Conversion of the BER II from HEU- to LEU-fuel

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1. Introduction

The BER II is a swimming pool reactor and mainly used for neutron scattering experiments. The BER II has been operating since 1973, and was upgraded from 1985 to 1991 to increase the neutron flux. Hereby, the power was increased from 5 to 10 MW. In addition the core size was decreased and was then encompassed by a beryllium reflector. Finally, a Cold Source was installed.

When the reactor restarted 1991 with HEU-fuel, we applied for a license to convert to LEU-fuel, which was granted in 1993. However, we still had to solve the problem of getting rid of our spent LEU-fuel assemblies. At that time, we also had about 30 HEU-assemblies on storage. This was the main reason why we only started conversion after August, 1997, when our HEU-fuel was used. At this point, we signed a contract with US-DOE dealing with the return of the spent fuel assemblies to the USA.

Since then, at each refueling, we have exchanged 2 to 5 HEU-fuel assemblies by LEU-assemblies. Each time we had to perform several measurements to ensure for the necessary safety requirements. Even after the completion of the conversion in February 2000, we have to do this also for each pure LEU-core.

These measurements and their results are presented in the following paper.

Loading procedure for a new mixed core

Before building a new core we have to prove that the stuck rod criteria is fulfilled. In our case the stuck rod criteria means, that when the most effective of the 6 control rods is drawn out to its end position, there remains a shut down reactivity of at least 1%.

The calculation of the excess reactivity is no problem for a pure HEU- or LEU-core with a smooth distribution of U-235 within the core. This is not the case in a HEU/LEU-mixed-core, because LEU-fuel plates contain about twice as much U-235 as HEU-fuel plates.

Thus, we can calculate the excess reactivity only roughly, and in order to measure the excess reactivity our loading procedure has to be interrupted for calibration of the control rods.

The calibration is done by measuring the positive reactor period after a control rod is withdrawn about 30 mm from the critical position. Thereafter, the released reactivity is compensated by driving in another control rod. This procedure is repeated approximately 20 times until the control rod with a length of 60 cm is fully drawn out. The calibration of all 6 control rods, in this manner, takes about two days.

After loading two fresh LEU-fuel assemblies into the core, all 6 control rods are calibrated. A further loading of two assemblies is only permitted, if the calibration results show that there still remains a sufficient shut down reactivity.

In repeating this procedure, we usually achieve replacing 4 HEU-fuel assemblies per new mixed core. On two occasions, we were even able to replace 6 assemblies. This was sufficient to run the reactor for 100 days without reloading.

Measuring of neutron flux distribution

After loading a new mixed core and proving that the stuck rod criteria are fulfilled; the next step is to measure the neutron flux distribution within the core, which has be done twice. The first time under normal operating conditions, which means that all 6 control rods are equally drawn out. For the second measurement of the 6 control rods, one is fully driven in, while one control rod is drawn out 100 mm above the 4 remaining rods. This simulates an extremely irregular neutron flux, whereby, the power distribution for a sufficient burn-out margin has to be proven.

The neutron flux distribution is determined by activating copper wires, which are inserted into 50 cooling channels over the whole core. These wires are then fixed on aluminum plates, which can be adjusted between the surrounding fuel plates.

After irradiation, at 1.5 kW, the wires are removed and the Cu-60 activity is measured for each wire in 12 different positions. Because the activity is proportional to the neutron flux a three-dimensional flux distribution can be derived from the data.

However, only the flux distribution, not the absolute flux, can be gained in this way. This is sufficient for the thermohydraulic calculations, because from the flux distribution and the uranium distribution within the core, the relative power can be derived which is produced in each fuel plate. The actual power, gotten by multiplying the relative power with the total reactor power (10 MW), is used to verify the results to prove the burn-out safety margin.

Burn-out safety

To prove a sufficient burn-out safety margin, thermohydraulic calculations were carried out only for the cooling channel assuming under the worst conditions. This channel is surrounded by fuel plates with the maximal nuclear power.

Its location is derived from the measurement of the flux distribution and the uranium contents in the fuel plates.

It has to be proven for this channel, that the so-called bubble release coefficient exceeds the critical value multiplied with a safety margin of 1.42. The bubble release coefficient is defined as:

$$\eta_{(x)} = \frac{(T_s - T_K(x)) \bullet v}{q(x)} \qquad \text{with:}$$

T_s [K]	boiling temperature
T_k [K]	coolant temperature
v [cm/sec]	coolant velocity
q (x) [W/cm^2]	heat flow density.

The critical value of η results from experiments and comes to $\eta c = 32.83$ cm^3 K/J.

To exceed this value ensures, that in 95% of the channel, the probability of flow instability is less than 5%. This requirement has to be met according to German Nuclear Technical Regulations (KTA 3101.1).

The calculated safety coefficient for the mixed cores are shown in Tab. I. In four cases the required value of 1.42 could only be met under reduced reactor power. Therefore, the cores No. 1, 7, 9 and 10 could only be operated with a maximal power of 9.5, 7.0, 9.7 and 9.9 MW, respectively. All other mixed cores could be operated with the nominal BER II power of 10 MW.

2. Summary

For the complete conversion of the BER II core, 10 HEU/LEU-mixed-cores had to be built (s. Fig. 1). The safety margins for each core had to be verified by measurements, which took about two weeks time, respectively. Leading to a loss in the experimental period for the scientists of about 25% (20 weeks), compared to the normal operation time of 35 weeks per year. For two cores, however, the reactor could only be operated with a maximum power of 9.5 and 7.0 MW, respectively.

Due to the high U-238 mass in LEU-fuel plates, the minimal U-235 mass needed to become critical, rose from ca. 4 kg (HEU-standard core) to 5 kg (LEU-standard core). Nevertheless, the core size had to be reduced to maintain a sufficient shut down reactivity. Therefore, 7 positions on the grid, which where set with HEU-fuel assemblies, are now set with beryllium reflector elements. The core consists now of 24 standard fuel assemblies, 6 control fuel assemblies, 1 irradiation device and 11 beryllium reflector elements (s. Fig 2).

However, due to the conversion there was only a slight impact on the neutron flux at the beam tubes. Therefore, the practical use of the BER II as a neutron supplier for neutron scattering research experiments was not impeded.

Core Nr.	**min. U235 mass for critical condition [g]**	**U235 mass [g]**	**Excess reactivity [%]**	**HEU Fuel assemblies**	**LEU Fuel assemblies**	**max. reactor power [MW]**	**Safety margin at max. power**
0	3900	4729.5	6.0	35	--	10	2,4
1	4050	4946.1	6.59	32	3	9.5	1,42
2	4300	5003.5	4.28	30	5	10.0	1,55
3	4350	5172.9	5.95	29	6	10.0	1,87
4	4470	5329.9	5.96	22	10	10.0	1,62
5	4470	5200.7	4.76	22	10	10.0	1,43
6	4600	5696.9	7.07	16	16	7.0	1,74
7	4670	6216.2	11.18	12	18	10.0	1,82
8	4750	5995.7	8.50	10	20	10.0	1,46
9	4950	6250.7	8.88	6	24	9.7	1,43
10	4950	6269.0	10.47	2	28	9.9	1,43
11	4950	6058.6	7.56	--	30	10	2.07

Tab. I: Data of HEU/LEU mixed cores

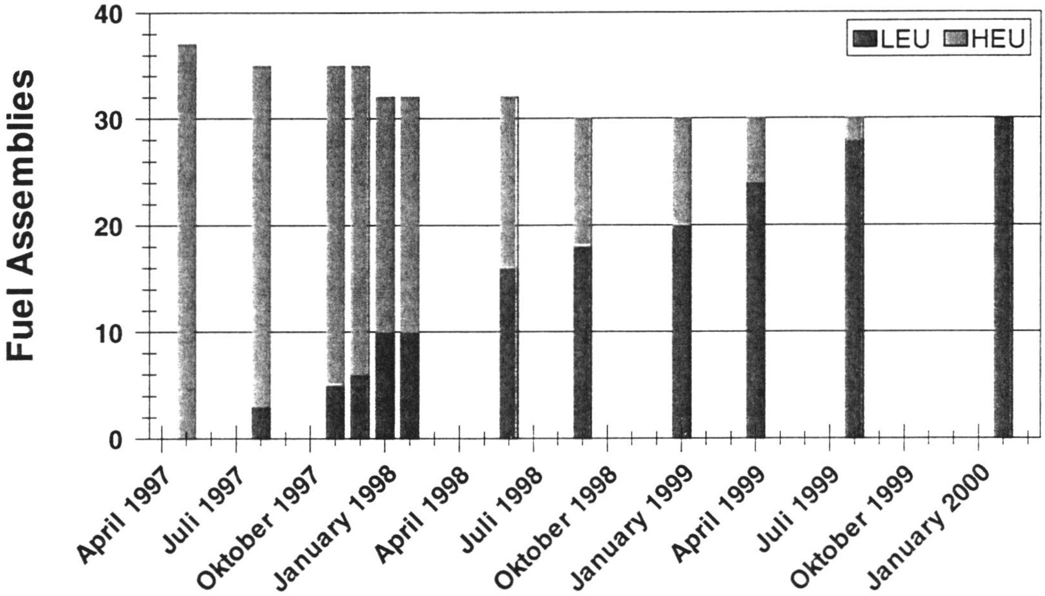

Fig. 1: Number of Fuel Assemblies in BER II Mixed Cores