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Evaluation of Irradiation Conditions after LVR-15 HEU to LEU Conversion

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ABSTRACT

The LVR-15 research reactor finished the HEU to LEU conversion almost an year ago. For this period, a summary of the LEU fuel influence on reactor operations and irradiation conditions could be performed and therefore experiences obtained from the variety of activities are presented. This part of the contribution includes both experimental data and results of theoretical calculation from major reactor utilizations. Also, the most interesting tasks scheduled for the future, such as the ^{99}Mo production from new low enriched uranium targets, planned increase in the silicon doping, and material test program and horizontal channel operation for BNCT experiments, will be discussed in the paper.

1. Introduction

After the successful conversion of the LVR-15 research reactor to LEU IRT-4M fuel in September 2011, 12 operating cycles have been already performed. Within these cycles, the whole range standard reactor applications were in operation. These applications included silicon doping, production of ^{99}Mo, and material test irradiation. Experimental conditions for these applications will be shown and if possible, also compared to the conditions before and after the conversion.

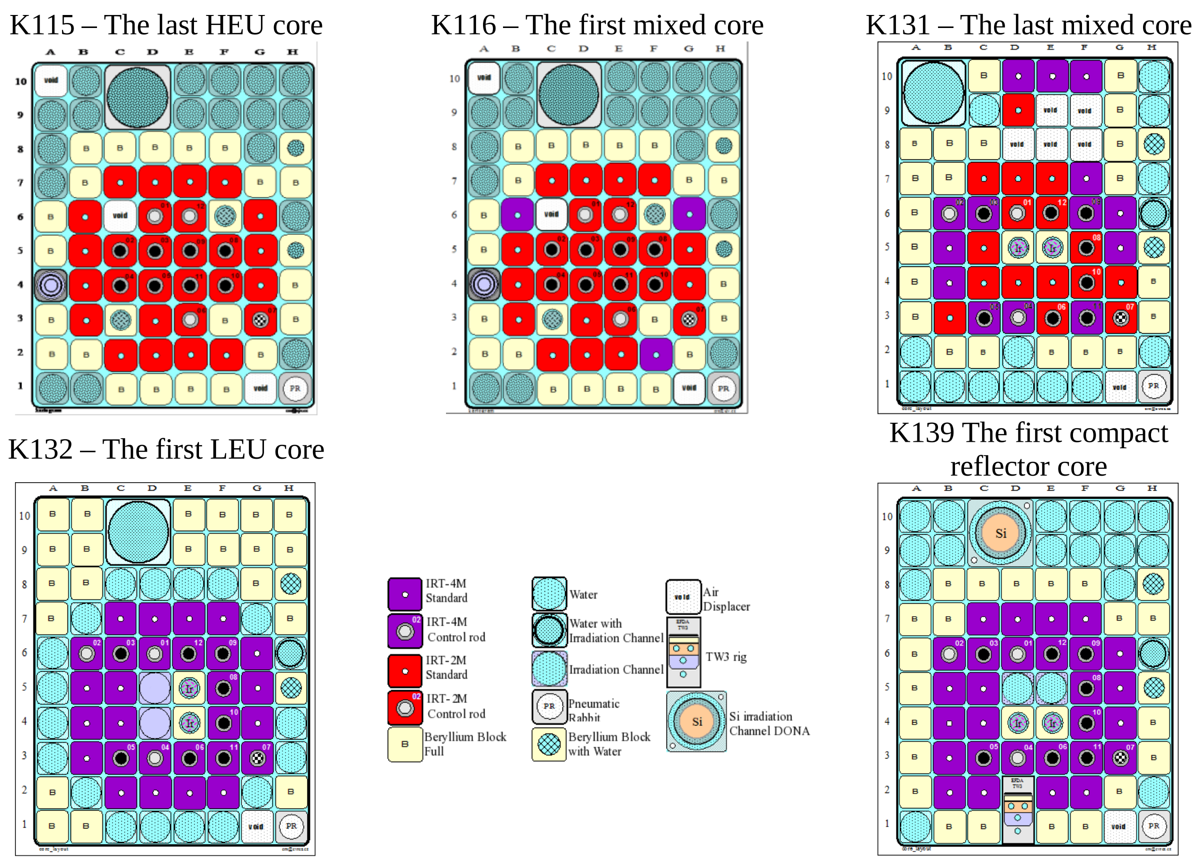


Figure 1 Important cores of the conversion and LEU operation

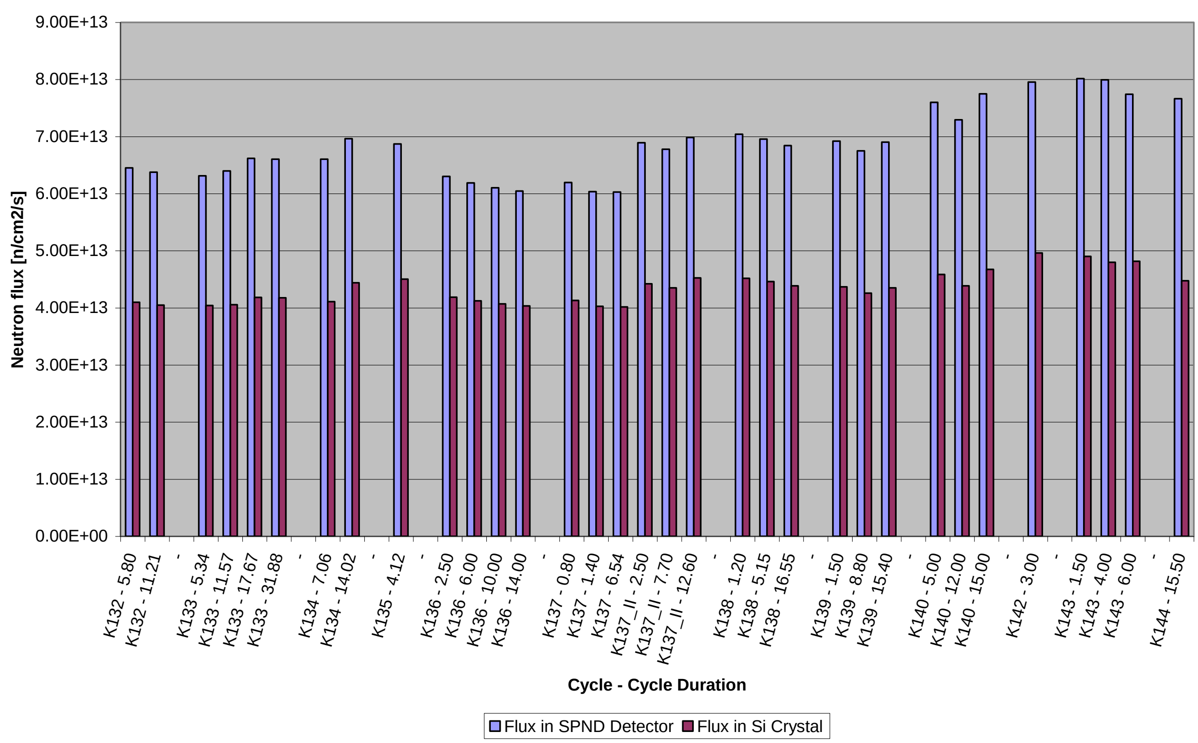


Figure 2 Overview of irradiation conditions in Si irradiation channel DONA for LEU cores

2. Silicon doping

One of the crucial utilizations of the LVR-15 reactor is for silicon doping. Si crystals are irradiated in DONA rotational channel placed to the position C,D – 9,10 of the reactor core behind the beryllium reflector. The irradiation channel has the ability to irradiate crystals with standard dimensions up to 3” in diameter and 300 mm in length. The irradiation is controlled by the self powered neutron detector (SPND) located near the channel in the corner of the channel displacer. The comparison of irradiation conditions in DONA channel for mixed cores with compact beryllium reflector with first fully LEU core with partial Be reflector showed a slight decrease (~1%) in thermal neutron flux compensated by the growth of fast neutron flux (~2%). Compacting the reflector in LEU cores resulted again into increase (~8%) of the thermal flux. The evaluation of the thermal neutron flux in Si crystal and in SPND for LEU cores is in the Figure 2.

Due to the request for irradiation of 4”crystals (max. length 310 mm), a new DONA rotational channel was designed. The new DONA channel is planned to be put in position A,B – 9,10, while the old channel will be moved to the F and G lines. Neutron flux distribution will be measured by SPNDs placed in the displacers of both channels and in new measurement channel in H9. The proposed layout is in the Figure 3

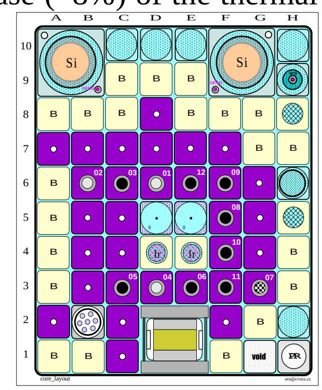


Figure 3 Core layout for 2 DONA channels

3. ^{99}Mo production

The irradiation of HEU targets for ^{99}Mo production started along with the mixed core operation in May 2010. The manufacturer of the ^{235}U targets is CERCA, the subscriber is The Institut National des Radioelements. Since the beginning of the project, several improvements in core configuration, design of the irradiation channel and system of manipulations were done with respect to the effectivity and safety of the irradiation. The major changes were establishment of the neutron trap and shortening of manipulations in the core for 1 hour maximum, so that the reactor avoids the xenon poisoning. All these improvements resulted into stable irradiation process with only minor discrepancies caused by the flexibility in irradiation requirements. Achieved target burnup and ^{99}Mo activity in MIXED and LEU cores are shown in the Figure 4 and Figure 5. Results show (with respect to the improvements) stable irradiation condition within the process of conversion and operation of LEU cores. The effect of hardening neutron spectra for LEU had positive influence on target irradiation.

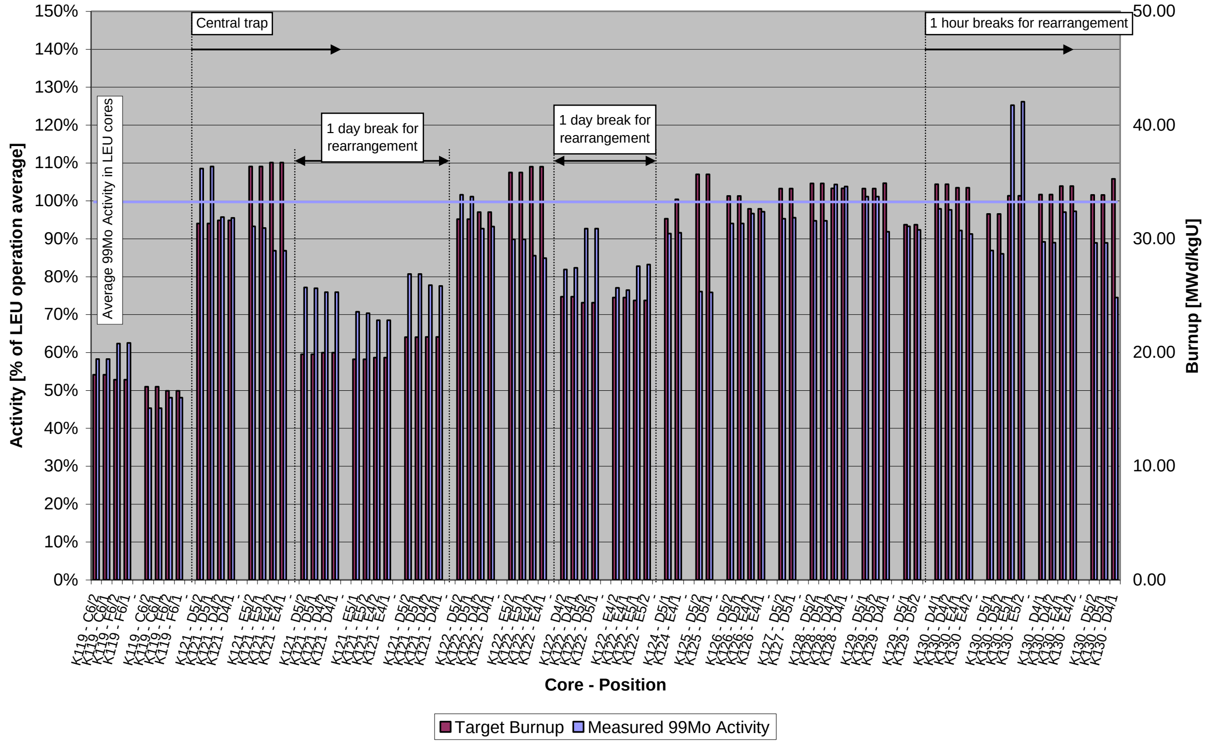


Figure 4 ^{99}Mo production in mixed cores during the conversion

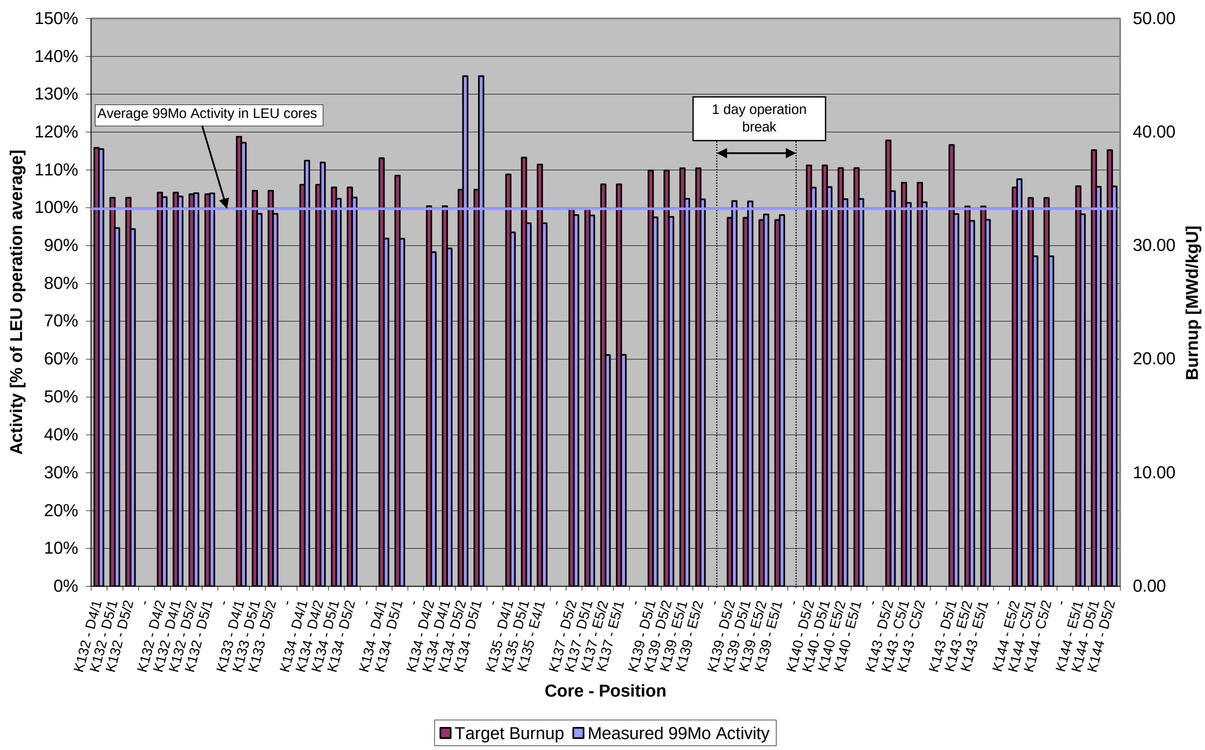


Figure 5 ^{99}Mo production in LEU cores after the conversion

In the future, enrichment of the temporary HEU targets will be also reduced to 19.7% of ^{235}U. Also, the geometry of the target will change significantly, the original cylindrical shape will be replaced by plates. The total mass of ^{235}U in one target remains almost the same. Therefore, a new holder for the new LEU targets has to be designed. At the present, the theoretical calculations for the issue are performed in the MCNPX transport code and the optimal number of targets and their optimal distribution inside the holder are searched. The aim for the optimization is to get maximum possible mass of ^{99}Mo within one irradiation

4. The BNCT experiments

The BNCT facility has been operated since middle of nineties. Since the installation, the beam filter and core patterns underwent several changes from the original design. All the time, the beam had been systematically monitored by the set of thermal, resonance and threshold monitors. The influence of the conversion of the core could be evaluated from the following characteristics:

- $R_{Mn/Au}$ - the reaction rate ratio of Mn to Au in cadmium describing the stability of measurement
- $R_{Ni/Au}$ - the reaction rate ratio of Ni to Au in cadmium showing the ratio of the fast to the epithermal neutrons in the beam
- R_{Cd} - the cadmium ratio for the determination of the thermal neutrons contamination of the beam
- Φ_{epi} - the epithermal neutron fluence rate[$m^{-2}s^{-1}$].

Uncertainties of the R_{Cd} and $R_{Mn/Au}$ are usually better then 4% and that of $R_{Ni/Au}$ varies from 5% to 7%.

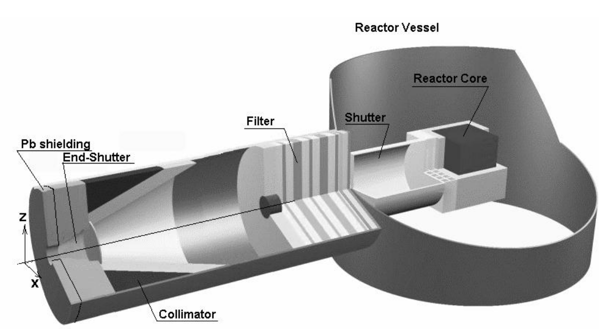


Figure 6 The filter of the LVR-15 beam with the additional lead shielding.

Table 1 BNCT beam parameters

reactor core*)	$R_{Mn/Au}$	$R_{Ni/Au}$	R_{Cd}	Φ_{epi} [$m^{-2}s^{-1}$]	STD [%]
HEU-1999	1.05E-02	1.14E-05	1.14	8.05E+12	4
HEU-2001	1.15E-02	1.19E-05	1.06	5.48E+12	6
HEU-2002	1.20E-02	1.02E-05	1.09	7.67E+12	5
HEU-2003	1.10E-02	1.09E-05	1.06	7.33E+12	6
HEU-2006 Pb shield	1.32E-02	1.21E-05	1.04	3.92E+12	5
HEU-2009 Pb shield	1.31E-02	1.20E-05	1.06	7.04E+12	4
MIXED-2010 Pb shield	1.33E-02	1.18E-05	1.06	7.16E+12	5
LEU-2012 Pb shield	1.13E-02	1.13E-05	1.08	7.43E+12	4

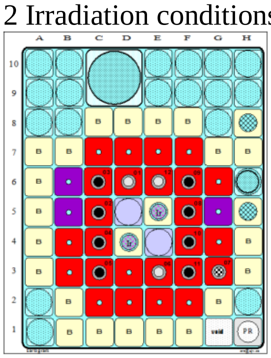
*)HEU/LEU indicate the core from HEU/LEU FAs, respectively
MIXED indicates the core composed from both LEU and HEU FA’s
Pb shield – additional Pb shield of 5 cm thickness, see Figure 6.

Comparing the resulting values of $R_{Ni/Au}$, R_{Cd} and $R_{Mn/Au}$ hardly shows any tendency. The beam intensity changes depend on an actual situation of the reactor operation. Spread in the neutron fluence rate results from actual reactor power requested by requirements of other facilities and burnup of the fuel in the booster. Comparing the measurement of the last HEU core with the MIXED and LEU cores detects no decrease of epithermal fluence rate. The results show, that the conversion of the reactor has only minor influence on BNCT facility characteristics.

5. Neutron spectra in irradiation positions and material test facilities

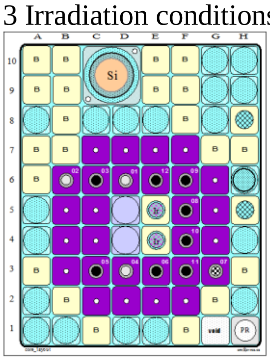
The estimation of the change of the neutron spectra in central trap was made for mixed cycle K124 and LEU cycle K134. The results are presented in Table 2 and Table 3. A comparison of results for the central trap in these two configurations indicates with respect to slightly different configuration of the trap a slight decrease in the thermal neutron flux with an increase in the fast region of the spectra.

Table 2 Irradiation conditions in central trap in mixed core K124



Energy	Neutron Flux ($n.cm^{-2}.s^{-1}$)			
	D5	D4	E4	E5
< 0.625 eV	1.54E+14	1.74E+14	1.65E+14	1.73E+14
0.625 eV - 5.53 keV	6.85E+13	7.35E+13	7.30E+13	7.38E+13
5.53 keV - 0.821 MeV	7.59E+13	7.16E+13	7.96E+13	7.24E+13
0.821 MeV - 20 MeV	8.85E+13	5.20E+13	9.47E+13	5.23E+13

Table 3 Irradiation conditions in central trap in LEU core K134



Energy	Neutron Flux (n.cm-2.s-1)			
	D5	D4	E4	E5
< 0.625 eV	1.54E+14	1.59E+14	1.45E+14	1.43E+14
0.625 eV - 5.53 keV	7.54E+13	7.70E+13	7.83E+13	7.62E+13
5.53 keV - 0.821 MeV	8.39E+13	8.41E+13	7.37E+13	7.60E+13
0.821 MeV - 20 MeV	9.41E+13	9.63E+13	5.11E+13	5.08E+13

No systematic monitoring of neutron spectra has been performed for irradiation channels located in positions H5, H8 (beryllium) and H6 (water) yet. The reason is that only samples that could be prior to the irradiation checked by activation analysis of suitable monitors were irradiated so far. The experimental determination of spectra in K134 for irradiation of Xe filled capsule shows following neutron flux distribution in H5.

Table 4 Neutron spectra in irradiation channel H5

Energy	Neutron Flux [n/cm2/s]
(0.0 ,0.501 eV)	6.70E+13
(0.501 eV,10 KeV)	3.15E+13
(10 keV ,.1 MeV)	7.36E+12
(.1 MeV ,20 MeV)	2.98E+13
(.5 MeV ,20 MeV)	2.11E+13
(1. MeV ,20 MeV)	1.53E+13

Material test irradiation capabilities of the LVR-15 reactor are demonstrated on calculation results for CHOUCA and TW3 rigs. The CHOUCA rig is dedicated to the irradiation of material test specimens. Presented results are for the rig positioned in positions A1 (K136) and B2 (K145). The position B2 shows roughly 30% higher radiation heating values. Comparing experimental and theoretical values for cycle K136, calculated radiation heating in periphery is roughly 2.5 times underestimated.

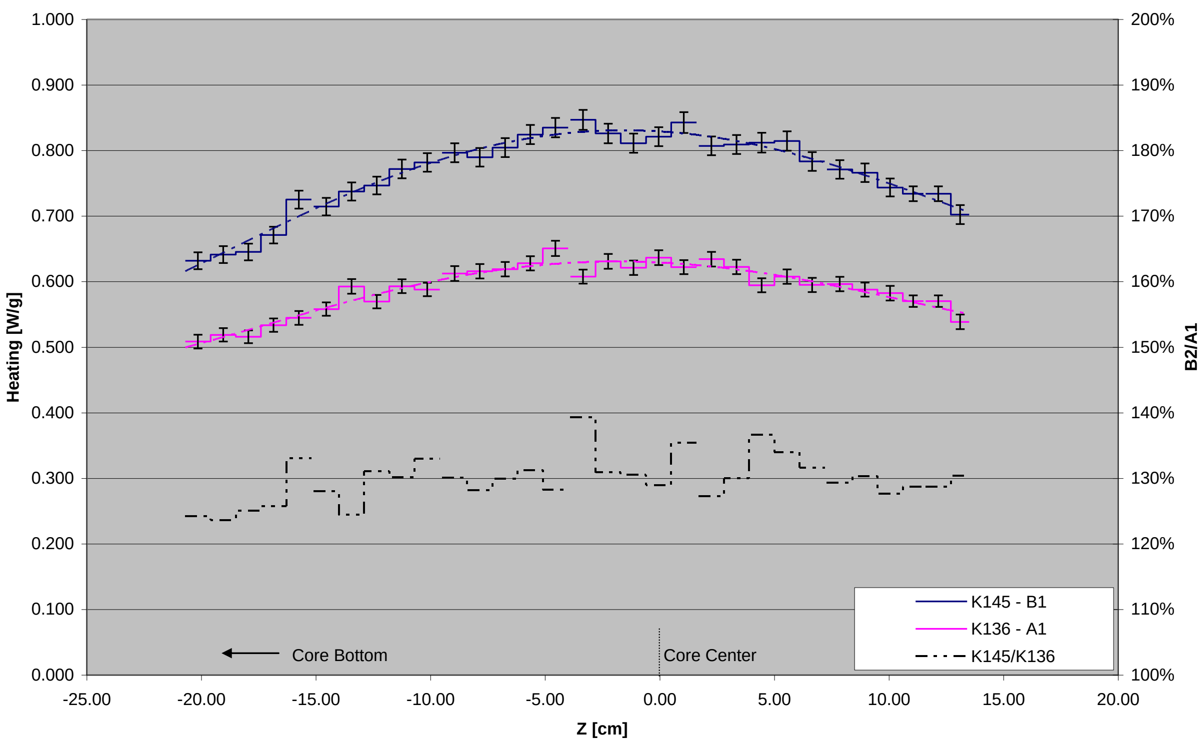


Figure 7 Radiation heating profile in material test rig CHOUCA

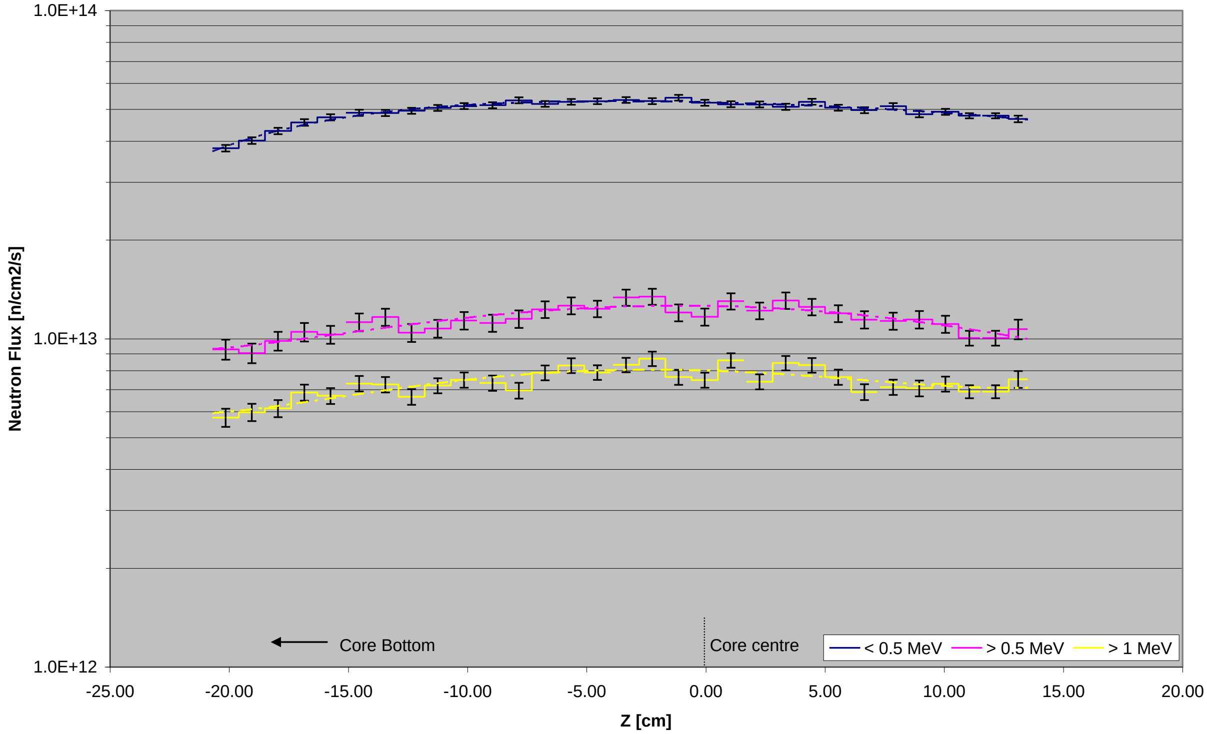


Figure 8 Neutron flux profile in material test rig CHOUCA

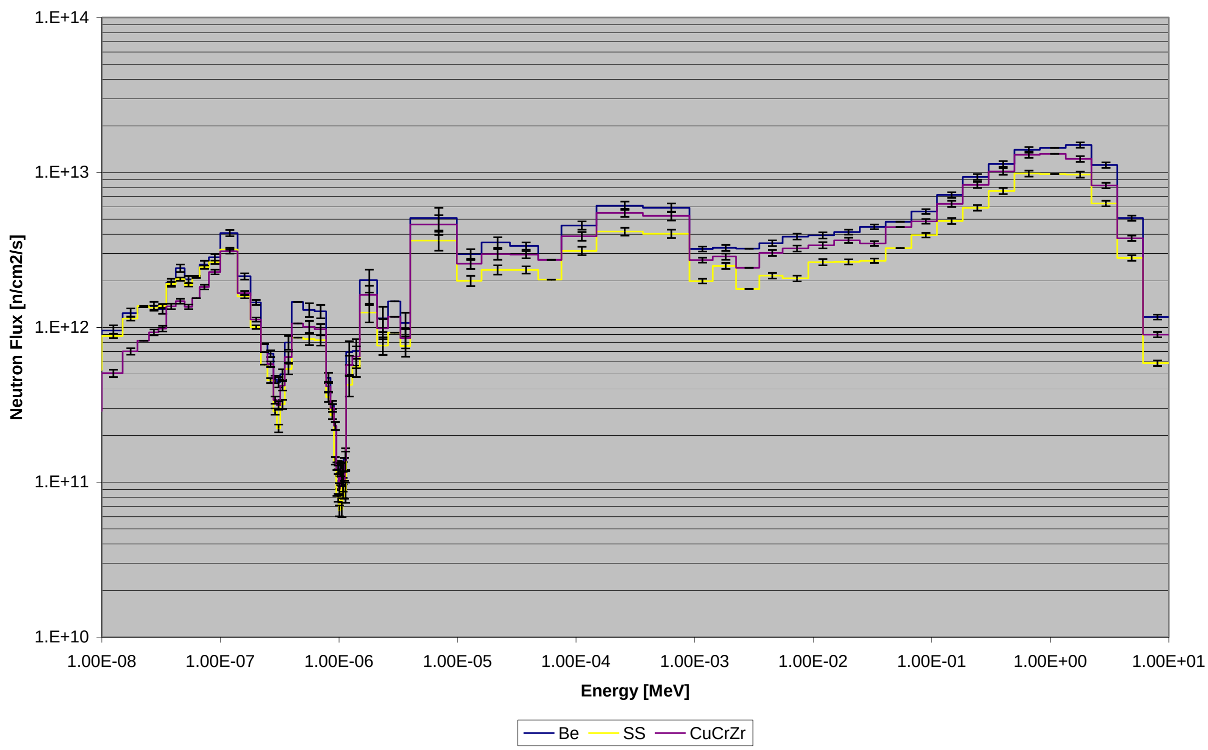


Figure 9 Neutron spectra in the TW3 rig sample

The TW3 rig was dedicated to the fusion applications. An in-pile test with cyclic heat load of Beryllium – CuCrZr HIP joint of ITER´s primary first wall mockup was performed. Within this test, the rig was placed in D1,2 position. The calculated DPA rate in irradiated samples was 0.00017 dpa/h (in beryllium and CuCrZr) and 0.000125 (for stainless steel) respectively. Neutron spectra in the sample are shown in the Figure 9.

6. Conclusion

The LVR-15 reactor has been successfully operated LEU fuel for almost a year. Within this period, no significant deterioration of irradiation conditions was observed. For certain applications, the combination of HEU to LEU fuel exchange together with changes in strategy of reactor operation, resulted in positive influence on irradiation conditions for these applications.

7. Acknowledgements

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8. References

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