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HOR: Criticality Comparison Using a Nodal Code, Monte Carlo Codes and Plant Data

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At the Interfaculty Reactor Institute (IRI) of the Delft University of Technology the HOR pool-type research reactor has been in transition from high-enriched uranium (HEU) fuel to low-enriched uranium (LEU) fuel elements since 1998. At the same time the layout has been changing to a more compact core and some of the in-core and beam line configurations have changed. Reactor core calculations, reactor physics experiments, and measurements are continuously performed and evaluated. Monte Carlo codes and a nodal code are used for these calculations. There is a good agreement between the calculations and plant data. In addition feasibility studies have been performed for modifying and upgrading the HOR with the aim to improve the utilisation performance in combination with the installation of a cold neutron source. The calculations suggested that such an ultra-compact core (3x3 elements) with high fuel loadings is possible.

KEYWORDS: test reactor, MTR fuel, HEU, LEU, criticality, Monte Carlo, nodal methods

1. Introduction

The core neutronic simulation of research reactor core reloads and cycles histories remains a challenging task, especially since the reactors are typically small and non-uniform in layout. The presence of irradiation or experimental rigs within the core, sometimes loaded with samples with large neutron absorption, adds another interesting twist. The use of in-core control rods, also to overcome the begin of cycle excess reactivity, add steep axial flux profiles and a large variation in the flux and burn-up profiles during the cycle. Finally, the ex-core configurations are also quite complex with beam lines, reflector elements and other experiments having a noticeable effect on the core reactivity and flux profiles.

At the Interfaculty Reactor Institute (IRI) of the Delft University of Technology the HOR pool-type research reactor has been in a transition from high-enriched uranium (HEU) fuel to low-enriched uranium (LEU) fuel elements since 1998. At the same time the layout has been changing to a more compact core and some of the in-core and beam line configurations have changed.

In support of the transition from HEU to LEU, core reactor calculations and reactor physics experiments and measurements are continuously performed and evaluated to ensure safe and optimal operation. During the transition and part of normal reactor operations the reactivity, flux distributions, power distributions, burn-up distributions, and control rod reactivity were measured and calculated.

A horizontal map of the mixed HEU-LEU cycle 0304 is given in Figure 1. The grid has six

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columns (A-F) and seven rows (1-7). This compact core has 20 fuel elements. In detail: two standard HEU fuel elements (D), one HEU control- fuel elements (DC), three LEU control-fuel elements (EC), and 14 standard LEU fuel elements (E). Two irradiation facilities, Bigbebe and Smallbebe, are available. The core is surrounded by 19 beryllium reflector elements (R) and a single beryllium-oxide reflector element in position A7. The HOR reactor utilizes typical plate type MTR fuel element (19 plates) and a control-rod fuel element (10 plates) where the absorber blades are inserted. A detailed description of the fuel- and control-fuel element can be found in reference [1].

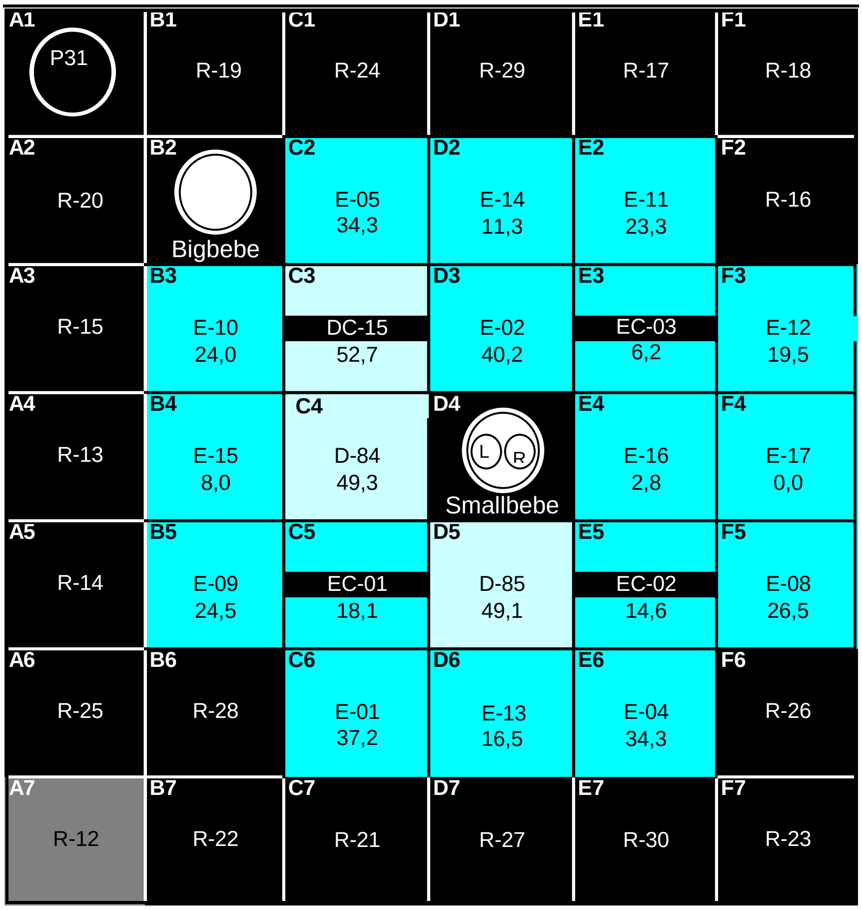

Fig. 1 Horizontal map of core 0304.

Since the flux levels within the current HOR design is too low to really support scientifically competitive neutron beam research, feasibility studies have been performed for modifying and upgrading the HOR with the aim to improve the utilisation performance in combination with the installation of a cold neutron source. The design should be for the licensed thermal power level of 3 MW and the core layout such that the maximum flux should occur at the position of the beam port entrance coupled with a cold neutron source.

In this paper a summary of the results of calculations performed during the transition and comparisons with measured data are provided with the focus of recent improvements made in the OSCAR-3 core representation and few-group cross section library. Updated results obtained for the proposed compact HOR-2 core layout is also given.

2. Calculational Methods

2.1 The INAS Code System

At IRI a comprehensive reactor code system and evaluated nuclear data called INAS was implemented for detailed mixed core calculations. This reactor physics code system is based on the JEF-2.2 [2] evaluated data, the NJOY [3] code, and the SCALE [4] code system. The reactor calculations are performed in a fine group structure (172 XMAS group structure) and all the geometrical detail is modelled explicitly in the three-dimensional Monte Carlo code KENO-Va. [4]

The Monte-Carlo code MCNP4C-2 [5] is also used. A MCNP model was established to calculate present HOR configurations and to study the upgrading alternatives. The model describes the fuel assemblies by individual fuel plates and uses 15 axial regions along the height of the fuel. All the beam tubes are represented in the model while the insertion of the control absorbers can be changed individually.

The material composition of the fuel is given per fuel assembly and per axial region. The burn-up dependent fuel composition is determined separately (from the INAS system) making use of an axial burn-up shape determined from nodal 3-D calculations. For the calculations the ENDF/B-VI data library was used as distributed with the MCNP4C-2 code package.

In addition, the OSCAR-3 [6] code package, based on a three-dimensional nodal diffusion method, is used to perform core follow calculations in few groups making use of homogenised assembly cross sections.

2.2 The OSCAR-3 Core Calculational System

OSCAR-3 [7] [8] [9] is an acronym for an “Overall System for the Calculation of Reactors”. The code system has been developed by NECSA over many years and the current focus is on application to plate-type research reactors with emphasis on validation by comparison to plant data, measurements and other calculations. The code is used in the daily support of the SAFARI-1 reactor [10]. The validation of the code has focused on several areas of modelling. For example the representation of the beam lines and experimental rigs outside the core has been studied for the HOR reactor and compared to reference Keno-Va results [11] while the representation of experimental and irradiation rigs inside the reactor has been studied for the R2 reactor [12].

2.3 Updated OSCAR-3 Models and Few-group Cross-Section Library

Improvements were made in the core nodal representation of the reflector regions above and below the active fuel height represented by fifteen 4 cm meshes. Whereas only a single axial node was used to represent the top or bottom reflector, an additional node or material mesh has been added both to the top and bottom reflector regions. This enables the preparation of two sets of cross sections to distinguish between the areas directly above and below the active fuel, which typically contains more structural materials, and the water reflector beyond. The additional meshes should also improve the accuracy of axial flux profiles and enhance convergence behaviour.

In previous work [11] [1] a five group cross-section library was utilized in the HOR analysis, which corresponded with the group structure used historically at IRI in the SILWER nodal code. In this work the few group library was updated and regenerated with six groups, including a second thermal group, and thus adopting the group structure used in SAFARI-1 analysis [10]. The number of isotopes treated microscopically in the OSCAR-3 core follow calculations was at the same time increased from 16 to 38 to include americium and curium in addition to the uranium-neptunium-plutonium burnup chains. A more detailed representation of the cerium-promethium-samarium burnup chains was also included.

A mismatch between the amounts of ^{235}U burned per unit energy delivered was observed between OSCAR-3 and the INAS code system, both based on JEF-2.2. On closer inspection the isotopic energy release per fission values on the HEADE fine group cross-section library, based on the WIMS7 cross-section library [13] were found to be considerably larger (nearly 4% in the case of ^{235}U) than the values in the JEF-2.2 library. The reason for this is still being investigated and its effects on results and inventory reporting are being investigated as part of future work. For consistency with the INAS code system the energy release per fission values were updated to the JEF-2.2 values for the generation of the updated HOR few-group library (used in this work).

In a further step to try and improve the consistency between the OSCAR-3 and KENO-Va calculations the starting conditions of the OSCAR-3 core follow calculations were updated. The OSCAR-3 core-follow analysis started with cycle 9703, the last cycle fully loaded with HEU fuel, and therefore the fuel and control rod elements' burnup (mass of ^{235}U left) and axial burnup shapes must be given as input. Whereas the data was originally taken from historical SILWER code results and adjusted to give the correct ^{235}U masses, the ^{235}U number densities and axial shape are now derived by the same method by using the KENO-Va pre-processing code. It should be noted that although this is seen as an improvement the INAS fuel-element ^{235}U mass calculations, based on a combination of 2-D core calculations and copper wire measurements, is not a validated reference. Since OSCAR-3 performs the actual core follow calculations, with the control bank positions and power history taken into account, one will expect deviations between the cycle starting conditions as calculated in OSCAR-3 and INAS.

2.4 Measurements

After each core reload operation the (differential) reactivity worth of all four rods is measured separately by using an inverse kinetics calculation method for a point core model. In [1] details on the measurement method is provided.

The observed critical bank position at begin of cycle or startup is recorded for each cycle together with the coolant temperature at the time of the measurement. This critical position corresponds to a situation with all four rods in equal bank position.

3. Results for HOR Cycle Analysis

3.1 Transition from HEU to LEU

Until the end of cycle 9703 the reactor was operated using HEU (High Enriched Uranium, 93 $^{w}/_{o}$ ^{235}U) fuel. This cycle was selected as the starting point for the OSCAR-3 analysis to be performed and compared to the INAS results. In cycle 9801 two LEU (Low Enriched Uranium, 19.75 $^{w}/_{o}$ ^{235}U) fuel elements were introduced in the HOR reactor. Up to cycle 0304, the most recent reload history to be included in this work, eighteen reloads have been performed.

In Figure 2 the progress of the transition is depicted. Each of the assembly types is shown relative to the final outcome of the transition to the compact LEU core envisaged. During the conversion process the core size (number of fuel assemblies) was reduced from 30 fuel elements to 20 fuel elements (1.5 relative to 1.0). The compact core was accomplished in cycle 0104. At the same time the number of beryllium reflector elements has increased while a central irradiation facility (CIF) was introduced in the centre of the core. The two empty positions, initially in row 1, were also filled by some of the beryllium reflector elements (total number of core elements increased). The systematic increase in the LEU fuel assemblies can clearly be seen until cycle 0103 after which the first LEU control-fuel element was introduced. Further two LEU control-fuel elements were since introduced with only a total of three HEU elements remaining.

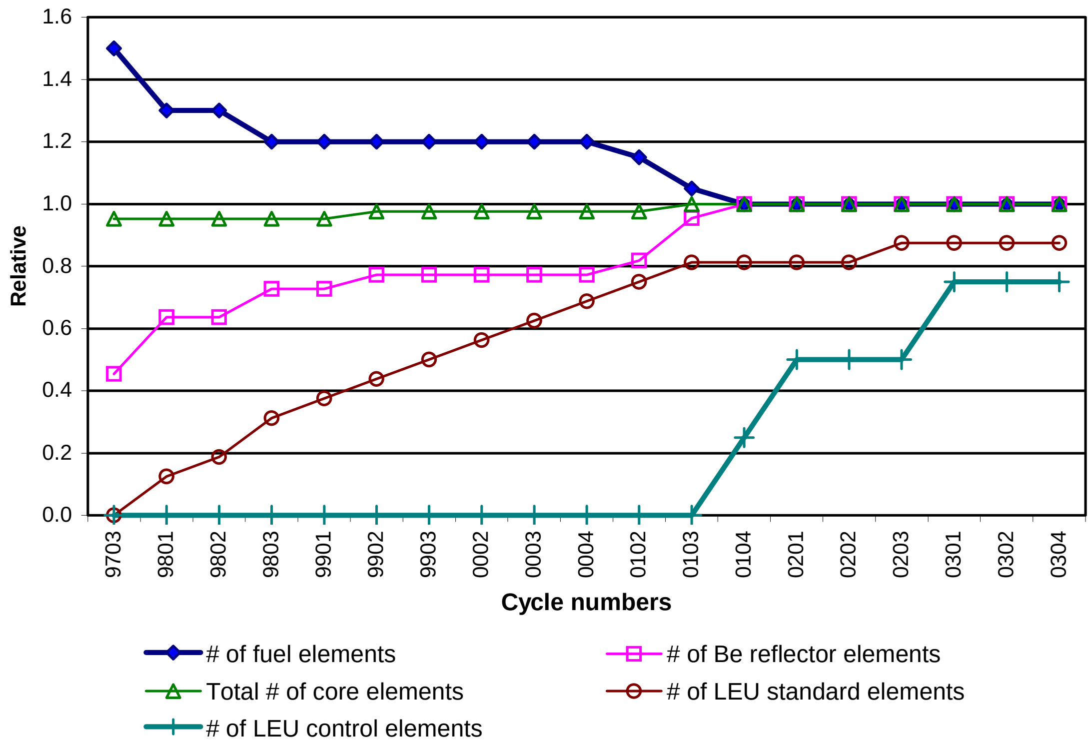

Fig. 2 Relative numbers of assemblies in core.

3.2 Calculated BOC k-effective

The INAS calculations showed good agreement with the operational (cycle first criticality) and measured (excess reactivity) data before the transition to LEU started. However, after the first LEU fuel elements were introduced, increasing discrepancies were found [14] between the calculated and the measured reactor physics characteristics of the mixed cores. To improve the full mixed HEU/LEU core reactor physics calculations several changes in the use of the different codes are being analysed, a process that is on going. For example, special attention was already given to the modelling of the beam tubes [11] with the focus on the reactivity effects of the beam tubes when emptied (utilized in experiments) or full (flooded with water). It was found that the negative reactivity effect could be as large as –0.5% and models were updated to take the status of the beam tubes into account.

Another example of an attempt to improve results was the adjustment of the ^{235}U number densities prepared for KENO-Va calculations. It was found that the burnup of fuel, as calculated with the SAS6 (a modified SAS2H sequence of the SCALE where XSDRNPM is replaced by WIMSD4), under estimates the amount of ^{235}U burned. The corrections that were introduced worked well for the HEU cycles. However, it was found that as the transition progressed the discrepancy between the KENO-Va results and the begin of cycle (BOC) critical condition (k-eff = 1.0) increased.

The calculated begin of cycle (BOC) k-eff for the given critical (k-eff=1.0) control rod positions and temperature conditions are shown in Figure 3 for different cycles. The KENO-Va results, although calculated at 20^0C were adjusted to the actual plant conditions by correcting the k-eff at 20^0C by -22 pcm/^0C. It can be seen that the difference from the actual operation history (k-eff = 1.0) increases from less than 0.5% to over 1%.

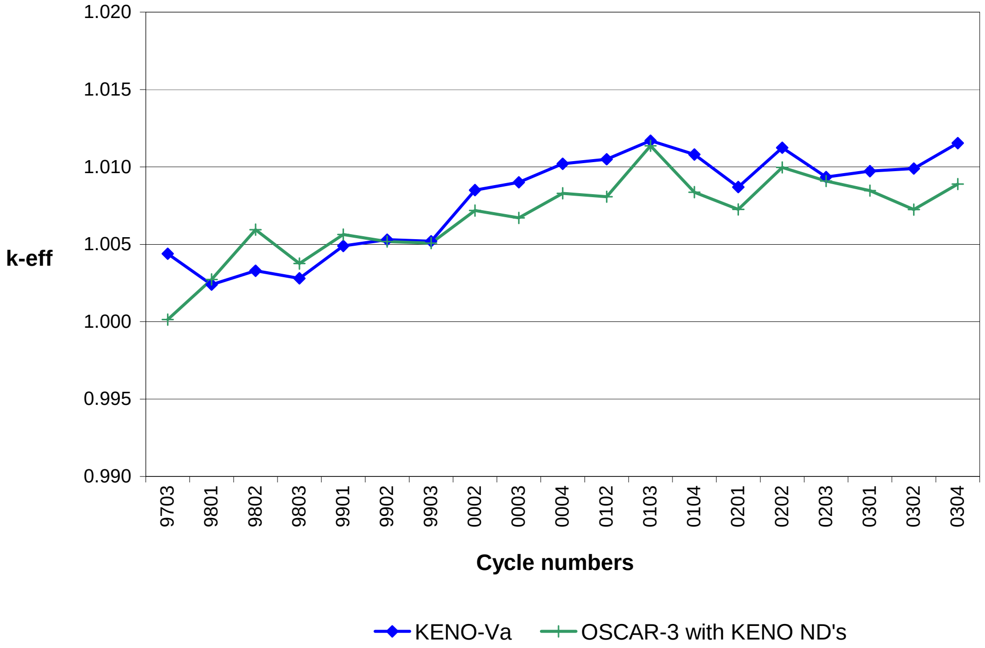

Fig. 3 BOC calculated k-effective from INAS ^{235}U mass distributions compared with start-up critical conditions.

Also shown in Figure 3 are the OSCAR-3 k-eff results for BOC calculations making use of the number densities from the KENO-Va calculations. The most important isotope number densities (^{234}U – ^{238}U; ^{239}Pu – ^{241}Pu) were updated with the rest taken from OSCAR-3 cycle analysis (see below). The results show excellent agreement between KENO-Va and OSCAR-3 with a maximum difference of 430 pcm (pcm defined as 10^{-5} Δk-eff) and average difference of only 155 pcm (< 0.2% Δk-eff). Compared to operation the two sets of results shows the same trend of an increased discrepancy. This may indicate an inconsistency in the burnup calculation in SAS6 (where the input number densities for KENO-Va are obtained from) or that the correction applied to the ^{235}U number densities is insufficient.

A second set of OSCAR-3 calculations (cycle analysis) was performed but this time the reactor multi-cycle operation history was simulated in detail. The control rod positions, beam line status (experiment / flooded with water) and temperatures were specified for each cycle. The starting conditions for cycle 9703, specifically the fuel and control-fuel element ^{235}U masses and burnup profiles, were once again taken from the INAS code system. However, in this case the corrections to the ^{235}U number densities were not applied.

OSCAR-3 now calculates its own power distribution and ^{235}U mass distributions. The BOC critical control bank k-eff results are shown in Figure 4 and compared to the KENO-Va results also shown in Figure 3. Also shown are earlier OSCAR-3 results reported in [1] and obtained before the changes in the core model and cross-section library (as described in Section 2.3) have been made. The set is called "OSCAR-3 (Old Library)".

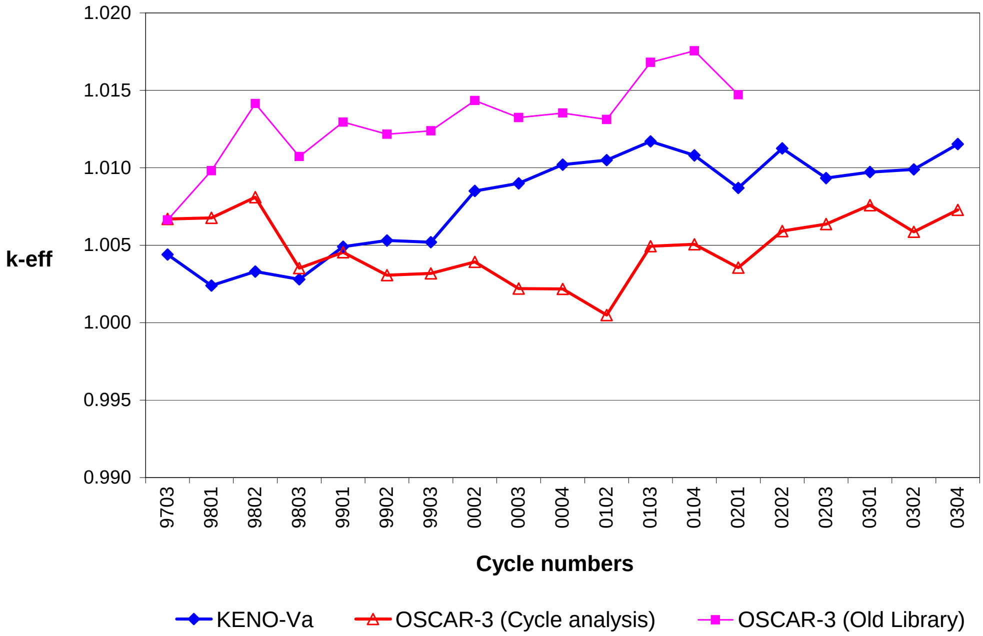

Fig. 4 BOC calculated k-effective compared with start-up critical conditions.

First of all it can be seen that the OSCAR-3 cycle analysis results do not follow the same trend as the KENO-Va results although an increase in the k-eff is seen from cycle 0102 onwards. In general the OSCAR-3 results shows smaller discrepancies compared to critical BOC startup (k-eff = 1.0) with differences below 800 pcm. Compared to the results obtained with the old library a significant improvement in the OSCAR-3 results can be seen. No attempt was made to quantify the exact contributions of each of the library and model updates. However, the larger part of the improvement is due to the update in the energy release per fission values. Since these values decreased by about 4% compared to the old library the amount of ^{235}U burned per cycle increased which naturally led to the lower k-eff values calculated.

Part of the improved OSCAR-3 results must also be due to the other model improvements. In a comparative study based on SAFARI-1 HEU cycles it was shown that the k-eff values are over estimated when fewer than six energy groups are used [15]. The difference between five and six groups was just below 200 pcm while for four groups it increased to over 800 pcm. For LEU cycles the group effects are expected to be larger due to more prominent spectrum effects.

So it is not easy to conclude what the (main) reason for the increase in the KENO-Va k-effective values could be. One possibility is that the SAS6 burnup sequence, based on simplified cell calculations are under estimating the amount of ^{235}U burned. Also the exact power level (MWd) can be important to determine the burnup of the fuel, which is important for the densities input in the Monte Carlo and nodal codes. Work to quantify these effects and to find a solution is continuing.

3.3 Fuel Element ^{235}U Mass Distribution

Since OSCAR-3 makes use of the INAS ^{235}U mass distribution as a starting condition the core and fuel element masses are identical for cycle 9703. However, the power distributions and the resultant element burnup during the cycle is calculated independently in the two code systems. One will expect differences to develop over time. In Figure 5 and 6 the element ^{235}U mass distributions are given for INAS and OSCAR-3 for cycle 0103 (just before the first LEU control-fuel element was introduced) and for the most recent cycle 0304. In each position the element ID, % mass burned according to INAS, OSCAR-3 and the difference between the two codes systems are given.

In general the burnup given by the two code systems compares well with most elements comparing within 1%. In cycle 0103 the largest difference is 3.2%, that represents 3.2 gram and in cycle 0304 a difference of 5.0% representing 5.0 gram was found. Incidentally it is the same HEU control-fuel element (DC-15) that displays these large differences. On closer inspection it was found that the OSCAR-3 burnup is almost always larger than the INAS values and also that the control-fuel elements exhibit the largest discrepancies. The core total ^{235}U mass as calculated in OSCAR-3 is in both cases just over 30 gram less than the INAS estimates. The larger burnup in OSCAR-3 (and associated lower core mass) is consistent with the lower k-eff values calculated at BOC.

The larger differences in the control-fuel elements can possibly be explained by the power distribution assumed in the cycle depletion in the INAS approach. The power delivered by the control-fuel elements during the cycle are obtained from the BOC power distribution as determined from copper wire activation and 2-D calculations. Since the control rods are deeply inserted at BOC the control-fuel elements will produce a lower power than later in the cycle when the control rods are further withdrawn. Since the actual control rod position history is included in the OSCAR-3 cycle analysis these effects are correctly taken into account.

A1 R-11	B1 R-19	C1 R-24	D1 R-29	E1 R-17	F1 R-18
A2 R-20	B2 R-33	C2 E-03 22.8 23.3 0.5	D2 E-12 2.6 2.7 0.1	E2 E-07 13.9 14.2 0.3	F2 R-16
A3 R-15	B3 E-01 23.4 24.0 0.6	C3 DC-05 54.4 55.5 1.1	D3 D-74 46.0 46.2 0.2	E3 DC-15 34.5 37.7 3.2	F3 E-10 7.2 7.6 0.4
A4 R-13	B4 E-06 16.7 16.9 0.2	C4 D-86 45.9 47.2 1.2	D4 D-75 41.3 41.7 0.4	E4 E-09 8.3 8.8 0.5	F4 E-13 0.0 0.0 0.0
A5 R-14	B5 E-02 23.8 24.3 0.5	C5 DC-13 54.9 55.3 0.5	D5 D-87 47.1 47.4 0.3	E5 DC-14 37.5 40.0 2.5	F5 E-08 10.3 11.1 0.8
A6 R-25	B6 R-28	C6 E-05 18.1 18.8 0.7	D6 E-11 5.0 5.2 0.2	E6 E-04 19.3 20.2 0.9	F6 R-26
A7 R-12	B7 R-22	C7 R-21	D7 R-27	E7 R-30	F7 R-23

Fig. 5 Element % mass ^{235}U burned according to INAS and OSCAR-3 for Cycle 01-03.

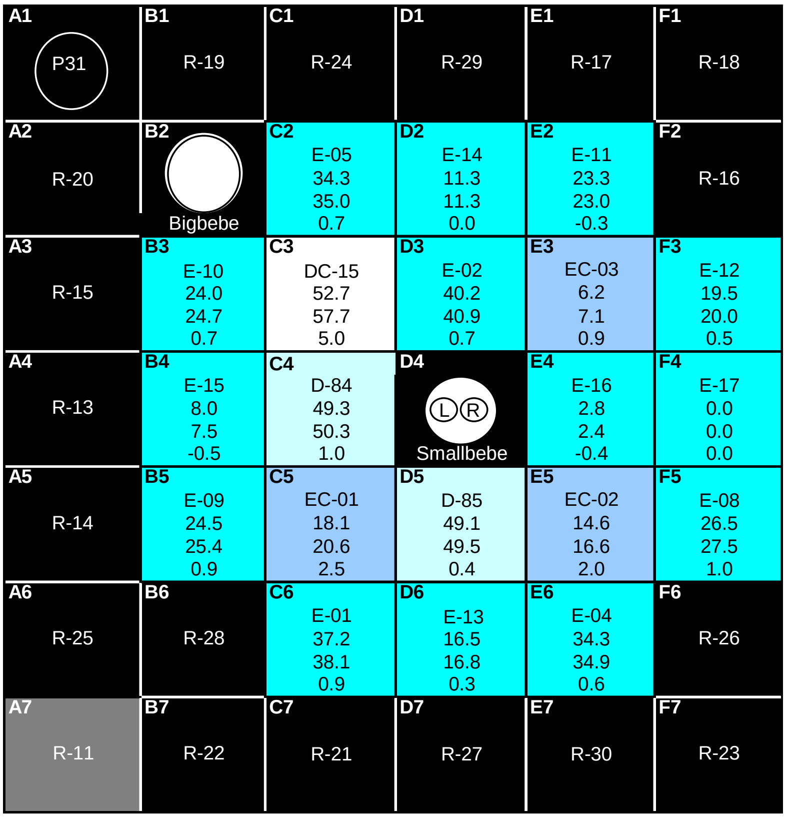

Fig. 6 Element % mass ^{235}U burned according to INAS and OSCAR-3 for Cycle 03-04.

3.4 Control Rod Reactivity

The prediction of control rod reactivity worths is important not only for safety studies but also for reactor operations in predicting cycle lengths and critical bank positions. As a next step the reactivity worth of individual control rods were re-investigated for the updated OSCAR-3 cross-section library. In [1] the incremental control rod worths (s-curves) were shown as calculated with KENO-Va and OSCAR-3 and compared with measurements. In the calculations the exact control rod configuration of the measurement were followed with one rod moving from 100% to 60% extracted, 60% to 30% and then 30% to 0%, in each case with the other three rods at the insertion depth that kept the core critical. The s-curves showed a favourable correspondence between the measurement and the calculated values. The tendency is for the calculations to slightly over-predict the measured value.

The conclusions made in [1] are still valid for the newest OSCAR-3 results obtained after the library update. In Table 1 the updated OSCAR-3 results are shown. The over-prediction of the measured control rod reactivity has continued and for three of the four rods actually increased. Similar behaviour was seen for two other cycles analysed.

Table 1 Cycle 0103 individual control rod reactivities [in %]

Case		100%-60%	60% - 30%	30% - 0%	Total	Delta
Rod 1	KENO-Va	0.725	1.200	0.676	2.601	0.158
	OSCAR-3 (Old Library)	0.748	1.273	0.671	2.691	0.249
	OSCAR-3	0.727	1.306	0.713	2.746	0.303
	Measured	0.751	1.106	0.586	2.443	
Rod 2	KENO-Va	0.706	1.320	0.666	2.692	0.149
	OSCAR-3 (Old Library)	0.755	1.258	0.653	2.665	0.122
	OSCAR-3	0.758	1.257	0.650	2.665	0.123
	Measured	0.719	1.195	0.628	2.543	
Rod 3	KENO-Va	0.686	1.242	0.685	2.613	0.025
	OSCAR-3 (Old Library)	0.686	1.251	0.646	2.583	-0.005
	OSCAR-3	0.715	0.823	0.646	2.183	-0.405
	Measured	0.736	1.255	0.597	2.588	
Rod 4	KENO-Va	0.725	1.389	0.636	2.751	-0.014
	OSCAR-3 (Old Library)	0.725	1.333	0.683	2.740	-0.024
	OSCAR-3	0.752	1.391	0.701	2.844	0.079
	Measured	0.865	1.288	0.612	2.765	

4. Ultra Compact Core

4.1 HOR-2 layout

In previous work the HOR-2 core design has been described [16]. Figure 7 gives a general view of the proposed core and beam arrangement showing the core only partially loaded with fuel and reflector assemblies. The core has a 3x3-arrangement, using LEU silicide fuel at the highest licensed and industrially available U-density of 4.8 g/cm^3. The core is composed of five standard fuel assemblies with an initial ^{235}U-loading of 546 g each and four control fuel assemblies with an initial ^{235}U-loading of 413 g each. The core is beryllium reflected at all sides, except at top and bottom. Moreover, at one core side the beam ports, including a cold neutron source facility, are embedded in a beryllium reflector block. A horizontal cross section of the 9-element core as plotted by MCNP is shown in Figure 8.

4.2 MCNP and OSCAR-3 calculations

MCNP calculations have been performed with two types of (conceptual) fuel: HOR-1 and HOR-2. Only the HOR-2 results are displayed in this paper and compared with updated OSCAR-3 results. The reader is referred to [16] for the HOR-1 configuration results and the detailed fuel description.

A set of calculations was performed with uniform burn-up, i.e. where all fuel assemblies in the core have the same burn-up. The dependence of k_{eff} on uniform burn-up is shown in Table 2. The reference MCNP results are shown and compared to two sets of OSCAR-3 results. The first set corresponds to the results reported at [16] and was calculated utilizing a six-group homogenised cross section library. In the second set an updated library was used reflecting two changes. First of all the updated energy release per fission values from JEF-2.2 were implemented as was done for the HOR cycle analysis. The second change is that the number of energy groups has been increased to eight. Although a study based on the HEU SAFARI-1 reactor [15] has shown that the use of six energy groups are adequate for cycle analysis it was not clear if the conclusion will also be valid for the ultra-compact LEU core, surrounded by the beryllium reflector. Additional energy groups may help to capture spectrum effects not included in the assembly calculation.

The OSCAR-3 results for the fresh core (0% burned) are nearly identical and therefore show no change due to the increased number of energy groups. The difference of only 230 pcm compared to the reference MCNP result is in any case very small. When the OSCAR-3 results for the different burnup

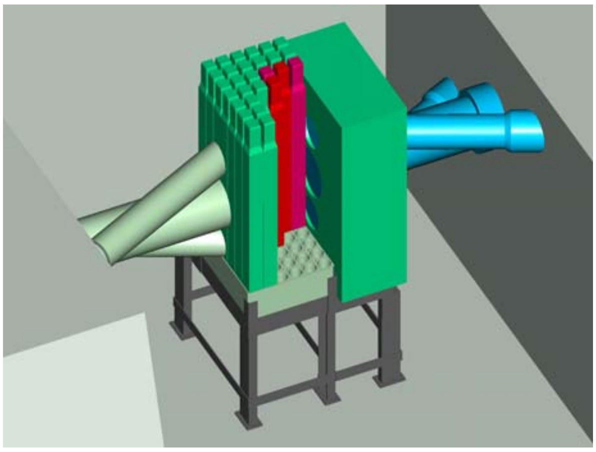

Fig. 7 General view with partially loaded core.

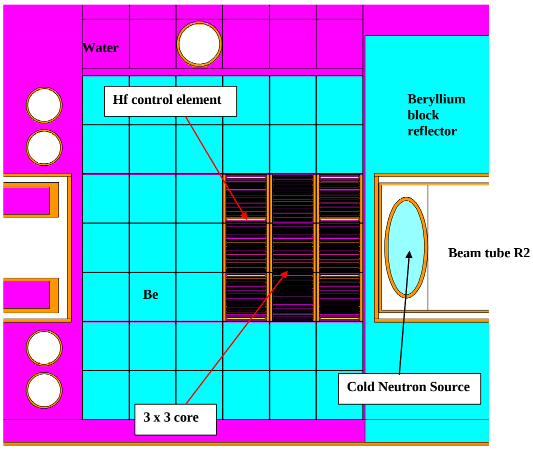

Fig. 8 Layout of a 9-element core.

cases are compared it is clear that the update of the energy release per fission values shows some improvement compared to the reference MCNP results with the difference nearly reduced by a factor of two.

Table 2 Comparisons of HOR-2 k-eff values between MCNP and OSCAR-3 for core with uniform burn-up

Element burnup %	MCNP (reference)	OSCAR-3 (Old Library)		OSCAR-3 (Updated / 8 groups)	
	k-eff	k-eff	pcm	k-eff	pcm
0	1.13934	1.14167	233	1.14164	230
6.4	1.10743	1.11175	432	1.11087	344
18	1.06423	1.07168	745	1.06893	470
28.2	1.01903	1.03237	1334	1.02762	859

A core with a uniform burnup of 17.0% was derived from realistic cycle calculations to simulate the BOC core conditions (achieve the same k-eff value). The critical rod position, the shutdown reactivity and the excess reactivity were calculated. In addition, the reactivity when any two control rods are in the fully withdrawn position while the other two are fully inserted, was also determined. In Figure 9 the reference MCNP results are compared with the updated OSCAR-3 results (updated energy release values and 8-groups).

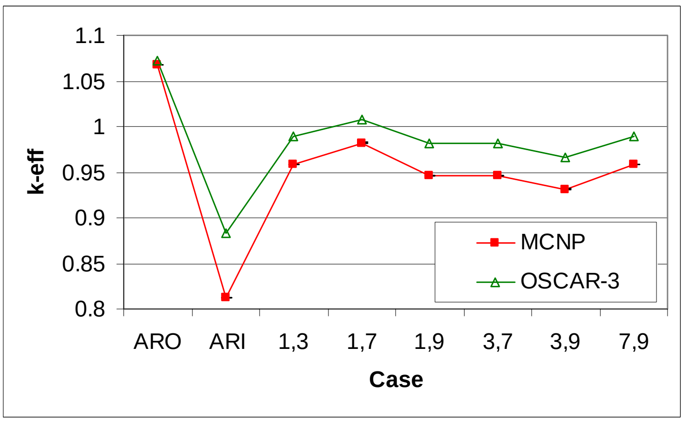

Fig. 9 HOR-2 BOC k-eff for different control rod configurations

Very promising results were obtained with OSCAR-3 for a un-rodded core (ARO) even though it is such a compact core layout. As shown in Table 2 the updated library has led to smaller differences due to burnup. The OSCAR-3 code system could be used to investigate cycle lengths and to compare different reload patterns. The estimation of the control rods reactivity effects is, however, under-estimated by some margin. These studies will benefit from an improved control rod representation in the assembly calculation with more accurate homogenised cross sections and control rod worths.

5. Conclusion

An overview of the criticality comparison using a nodal code, Monte Carlo codes and HOR plant data is given in this paper. Reactivity effects concerning the beam tube configuration, control rods reactivity effects and element burnup distributions have been calculated before with some updated results shown. These comparisons have lead to improvements in the modelling and using of data in both code systems.

The update of the energy release per fission values in the OSCAR-3 fine-group library to the JEF-2.2 values and the increase to a six-group homogenised few-group library have improved the OSCAR-3 results compared to plant data. It has also highlighted a possible reason for the deviating KENO-Va results in so far as the SAS6 sequence may underestimate the ^{235}U burned in LEU fuel. This was also seen in the larger burnup predicted in the OSCAR-3 cycle analysis compared to the INAS core burnup maps. The updated library has not invalidated any of the previous reported results with, for example, similar control rod reactivity worths found.

A separate study has been done for an upgrading of the HOR to an ultra-compact core (3x3 elements). The update of the energy release per fission values has also benefited the OSCAR-3 results for the uniform burned un-rodded core layouts. The increase of the number of energy groups from six to eight had a negligible effect on results. The upgrade to the ultra-compact core is feasible and the nodal code OSCAR-3 can be very useful to calculate a large number of possible core configurations.

In general there is good agreement between the codes and plant data. Some work is in progress to evaluate the burnup models and to improve the OSCAR-3 control rod modelling for the HOR-2 reactor. A detailed study on the effects of the energy release per fission values on cycle analysis and also in particular on inventory reporting is foreseen while a detailed study of the number of few-groups and few-group energy structure could be useful.

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