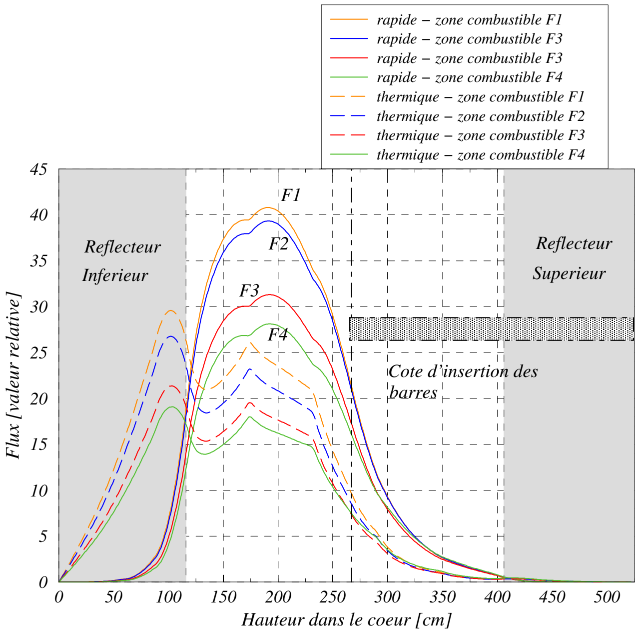

Figure 4: Axial neutron flux distribution - « full core » configuration – inserted CRs

2. 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. Indeed, The same codes have been used by UNIPI, CEA and NRG/IRI to estimate the control rod worth in the HTTR as well as the first criticality and the temperature coefficients.

A detailed description of the 3D calculation schemes and their associated assumptions is given in [1] and its support documents. However, additional informations have already been given in [2] and specific remarks are given below as far as the control rod modelling is concerned.

2.1. THE DIFFUSION MODEL WITH CRONOS2

From some previous calculations, the average fluxes of the fuel blocks were used as a 172 group-neutron source placed at the periphery of the control blocks to generate the averaged weighted library needed for core diffusion calculation. A similar collision probability method has been used in the 2D-geometry shown in Figure 5 for the control blocks with and without the control rods inserted.

As for the fuel blocks, the 8-group-constants have been created by spatial homogenisation on the overall control block geometry. Indeed, among the finite element meshes available in the CRONOS2 diffusion code, it was first impossible to take into account the position and the orientation of the fuel and control blocks by a heterogeneous geometric description of these elements. Likewise, it is noteworthy that **no transport-diffusion equivalence factors** have been considered for the control blocks when the control rods are inserted.

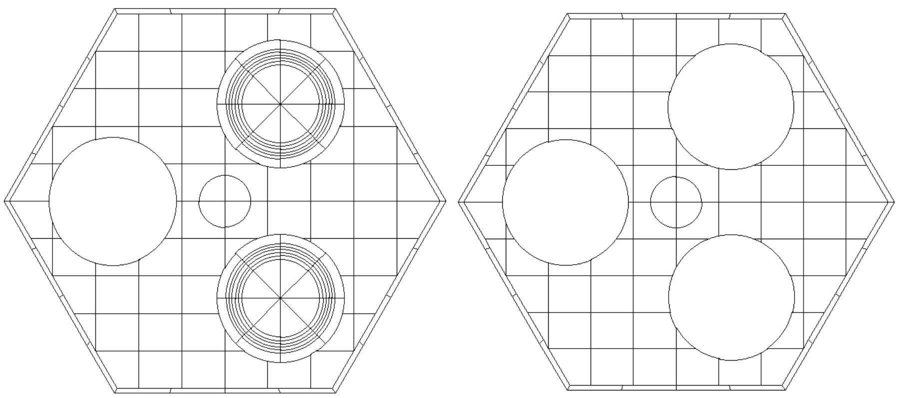

Figure 5: 2D-Control Rod Blocks Geometry in APOLLO2

A hexagonal 3D-geometry has been used for the core description in CRONOS2. Each fuel and control blocks have been represented by a hexagon with a heterogeneous composition. On this hexagonal mesh, the *finite element method* provides several polynomial approximations. In this case, a second order exact integration (standard parabolic Lagrange) has been adopted horizontally and leads to 19 flux values per mesh (equivalent to a 24 homogeneous meshes in finite difference method).

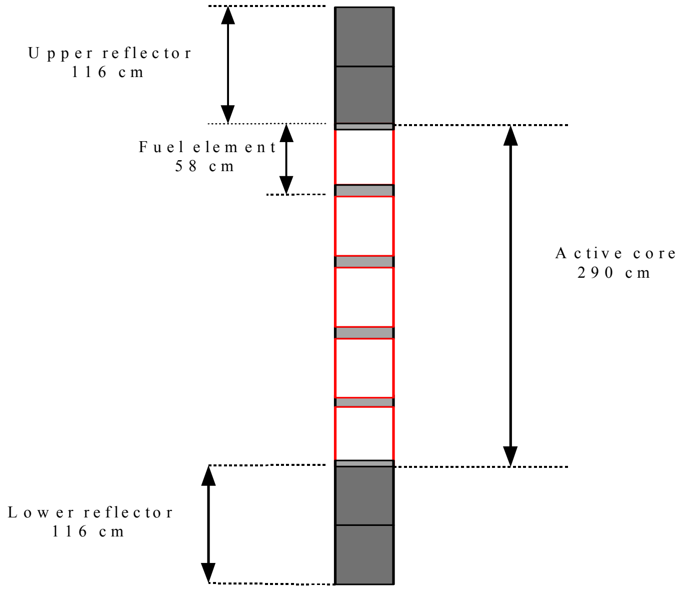

Figure 6: Core Axial Description for CRONOS2 code

Axially, a linear Lagrange method using Gauss Formula has been applied. Each fuel section (14 fuel compact stack) was divided into 6 meshes and the inter-space between these fuel sections (3.4 cm of graphite) has been described explicitly as shown in Figure 6.

2.2. THE MONTE CARLO MODEL WITH TRIPOLI4

As far as the second method is concerned (*transport-Monte Carlo*) it is noteworthy that, as recommended by the benchmark problem, the structural materials of the control rod have not been taken into account. Conversely, a detailed axial description of the control rods has been done as depicted in Figure 7.

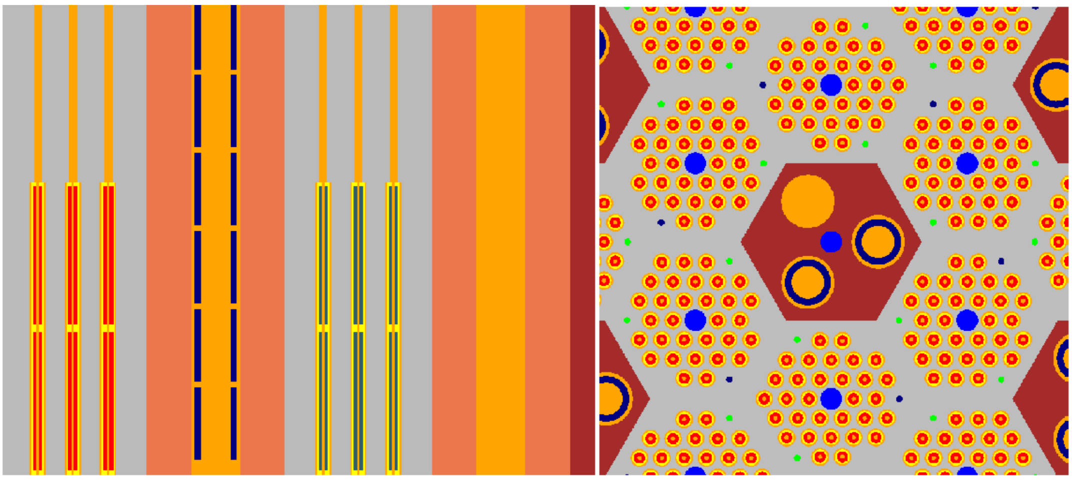

Figure 7: Axial Cross Section View of the Inserted Control Rods

The calculations aimed to tentatively evaluate the critical insertion depth of the control rod in the fully loaded core configuration have been performed. Two control rod insertion depths have been considered. The first one *-178.9 cm-* is the experimental value and the second one *–177.6 cm-* comes from a previous estimation of the control rod efficiency obtained in the diffusion calculations. The CR position for criticality has been found to **178.7 cm** with TRIPOLI4.

3. RESULTS

In this study, the CR worth has been evaluated in the fully loaded core configuration and according to:

$$\rho \quad = \quad \frac{k_{crit.} - k_{Control\ Rods\ IN}}{k_{crit.} \times k_{Control\ Rods\ IN}}$$

The effective multiplication factors should be calculated at the critical CR positions and the CR positions after scram. The results given in the following Table correspond to the scram reactivity of the reflector control rods on the one hand, and on the other hand to the scram reactivity of all the control rods. This is done for the fully loaded core configuration (32 fuel columns in the core). The control rod positions of the experiment for obtaining criticality with all the inserted CR are: **178.9 cm**.

First of all, the results using 3D **PANTHER** calculations lead to a k_{eff} = 1.0088 at critical position and k_{eff} = 0.7317 after scram of all control rods. That means a worth of 37.5%, which appears very low compare to the other results but can be explained by neutron streaming in the control rod holes and is to be recalculated by means of anisotropic cross sections.

The others results are gathered in the Table 2. The reflector control rod worths are in well agreement with the values given by the other international participants of the IAEA benchmark, nevertheless an underestimation of the control rod worth could be underscored compare to the experiment.

Control position	**KENO**	**TRIPOLI4**	**CITATION**	**CRONOS2**	**Exp.**
178,9 cm	**1.0093 ± 0.0006**	**1.00117 ± 0.00024**	**1.0031**	**1.00020**	**Crit.**
177,6 cm		*0.99972 ± 0,00038*		*0.99840*	*
Scram of refl. CRs □	**0.9178 ± 0.0005** *9.88 %*	**0.92215 ± 0.0004** *8.56 %*	**0.86535** *15.87 %*	**0.90245** *10.83 %*	*12 % (± 1.2)*
Scram of all CRs □	**0.6809± 0.0005** *47.78 %*	**0.68396 ± 0.0003** *46.32 %*	**0.67937** *47.50 %*	**0.63982** *56.31 %*	*46 % (± 4.6)*

Table 2: Control Rod Worth in the HTTR: k_{eff} (initial state and scram) and Δk/k in %

Likewise, these results underscore the fact that the CR worth is globally overestimated with the diffusion method compare to the Monte Carlo calculations, especially in this case where no equivalence factors have been used in order to respect either the flux or the absorption rates between the multi-group transport calculations and the broad group diffusion core calculations. Consequently, it is obvious that further investigations must be carried out in a near future in order to improve the CR modeling related problem especially for rods inserted in the reflector of a HTR. This problem is also addressed for the HTR-10 (HTR-N1's WP2).

4. SUPPORT DOCUMENTS

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

- HTR-N1-03/06-S-1.1.3-1_1
- HTR-N1-03/08-S-1.2.1-1_1

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