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THE CONVERSION OF THE DIDO-TYPE REACTOR FRJ-2

STUDIES AND CONCLUSIONS

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ABSTRACT

For the FRJ-2 (23 MW) of the KFA-Jülich the conversion from HEU- to LEU-fuel was investigated. Before starting the conversion calculations our methods were qualified for the application to heavy water moderated research reactors. A combination of LEU-elements with two different U-235 loadings of 180 g and 225 g was found as suitable for conversion. With these LEU-elements a working core and a transition phase was calculated. The change of the mechanical fuel element design was taken into account.

INTRODUCTION

This contribution deals with the investigations for the conversion from HEU- to LEU-fuel of the 23 MW-research reactor FRJ-2 operated at the KFA-Jülich. There are two items which influenced the studies essentially, a methodical one and a technical one

- As the DIDO-type reactor FRJ-2 is the only heavy water moderated research reactor in Germany our calculational methods had to be qualified for this purpose.
- When changing over from HEU to LEU the mechanical design of the fuel element has to be modified. As a consequence of this there arise additional steps within the conversion procedure.

BENCHMARK CALCULATIONS

Before starting special conversion calculations we had to adapt and to qualify our standard methods /1/ for the application to heavy water moderated research reactors. One way of obtaining this qualification was the calculation of the IAEA-benchmark problem for D_2O-research reactors /2/. A very good agreement with the results of ANL was achieved and is displayed exemplarily for the infinite multiplication factor in fig. 1 and for flux distributions in fig. 2.

The results strongly support the reliability of the methods in performing conversion studies on D_2O-research reactors. They are described here in a short summary.

The fuel element group constants in dependence on burn-up and several other parameters are calculated by the program MONSTRA. It was modified for the application to D_2O-reactors with respect to n,2n-reactions in D_2O, calculation of decay products and increase of the energy group number. The reflector group constants are generated by IANSN, an Interatom-version of the transport code ANISN. With these group constants as input data the xy-core calculations are performed in four energy groups by the program IAMADY based on the diffusion theory.

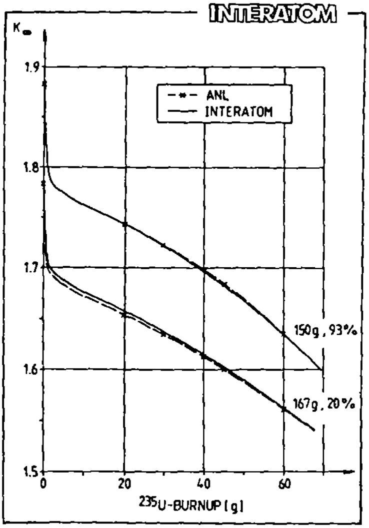


Fig. 1
K_∞ of benchmark calculations

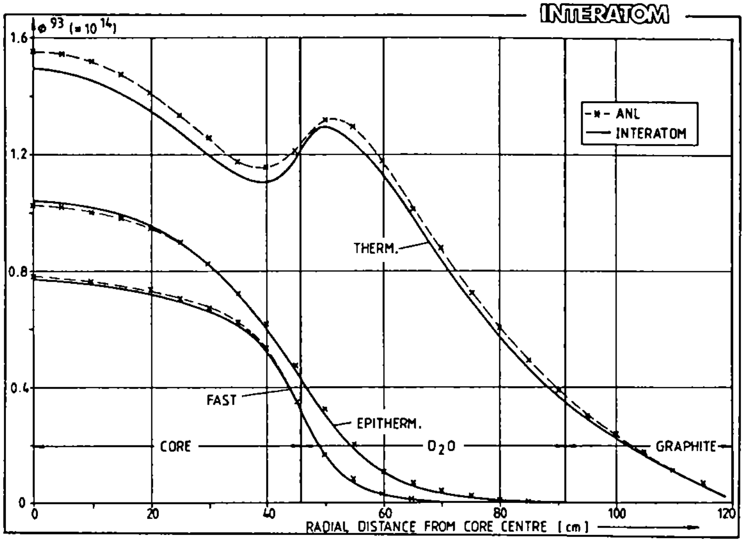


Fig. 2 Flux distribution of benchmark calculations

SHORT DESCRIPTION OF THE FRJ-2

The FRJ-2 is a DIDO-type heavy water moderated closed tank reactor operating at a nominal power of 23 MW. Its core is composed of 25 fuel elements. A large number of horizontal beam tubes and vertical facilities extend into the heavy water reflector. Six "signal arm" absorbers control the reactor. The arrangement of core, reflector and experimental facilities is shown in fig. 3a. The tubular fuel elements (cf. fig. 5,OD) consist of five concentric tubes, four inner ones of which contain the fuel, the outermost boron as a burnable poison. The core is composed of fuel elements with two different U-235 loadings of 150 g and 170 g with an enrichment of 80 %.

CALCULATION OF THE ACTUAL CORE STATUS

After having checked our methods at the idealized core configuration and boundary conditions of a benchmark problem we applied them to the actual HEU-core of the FRJ-2. This was done in order

- to obtain a further qualification under real conditions for a real core and reflector configuration and

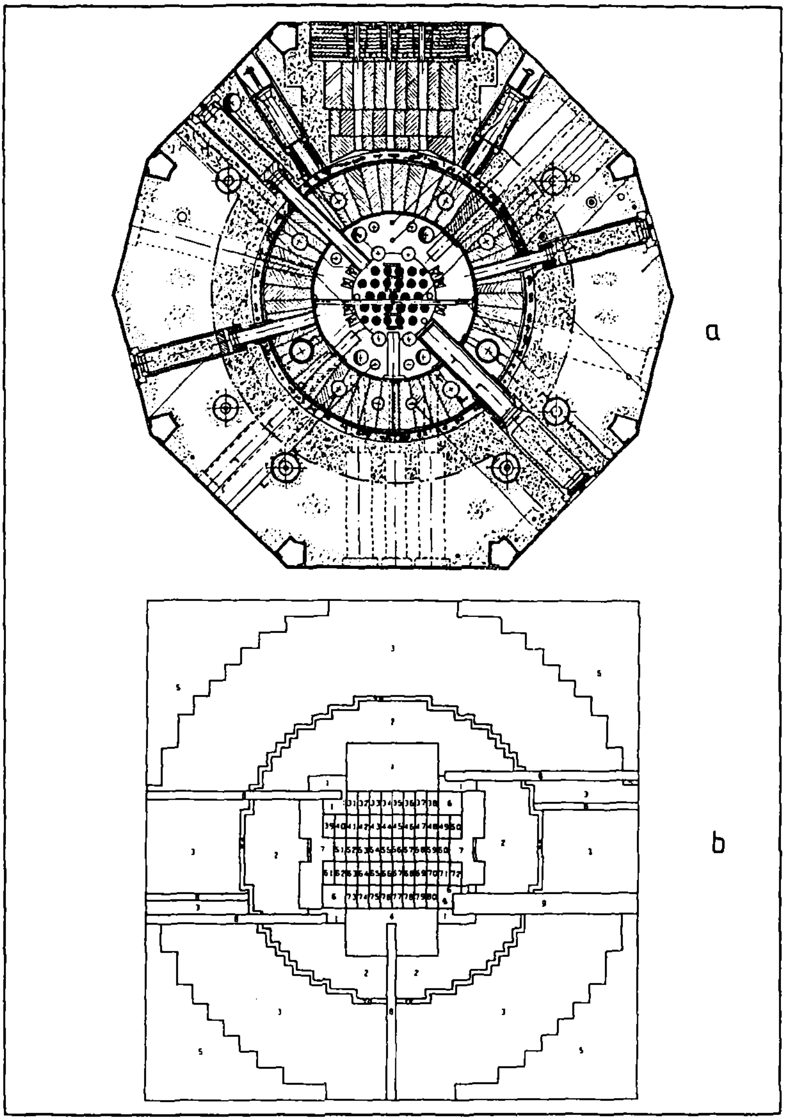


Fig. 3 **a** Cross section of FRJ-2 core and reflector
b Calculational model

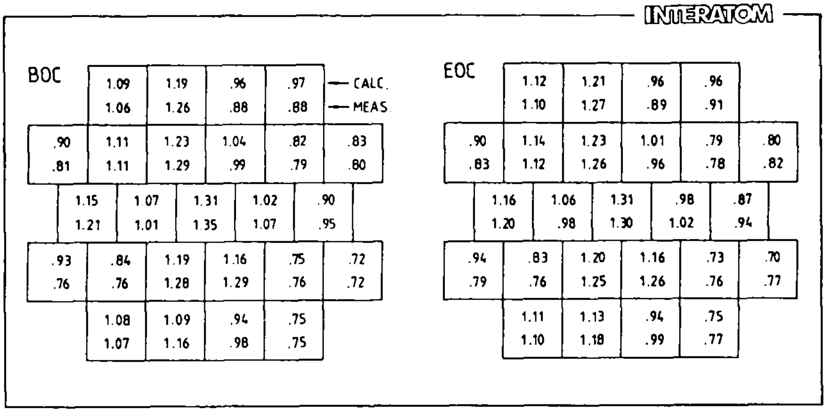


Fig. 4 Power peaking factors for HEU-core 2/83

- to assure that the used methods and models treat the special core and core-related components correctly.

The calculational model is given in fig. 3b. Calculations taking into account the absorbers were performed with the transport code DOT 4.2.

Seven states of currently used HEU-cores (four different cycles) were treated. The calculated excess reactivities for these states agree with the values from measurements within $\Delta\rho \leq \pm 1$ %. The power peaking factors from calculations and measurements agree in general better than within 10 % as shown in fig. 4.

DESIGN OF THE LEU FUEL ELEMENT

For the conversion to LEU originally a fuel element with 200 g U-235, U_3O_8-Al fuel at a density of 2.9 g U/cm^3 was chosen by the KFA-Jülich as a reasonable solution. Six elements of this type were fabricated by Nukem for irradiation tests. One of them was irradiated and discharged at a burn up of 55.98 %. Experience during LEU element fabrication has shown that the mechanical design must be modified in order to avoid high rejection rates. The new element design will in future provide for three bent fuel plates being connected to form the fuel tube by rolling into three aluminium webs provided with grooves. At present the three prebent plates are completed to form the fuel tube by electron beam welding. In fig. 5 the old design (OD) and the new design (ND) are shown for comparison. It is not intended to change other

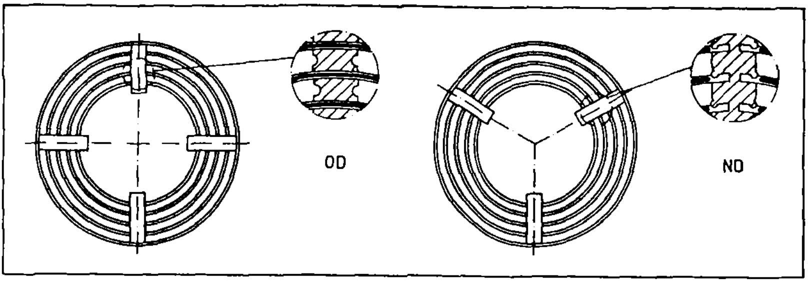


Fig. 5 Sketch of old design (OD) and new design (ND) fuel element

parameters, e.g. meat thickness and cladding thickness. Concerning the fuel material it was a clear outcome of the RERTR-meeting 1984 at ANL that for technical and economic reasons the use of silicide fuel for LEU-operation is preferable.

Consequently the fuel element for conversion to LEU will be a ND-element with U_3Si_2-Al-material.

CONVERSION PROCEDURE

In agreement with the licensing authorities the conversion is envisaged to be performed in two phases, after forerunning tests with 2 to 3 ND-elements with HEU-material (170 g U-235) as well as with LEU-U_3Si_2-material:

- Changing of the complete core from OD-HEU-elements to ND-HEU-elements.
- Conversion of the HEU-core with ND-elements to a LEU-core via a transition phase.

In this way the mechanical design change of the fuel elements will be taken into account sufficiently.

HEU-CORE WITH NEW DESIGNED ELEMENTS

With respect to the first phase of conversion the BOC- and EOC states of the HEU-core 2/83 were recalculated with the only change to ND-HEU-elements (same U-235 loading). This change effected a reduction of excess reactivity of about $\Delta\varrho$ = 1 % and only small deviations in flux and power distributions. Hence there are no serious problems to be expected from the neutron physical point of view. The result of a thermal hydraulic investigation was that

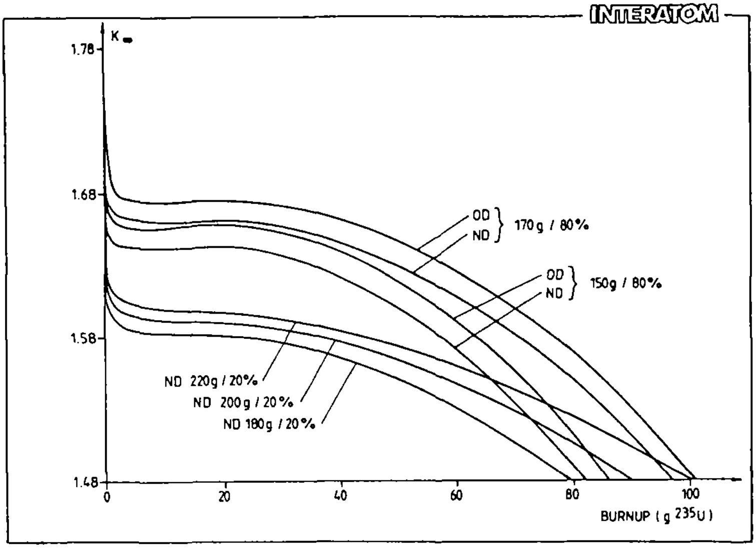


Fig. 6 K_{∞} for different fuel elements

there are also no objections against the change from OD- to ND-fuel elements with respect to flow instability.

LEU-CORE WITH UNIFORM U-235 LOADING OF FUEL ELEMENTS

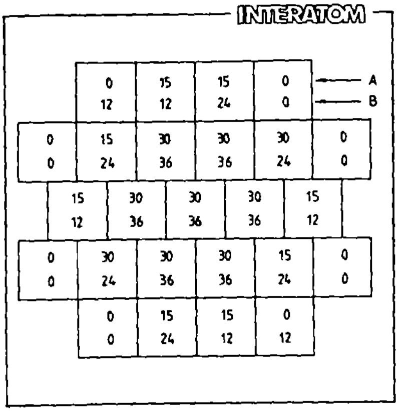
For a LEU-fuel element of new design with the originally envisaged U-235 loading of 200 g (3.1 g U/cm^3) cores with two different burn up distributions were investigated (fig. 7). Characteristic features are

- (A) 15 % burn up step; about 27 fpd cycle length; charging of 8 (9) fresh elements
- (B) 12 % burn up step; about 22 fpd cycle length: charging of 6 (7) fresh elements

The calculated reactivity values are within the assumed limits which we derived from calculated HEU-core states

- upper limit from BOC of core 2/83 (absorber angle 10.5 °)
- lower limit from EOC of core 4/84 (absorber angle 40°, completely withdrawn)

The corresponding HEU- and LEU-reactivity values are similar although there is a reduction of 5 % to 10 % for the infinite



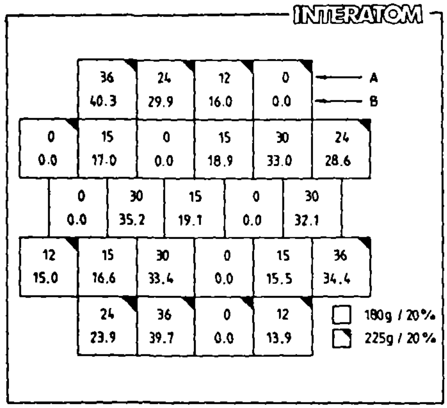


Fig. 7 Burn up distribution for 200 g-element

Fig. 8 Burn up distribution with two U-235 loadings

multiplication factor from HEU to LEU as shown in fig. 6. The compensation can be explained by the shift of the flux spectrum and the resulting increase of moderation outside the core in the LEU case.

According to the distribution with increasing burn up from outside to inside the core the power distribution is relatively flat. But it implies a shuffling of fuel elements at BOC.

The calculations proved the ND-LEU-element with 200 g U-235 loading as suitable for the conversion of the FRJ-2.

LEU-CORE WITH TWO DIFFERENT LOADINGS OF FUEL ELEMENTS

With the preceding results as a basis test calculations for the combinations 190 g/215 g and 180 g/225 g U-235 respectively were performed with respect to power distributions. The aim was to avoid the element shuffling at BOC. Evaluating the results the operator determined the combination of the U-235 loadings 180 g (2.8 g U/cm^3) and 225 g (3.5 g U/cm^3) for further investigations. A core configuration with an idealized burn up distribution is shown in fig. 8 with the characteristic features

- 15 %/12 % burn up step for 180 g/225 g
- 45 %/48 % discharge burn up
- about 23 fdp cycle length .
- charging of 4 (5)/3 fresh elements

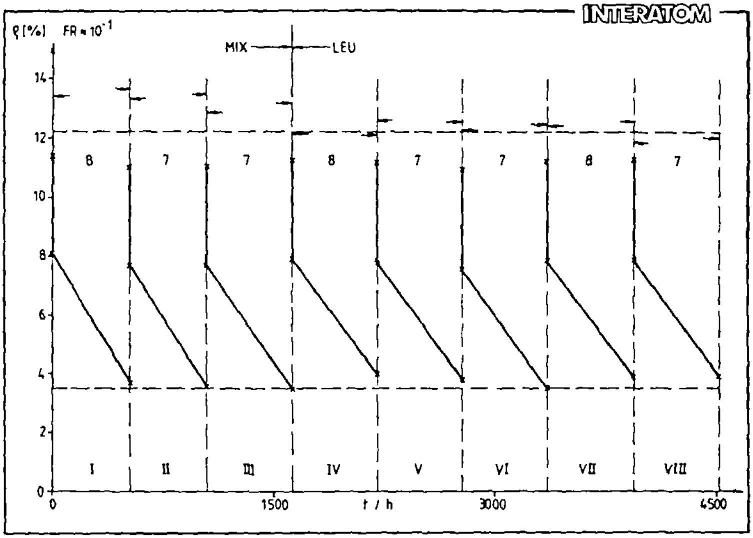


Fig. 9 Reactivity and power peaking factor (FR) in dependance on time

As there is no fuel element shuffling this idealized burn up pattern is repeated after 13 cycles. Such a chain was calculated with reasonable reactivity values within the assumed limits described in the preceding chapter.

Starting from EOC of HEU-core 2/83 (however with ND-elements) a transition phase from HEU to LEU was calculated exemplarily. Fig. 9 shows the reactivity as a function of time during the transition and for some cycles after complete conversion. Moreover the number of charged fresh LEU-elements is indicated. One can see that the conversion is completed at the beginning of the 4th cycle, i.e. after about 68 fpd. Up to the 7th cycle the complete chain was calculated without fuel element shuffling. At the beginning of the 8th cycle the elements were rearranged according to fig. 8,B obtaining a burn up pattern very similar to the idealized one (fig. 8,A). Fig. 9 shows additionnally that the radial (element averaged) power peaking factors (indicated by arrows) are in an acceptable range. The subcriticality for the shut down core during this chain of cycles was calculated to more than $\Delta\rho \approx -5.5$ %, whereas a minimum value of $\Delta\rho = -5$ % is allowed. A comparison of the thermal flux ($E_n < 0.625$ eV) of the HEU-core 2/83 at BOC and the 8th core (LEU) of the calculated chain shows in the LEU-case a reduction of about 15 % inside the core and about 10 % in the D_2O-reflector (fig. 10). The decrease of the fast group

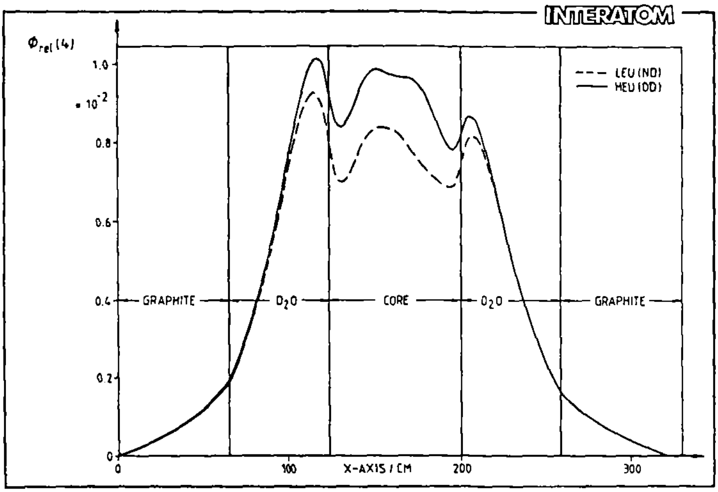


Fig. 10 Distribution of thermal flux ($E_n < 0.625$ eV)

fluxes is about 5 to 10 % in the core.

CONCLUSIONS

For the conversion of the FRJ-2 a LEU-element combination with two different loadings of 180 g and 225 g U-235 was evaluated as suitable. The corresponding densities of 2.8 g U/cm^3 and 3.5 g U/cm^3 are in a well qualified density region of U_3Si_2-fuel. With this element combination a LEU-core can be operated without element shuffling at BOC. For the transition phase from HEU to LEU core there are no serious problems to be expected. The first LEU-core will be reached after about 70 fpd. The thermal flux will decrease about 15 % in the core and about 10 % in the reflector. The change of the mechanical design will effect additional steps in the conversion procedure but no other serious nuclear or thermal hydraulic problems.

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