FUEL MANAGEMENT AT THE PETTEN HIGH FLUX REACTOR

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ABSTRACT

Several years ago the shipment of spent fuel of the High Flux Reactor (HFR) at Petten has come to a standstill resulting in an ever growing stock of fuel elements that are labelled "fully burnt up". Examination of those elements showed that a reasonably number of them have a relatively high ^{235}U mass left. A reactor physics analysis showed that the use of such elements in the peripheral core zone allows the loading of four instead of five fresh fuel elements in many cycle cores.

For the assessment of safety and performance parameters of HFR cores a new calculational tool is being developed. It is based on AEA Technology's Reactor physics code suite Winfrith Improved Multigroup Scheme (WIMS). NRG produced pre- and post-processing facilities to feed input data into WIMS's 2D transport code CACTUS and to extract relevant parameters from the output. The processing facilities can be used for many different types of application.

1. Introduction

The High Flux Reactor at Petten is a versatile Materials Testing Reactor, owned by the European Commission and operated by the Nuclear Research and Consultancy Group (NRG), a Dutch company (www.nrg-nl.com). It is located in "Medical Valley", surrounded by well equipped facilities that are needed for (non-) destructive materials research, neutron and gamma metrology, waste disposal and radioisotope production. The reactor core consists of 33 fuel elements, 6 control rods, 25 reflector elements and 17 experiment positions, see figure 1.

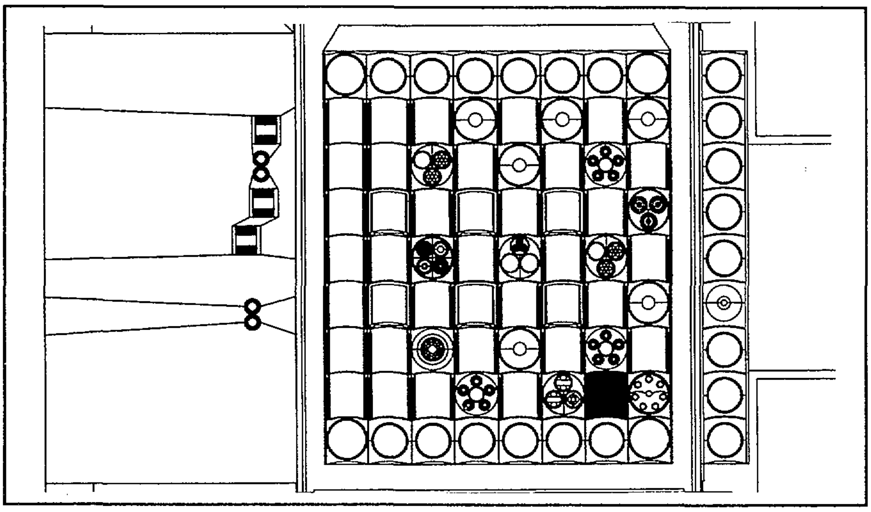

Figure 1. Horizontal cross section of the HFR core at centreline core.

At the west side of the core the reflector elements lack to let neutrons migrate into the Pool Side Facility unhampered. The control rods consist of a cadmium containing upper part and a uranium containing lower part. On start-up the control rods are moved upwards, simultaneously moving absorber material out of the core and introducing fissile material into it.

2. Fuel Management

Up until a few years ago the HFR core was loaded with 5 fresh fuel elements and 1 fresh control rod every cycle. In an attempt to reduce fuel element consumption several alternative loading schemes using 4 fresh fuel elements were evaluated, but none turned out to fulfil the following requirements:

- neutron fluence rates as close as possible to the values obtained so far;
- core excess reactivity enough to allow 25.7 full power days and to have reasonable time for restart after a scram (high xenon-poisoning);
- thermal conditions acceptable for safety and operation;
- parameters in accordance with the regulations HFR cores have to comply with.

The main problem was the lack of excess reactivity at end-of-cycle (EOC). To increase this parameter the peripheral fuel elements that would be loaded according to the calculated loading scheme were replaced by selected fuel elements actually in stock. These elements once were labelled "fully burnt up", but still contained higher quantities of ^{235}U compared to the calculated mass in the peripheral fuel elements.

The characteristics of the "boosted" 4 fresh fuel elements core are as follows:

- The neutron fluence rates in the experimental positions in the core show minor reductions in the fast groups (1 through 3) and -generally speaking- an increase in the thermal group (see figure 2).
- The EOC excess reactivity is approximately 1500 pcm in the new core, whereas it was 3000 pcm in the existing one. This means that there are more stringent limitations on:
  - the loading of extremely absorbing experiments;
  - the cycle length;
  - the time after reactor scram to overcome xenon poisoning.
- Maintaining the thermal safety margins results in a reduction of the maximum allowable primary coolant inlet temperature from 58.5 °C to 53 °C, because of the increase of the thermal load of fuel elements in the centre of the core.
- The maximum burnup of fuel elements and control rods is about 66%. An earlier study showed this does not give rise to problem with respect to swelling.

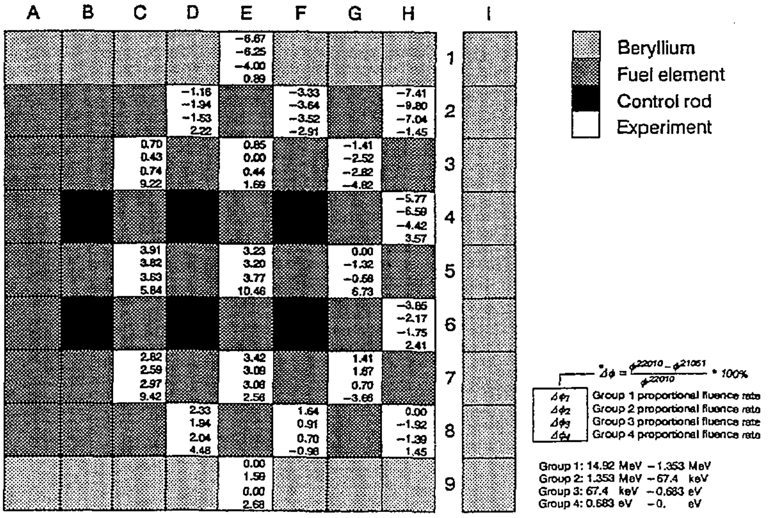

Figure 2: relative change in neutron fluence rates at experimental positions.
Core 21051 is loaded with 5 fresh fuel elements, core 22010 with 4.

The stock of fuel elements needed to load the peripheral positions of the new core is big enough to load some 55 cores. In the past four years the four-fresh-fuel elements core was loaded 23 times.

3. Calculational Tool Development

General

In case of a materials testing reactor the calculational route that is used for cycle-to-cycle calculations has to be flexible with respect to the modelling of the geometry. The reason for this is the variety of designs of the experiments that are loaded into the core. It is still common practise to use a cell code to homogenise details in an experiment into a smeared lattice cell for the core calculation. But nowadays the computer gets fast enough, and memory gets large enough to increase the level of detail in core calculations.

The set of codes used at Petten is based on AEA Technology's Reactor physics code-suite Winfrith-Improved Multigroup Scheme (WIMS) [2]. The code used for routine calculations is the 2D transport code CACTUS. The 3D Monte Carlo code MONK is used for verification of the modelling of 3D processes in CACTUS, such as the control rod movement during the cycle and axial neutron leakage. NRG produced pre- and post-processing facilities to feed input data into the code suite and to extract relevant parameters from the output.

CactusEdit

The first tool developed was CactusEdit [3]. Like a Computer Aided Design program CactusEdit allows the user to build geometries using a Graphical User Interface. An example of such geometry is given in figure 3.

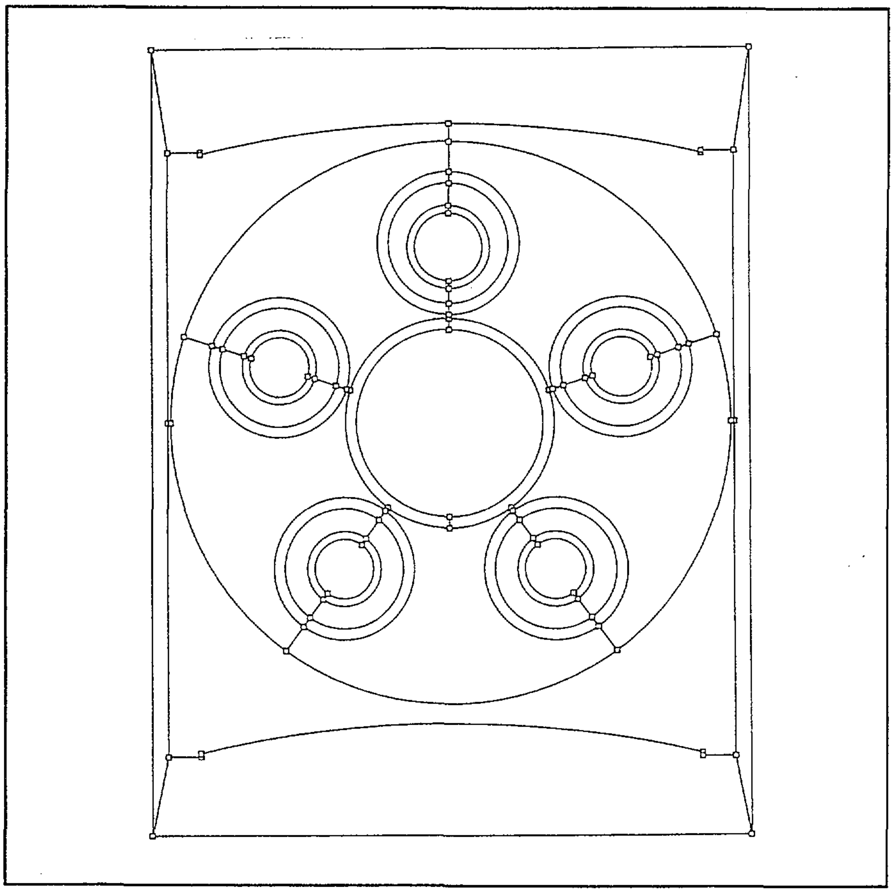

Figure 3: CACTUS geometry of an experiment

CactusEdit loads an input file for CACTUS and it will show the geometry described in it. After the editing process the work can be saved, resulting in a valid input file for CACTUS, now containing the modified geometry.

GeoCompose and MatCompose

The next modules made were GeoCompose and MatCompose. These modules construct the whole core model using templates of the empty-reactor-model and of experiments. The templates themselves are made using CactusEdit and consist of two parts: the geometry and the materials part.

The composition of the geometry is driven by the "CoreSpecification" file, in which is listed what element has to be loaded on what position. The figures 4 and 5 show the process of composing the whole core model.

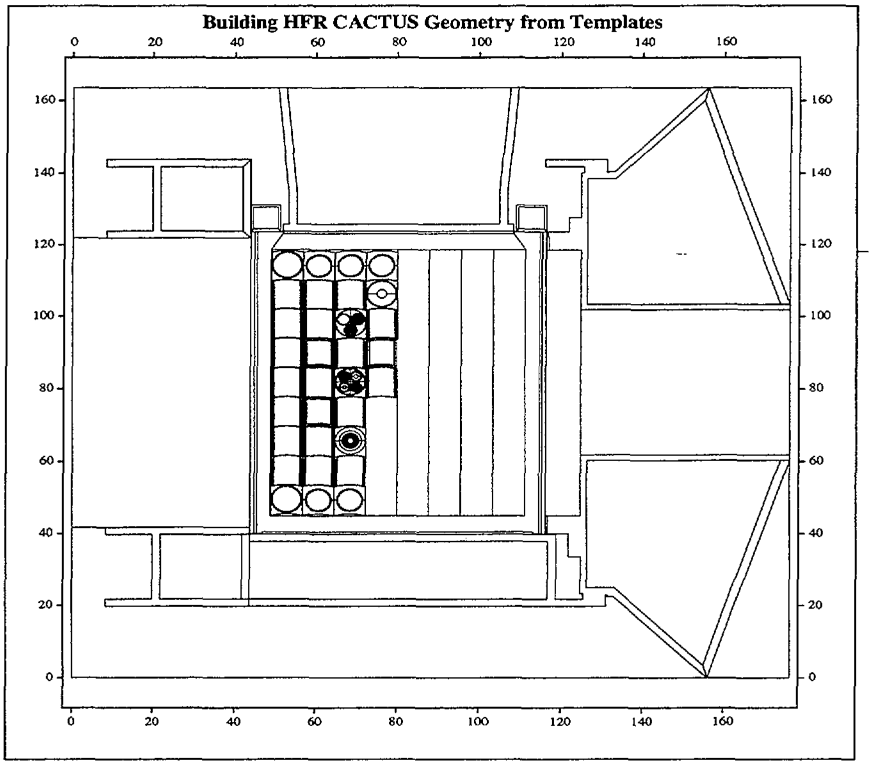

Figure 4: Example of a partially filled HFR core model

Compared to GeoCompose the module MatCompose performs a similar task, but here an input stream is generated for WIMS modules that calculate material properties. Besides keeping track of the right material numbers in the right places MatCompose can read standard materials from a library and construct mixtures of standard materials.

After the completion of the WIMS calculation an interface exists that contains the nuclear properties of all materials that are used in the whole core model.

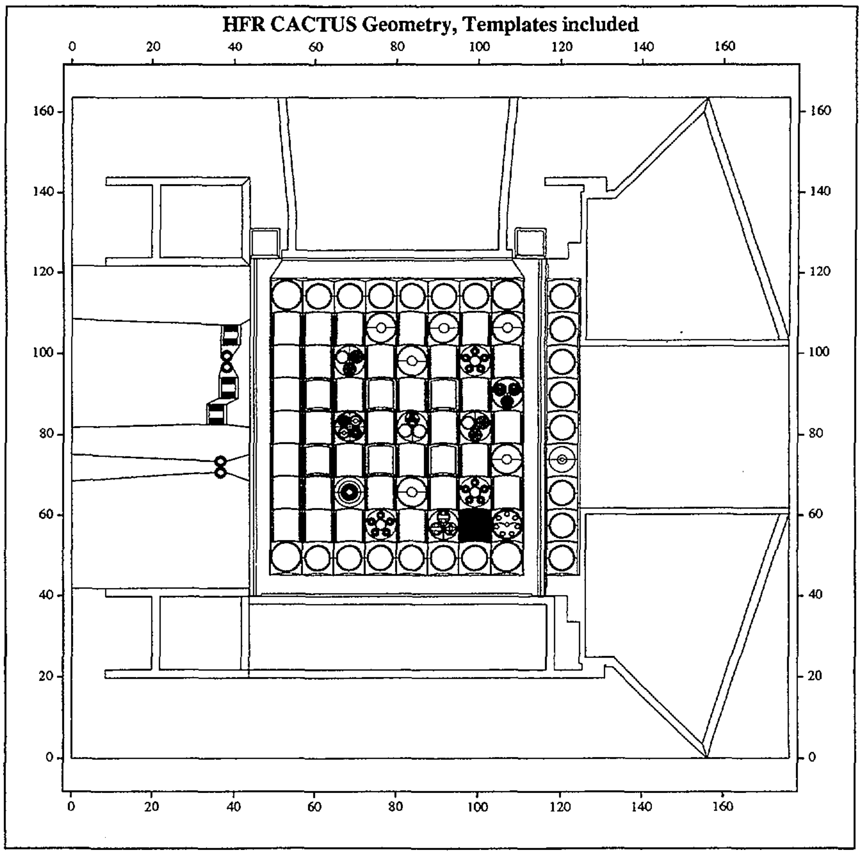

Figure 5: Example of a filled HFR core model

CacMesh

Once the reactor geometry is composed and the materials-interface is made CacMesh is invoked to generate the meshing needed for the correct spatial discretization in CACTUS. Several meshing criteria are at the user's choice, but probably the most elegant is the mesh size being a fraction of the transport mean free path. CacMesh will determine the necessary number of meshes in X- and Y-direction for every element in the model and modify the input stream for CACTUS.
The chart in figure 6 shows the relation between the modules.

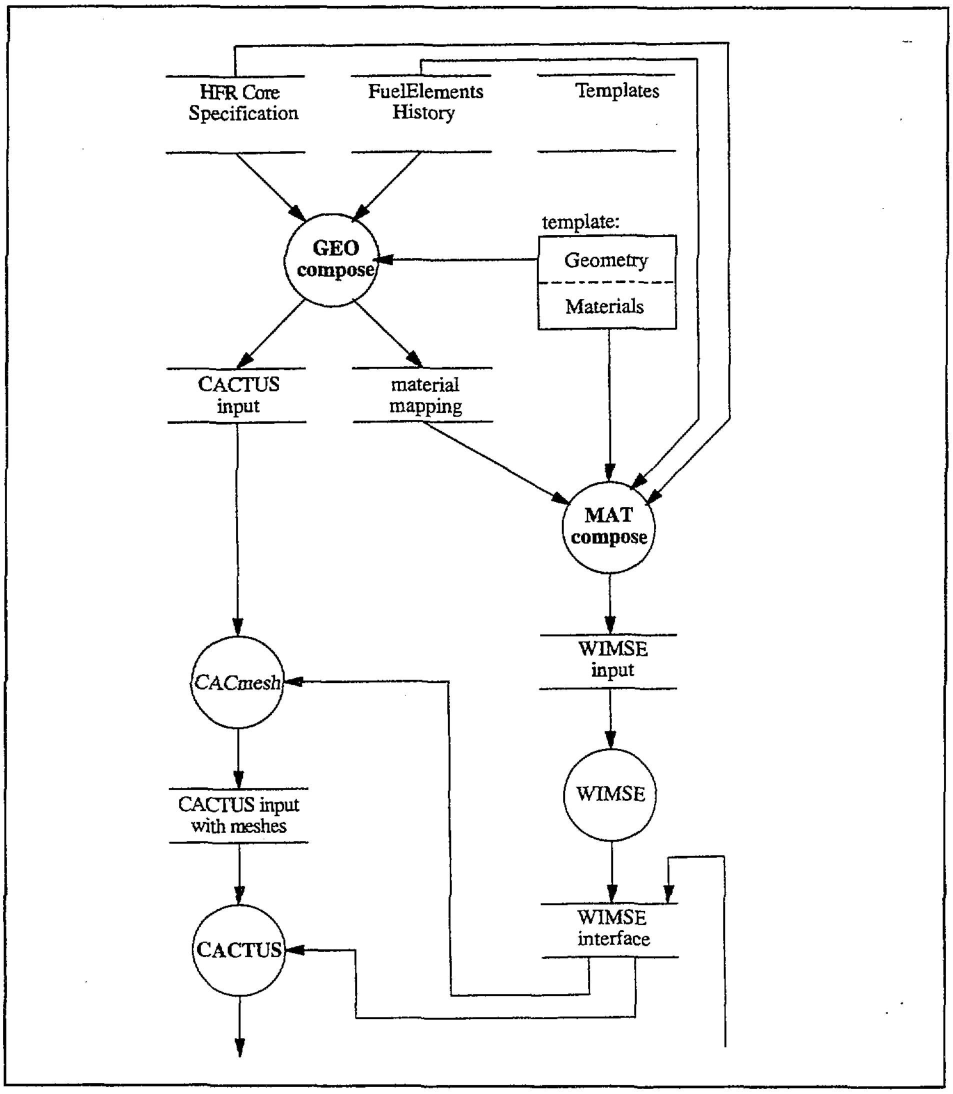

Figure 6: Flowchart of the Generation of WIMS-input for HFR core calculations

Calculational Results

First whole core calculations show good agreement with earlier obtained calculational results and measurements. At this moment the set of codes that will form the calculational tool for HFR calculations is being validated for use in safety analyses.

4. References

[1] K. Terpstra et. al., "Standard Core 22010", ECN-CX--93-110, ECN, Petten, NL, June 1994.
[2] WIMS User Guide, ANSWERS/WIMS(95)4, AEA Technology plc, Winfrith, UK.
[3] WIMS-CactusEdit User's Guide, ECN, Petten, NL, March 1995.