STATUS OF THE CONVERSION OF BER II AFTER SEVEN HEU/LEU-MIXED-CORES

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Abstract

Hahn-Meitner-Institut presented an overview concerning the HEU/LEU-conversion at the 15. RERTR-Meeting. Our last report at the 20. RERTR-Meeting dealt with the successful operation of the first mixed core.

Up to now, seven different HEU/LEU-mixed cores have been in operation. 21 standard fuel elements were replaced by 14 LEU standard fuel elements and 7 beryllium reflector elements. Four control elements were changed from HEU to LEU. In the sixth mixed core, the absorber material was changed from AgInCd to Hafnium. The reactivity of all control rods was increased from 13.5% $\Delta k/k$ to 16.5% $\Delta k/k$.

Reducing the power to 9.5 MW was necessary for the first mixed core. The sixth mixed core also required a reduction in power. Because of the hot channel, which was situated in a fresh LEU control fuel element, the power had to be limited to 7 MW, and the distorted control rod positions had to be reduced, too.

The next mixed core began it’s successful operation in September. The maximum power of 10 MW was reached again.

INTRODUCTION

The swimming-pool type reactor BER II is a typical beam hole reactor and in addition equipped with a Cold Neutron Source. The instrumentation of BER II is described in our previous report [1].

HMI chose for changing from HEU to LEU the gradual conversion over a number of re-fuelling cycles. The operation with pure HEU cores ended on July 27, 1997. Since August 26, 1997, the BER II is in routine operation with mixed cores. There are no fresh HEU fuel elements left on stock.

CONVERSION MANUAL

Before starting operation with a new mixed core, several measurements, calculations and adjustments must be carried out. The following steps are done according to the approved conversion manual:

a.) drawing up the loading manual
b.) release for loading
c.) power calibration 0-4%
d.) loading the fuel
e.) calibration of the control rods
f.) determination of the shut down safety
g.) determination of the maximum changing reactivity
h.) determination of the coolant flow by operation with two and three primary cooling pumps
i.) adjustment of underpressure for the primary coolant circuit (only when the number of fuel elements has changed)
j.) determination of flux mapping for balanced and distorted control rod positions
k.) location of the hot channel and proof of burn-out safety
l.) determination of changing reactivity by pouring the beam tubes and by driving in the in-core irradiation device
m.) adjustment of power limit for 70% (standard core) respective 60% (compact core) of the maximum power
n.) release for power up to 70% (standard core) respective 60% (compact core) of the maximum power
o.) power calibration for 70% (standard core) respective 60% (compact core) of the maximum power
p.) adjustment of distorted control rod positions
q.) release for power up to maximum power
r.) power calibration at 10 MW respective the maximum power limit

After completion of point m.) respective point p.) the licensing authority has to agree for going on to 70% of the maximum power respectively 100% of the maximum allowed power.

DESCRIPTION OF THE DIFFERENT MIXED CORES

Within the first mixed core, we replaced 5 HEU standard fuel elements with 3 LEU standard fuel elements (positions A2, A5 and G2) and with 2 beryllium reflector elements (positions B6 and F6).

3 standard fuel elements were replaced in the second mixed core by 3 LEU elements (C1, D6 and G4). Two of the first 3 LEU elements loaded within the first mixed core remained in their positions, the third was moved from position A5 to A4. Furthermore, the positions of 3 control elements were changed from B5, D5 and F5 to B4, D4 and F4. The other 3 control elements were left in their positions B2, D2 and F2. The in-core irradiation device were re-placed from position C4 to C3, too.

The third mixed core included loading up our 2 last fresh HEU control elements, they were put in the positions B2 and F4. No fresh fuel element was loaded. 3 partly burned-up HEU standard fuel elements were exchanged. The 6 LEU elements remained in their positions.

Because no fresh LEU element was loaded, the licensed conversion manual was shortened with permission from the experts (TÜV) and licensing authority.

After rearranging LEU- and HEU elements and loading 3 beryllium reflector elements in the positions C6, D6 and E6, 3 fresh LEU elements were put in the positions A2, F1 and G2 in the 4th mixed core (core no.42). After checking that shut down safety was sufficient , the permission of loading another fresh LEU element in position D1 was given from TÜV and licensing authority (core no.43). At that time, 10 LEU standard fuel elements were loaded.

In the 5th mixed core just 2 HEU standard fuel elements with a high burn-up were replaced by 2 HEU standard elements with a low burn-up (positions A5 and G5). All LEU elements remained in their positions. With permission from licensing authority and TÜV, the licensing manual was reduced to consideration of the reactivity balance.

The change of our absorbers from AgInCd to Hafnium took place within the 6th mixed core. 4 fresh LEU control elements were loaded in the positions B2, B4, F2 and F4.In addition to this, 2 fresh LEU standard elements were loaded in A3 and G3. The previous loaded LEU elements remained in their positions. Because changing the absorbers is time-consuming, this task was co-ordinated with other time-consuming projects around the reactor.

After rearranging LEU and HEU elements, 3 fresh LEU standard fuel elements were loaded in the 7th mixed core. The last 2 beryllium reflector elements required for the LEU standard core were put in the positions A5 and G5. Fig.1 shows the actual core no.49. It contains still 10 HEU standard fuel elements and 2 HEU control fuel elements. Concerning the number of fuel and reflector elements, the 7th mixed core is identical with the LEU standard core.

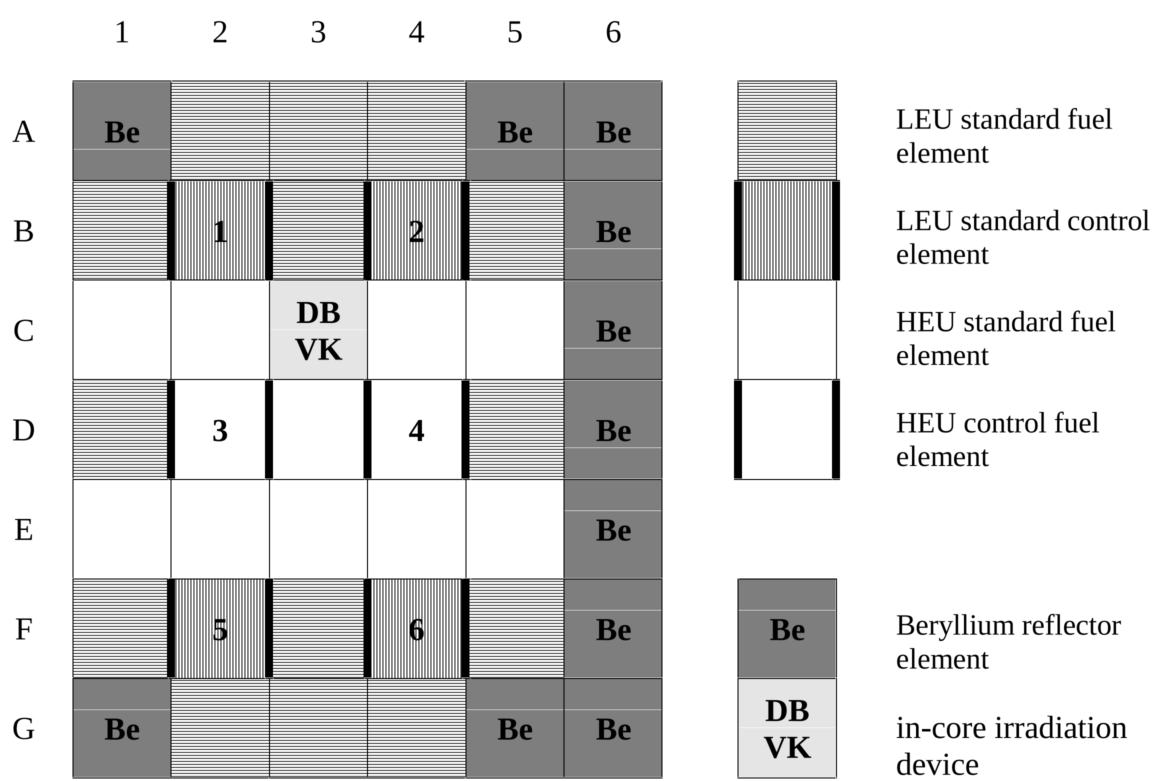

Fig.1: 7th Mixed Core (Core No.49)

Table 1 gives an overview of our first 7 mixed cores. The different core numbers are founded on fact that, every time a core went critical, it was given a unique core number, even when loading the core continued.

Time necessary for doing conversion was reduced from three weeks at the beginning to two weeks.

	1st mixed core	2nd mixed core	3rd mixed core	4th mixed core	5th mixed core	6th mixed core	7th mixed core
core no.	39	40	41	42 / 43	44	45 / 46	47 – 49
fresh LEU standard el.	3	3	-----	4	-----	2	4
fresh LEU control el.	-----	-----	-----	-----	-----	4	-----
fresh HEU control el.	-----	-----	2	-----	-----	-----	-----
new Be re-flector el.	2	-----	-----	3	-----	-----	2
conversion and mainte-nance	97-08-04 until 97-08-26	97-10-24 until 97-11-10	97-11-24 until 97-12-08	98-01-12 until 98-01-26	98-02-23	98-04-01 until 98-06-30	98-08-31 until 98-09-21
running from	97-08-26 until 97-10-19	97-11-10 until 97-11-23	97-12-08 until 98-01-10	98-01-26 until 98-02-15	98-02-23 until 98-03-15	98-06-30 until 98-08-30	98-09-21 up to now
EOC in MWd	398.2	113.7	163.8	184.6	201.3	314.5	

Tab.1: Period of Time each Mixed Core was in Operation, changed Elements and produced Power in MWd

REACTIVITY BALANCES

Table 2 show all important parameters concerning the reactivity of each core.

The shut down safety is determined by subtracting the excess reactivity, the reactivity of the most effective control rod and another 1% $\Delta k/k$ for experiments (0.7% $\Delta k/k$ for the beam tubes and another 0.3% $\Delta k/k$ for the in-core irradiation device) from the reactivity of all the six control rods. Normally, the shut down safety is demanded for at least 1% $\Delta k/k$. During conversion, the calculated shut down safety used in drawing up the loading manual is based on the calibration curves of the previous coretype. For compensating this uncertainty, the calculated shut down safety is increased to 2% $\Delta k/k$ before calibration of the control rods.

The maximum changing reactivity velocity has to be less then 0.0292 % $\Delta k/k$ /s. The reactivity influence of each beam tube must be less then 0.2% $\Delta k/k$ and the one caused by the in-core irradiation device less then 0.29% $\Delta k/k$.

The 5th core included only changing from HEU to HEU, no LEU fuel element was rearranged. Therefore, the core went in operation without running through the conversion manual with permission from TÜV and licensing authority. For the reactivity balance, the values

	1st mixed core	2nd mixed core	3rd mixed core	4th mixed core	5th mixed core	6th mixed core	6th mixed core	7th mixed core	7th mixed core
core no.	39	40	41	42/43	44	45	46	47	48/49
mass U-235 BOC [g]	4946.1	5003.5	5172.9	5329.9	5200.7	5606.7	5969.8	5734.5	6218.9
mass U-235 EOC [g]	4452.3	4862.5	4969.9	5101.0	4951.2	-----	5579.8	-----	
reactivity of all control rods [% $\Delta k/k$]	12.48	12.68	12.64	13.52	like core no.44	17.25	16.54	19.26	16.76
most effective control rod [% $\Delta k/k$]	2.84 no.5	2.52 no.4	3.13 no.6	2.69 no.6	like core no.44	3.12 no.6	2.98 no.6	4.48 no.1	3.47 no.6
excess reactiv-ity [% $\Delta k/k$]	6.59	4.28	5.95	5.96	4.76	7.07	7.77	9.64	11.18
shut down safety [% $\Delta k/k$]	3.05	5.88	3.56	4.87	6.07	7.06	5.79	5.14	2.11
max. changing reactivity ve-locity [% $\Delta k/k$ / s]	0.012	0.012	0.013	0.014	like core no.44	0.019	00.018	0.022	0.016
$\Delta\rho$ beam tubes: maximum [%] total [%]	0.06 (T5) 0.19	0.09 (R2, R3) 0.30	-----	0.05 (T5) 0.16	-----	-----	0.06 (T5) 0.18	-----	0.05 (T5) 0.12
$\Delta\rho$ in-core irra-diation device [%]	0.14	0.21	-----	0.17	-----	-----	0.20	-----	0.08

Tab.2: U-235 Mass, Reactivity Balances and Reactivity Influences from Beam Tubes and In-Core Irradiation Device of all Mixed Cores

from core no. 43 (4th mixed core) were assumed. It was necessary, to determine the shut down safety on basis of the curves from core no. 43. The demanded shut down safety was increased from 1% $\Delta k/k$ to 1.2% $\Delta k/k$.

The significant increase in reactivity of all control rods within the 6th mixed core was due to the change of the absorber material from AgInCd to Hafnium.

For the 6th and the 7th mixed core respectively, two complete control rod calibrations had been carried out. In the 6th mixed core, after changing the absorber material of all 6 absorbers and loading 4 fresh LEU control fuel elements, a complete control rod calibration was carried out. On the basis of that calibration, two further fresh LEU standard fuel elements were loaded.

To load as many fuel elements as possible with respect to shut down safety, after loading 3 fresh LEU elements a complete calibration of the control rods was done in the 7th mixed core. After that, an HEU element was changed with a partly burned-up LEU element, the stuck-rod criterion was checked and the core was made critical (core no.48). On the basis of the critical control rod position, which is not allowed to be less than 250 mm, another fresh LEU fuel element was loaded.

THERMOHYDRAULICS

The coolant flow has to be measured in at least three positions; the difference is not allowed to exceed more than 5%.

Every time the number of fuel elements changed, the difference in pressure by operation with 3 and 2 primary cooling pumps respectively must be measured and the new underpressure of the primary cooling circuit has to be adjusted. This value is monitored by the reactor safety system.

Determination of neutron flux density, power distribution, hot channel and bubble release coefficient η is described in detail in our previous report [2].

Table 3 represents the relevant thermohydraulic data for the seven mixed cores under operation. Concerning the distorted control rod positions, all mixed cores had to be limited to one control rod (usually the most effective) 100 mm over the others and the opposite control rod is full in (0 mm). It is scheduled to reach distorted control rod positions without any limitations within the next mixed cores.

Because of the uneven distribution of uranium 235 in the first mixed core, the hot channel limited the maximum power to 9.5 MW by distorted control rod positions. The values in table 3 for distorted control rod positions refer to the maximum power of 9.5 MW where the values for balanced rod positions refer to 10 MW. The hot channel was situated in the first cooling channel next to the reflector element G1 in the fresh LEU element in position G2.

As in the first mixed core, the hot channel in the second mixed core was located in the cooling channel of a fresh LEU element next to a reflector element (D6-22).

	1st mixed core	2nd mixed core	3rd mixed core	4th mixed core	5th mixed core	6th mixed core	7th mixed core
no. of fuel plates	769	769	769	700	700	700	654
coolant flow [m^3/h] 3 and 2 pumps	24.20 18.38	24.47 18.58	like core no.40	26.20 19.60	like core no.43	25.97 19.81	27.03 20.64
coolant velocity [m/s] 3 and 2 pumps	2.04 1.55	2.06 1.57	like core no.40	2.21 1.65	like core no.43	1.64	2.28 1.74
underpressure [mbar]	295	like core no.39	like core no.39	319	like core no.43	like core no.43	329
hot channel	G2-1	D6-22	D6-22	G2-1, F1-21	-----	F4-1 (F3-22)	F5-22
power peaking form factors radial – axial *	2.05 – 1.36 2.55 – 1.32	2.09 – 1.23 2.43 – 1.28	----- 2.25 – 1.33	1.99 – 1.74 2.20 – 1.47	-----	2.26 – 1.91 3.04 – 1.68	1.71 – 2.05 1.94 – 1.70
mean power per fuel plate [kW]*	11.70 11.12	11.70	11.70	12.86	12.86	9.00	13.76
mean heat flux density [W/cm^2]*	15.54 14.77	15.54 15.54	----- 15.54	17.07 17.07	-----	11.95 11.95	18.28 18.28
mean heat flux density (hot channel) [W/cm^2]*	51.23 60.54	52.23 60.73	----- 56.23	54.64 60.40	-----	44.20 59.58	50.25 57.01
max. heat flux density (hot spot) [W/cm^2]*	90.78 104.13	88.59 107.18	----- 95.55	122.66 114.56	-----	108.94 129.15	131.61 123.82
bulk temperature (hot spot) [°C]*	73.79 79.57	74.06 79.28	----- 76.52	73.79 77.15	-----	74.47 77.01	69.77 73.50
outlet temperature (hot channel) [°C] *	81.74 88.96	82.08 88.60	----- 85.15	81.74 85.94	-----	67.97 85.76	76.71 81.38
bubble release coefficient η (hot spot)*	2.09 1.56	2.15 1.55	----- 1.87	1.65 1.62	-----	2.11 1.43	1.78 1.74
flux skew factor due to distorted control rods	15.0% no. 5 and 2	14.4% no. 4 and 5	14.6% no.6 and 1	16.2% no.5 and 2	-----	15.3% no.6 and 1	14.9% no.6 and 1
max. power [MW]	9.5	10	10	10	10	7	10

*: first value: balanced rod positions
second value: distorted rod positions

Tab.3: Thermohydraulics of all Mixed Cores

The third mixed core showed the same hot channel as the second mixed core. No measurements of flux mapping with balanced control rod positions were done.

In the 4th mixed core, control rod no.5 was driven 100 mm over the bank instead of the most effective control rod no.6, because around the almost equal effective rod no.5 two fresh LEU elements were situated and the hot channel was expected to be there.

The maximum power in the 6th mixed core was limited to 7 MW. The values in table 3 refer to 7 MW. The hot channel was placed in the fresh LEU control fuel element F4 (F4-1) near the burned-up HEU element F3. The coolant flow through control fuel elements is decreased by 2% with respect to the standard fuel elements. The calculations concerning burned-out safety were carried out with the reduced coolant flow because the hot channel was situated in a control fuel element.

For reducing the hot channel, low burned-up LEU standard fuel elements are presently placed between the 4 LEU control fuel elements in the 7th mixed core. The hot channel is not situated in the cooling channel with the greatest power form factor because the axial form factor is relatively low (G4-22: 1.90 – 1.37 and 2.12 – 1.38). The hot channel situated in F5-22 shows a great radial as well as axial power form factor.

SUMMARY

Up to now, 21 standard fuel elements and 4 control fuel elements were replaced. The core size was reduced to 30 fuel elements from the 37-element HEU standard core.

There are still 12 HEU elements to replace. We expect to reach the pure LEU standard core with the end of 1999.

At the moment, we don’t intend to go straight away to LEU compact core. But like HEU compact core, which was never in operation, we will keep this option open for the future.

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