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Operational Experience of Kyoto University Research Reactor (KUR) with LEU Fuel

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ABSTRACT

The Kyoto University Research Reactor (KUR) has been converted to LEU fuel with silicide fuel of 3.2gU/cc on March 2010 and have been successfully operated since then. This paper describes the operational experiences of LEU fueled KUR since the conversion, mainly focusing on the prediction accuracy of the reactor core characteristics, such as criticality, reactivity coefficients and burnup characteristics using both Monte-Carlo and deterministic neutronics codes with JENDL-3.3 as the nuclear data library. The present status of the utilization of KUR, especially for the BNCT, will be also described to show the recent contribution of the KUR to the academic society.

1. Introduction

Kyoto University Research Reactor (KUR) is light water moderated / cooled tank-type reactor. KUR attained to first critical at 1964, and since then it is used for various experimental studies on engineering, material science, physics, chemistry, biology and so on. In addition, the neutron beam from KUR core is extensively used for Boron Neutron Capture Therapy (BNCT) in recent years, making KUR the most contributing facility in BNCT in the world.

The operation of KUR with high enriched uranium (HEU) fuel was ended on February 2006 and the conversion project for KUR from HEU to low enriched uranium (LEU) fuel was successfully terminated in 2010. KUR with LEU core has been operating since May 28, 2010[1][2].

In this paper, the operational experiences of LEU fueled KUR since the conversion, mainly focusing on the prediction accuracy of the reactor core characteristics, such as criticality, reactivity coefficients and burnup characteristics using both Monte-Carlo and deterministic neutronics codes with JENDL-3.3 as the nuclear data library. The present status of the utilization of KUR, especially for the BNCT, will be also described to show the recent contribution of the KUR to the academic society.

Figure 1: KUR reactor room

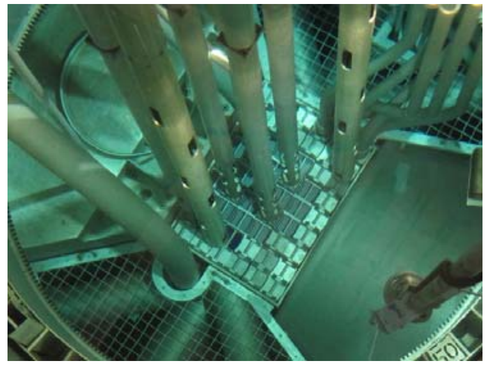


Figure2: KUR core

2. Specification of KUR LEU

The KUR LEU fuel is an MTR type fuel. The geometrical configuration of LEU fuel is same as HEU fuel. In KUR core, the two types of fuel element are loaded. The one is a standard fuel element and the other is a special fuel element in which the control rod is inserted. The standard fuel element consists of 18 fuel plates and the special fuel element and the special fuel element has 9 fuel plates (see Fig. 3 and 4). The fuel plate consists of 0.5mm-thick fuel meat with aluminum cladding of 0.51mm thickness. Thus, the thickness of fuel plate is about 1.5mm. The water gap between the fuel plates is about 2.8mm. Table 1 shows the comparison of LEU fuel and HEU fuel. The composition of fuel meat in LEU fuel is U_3Si_2-Al, with ^{235}U enrichment of 19.75wt%.

Figure 3: Standard fuel element (left) and special fuel element (right)

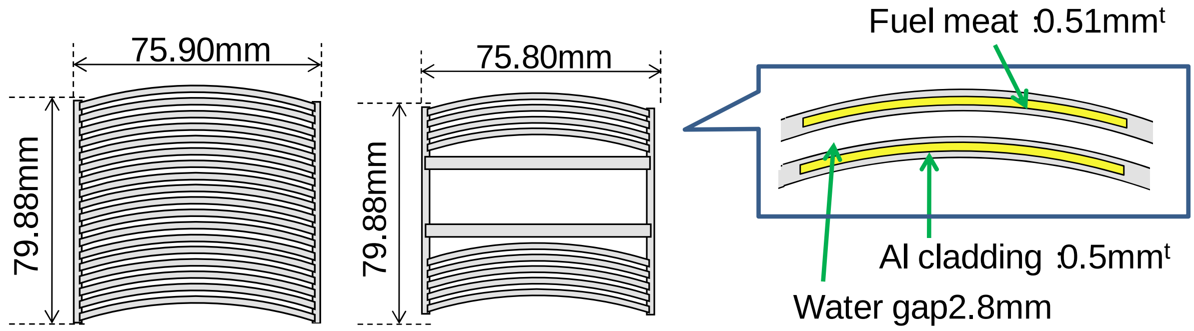


Figure 4: Cross section of fuel element and fuel plate

Table 1 Comparison of LEU fuel and HEU fuel

	^{235}U enrichment	U-density	Composition
LEU	20wt%	3.2gU/cm^3	U_3Si_2-Al
HEU	93wt%	0.58gU/cm^3	U-Al

3. Operation of KUR LEU core

Due to the limitation of fuel inventory, the operation cycle has been changed from the original 5MW continuous operation to combination of 1MW and 5MW operation as shown in Fig. 5 After the start-up, the 1MW of thermal power is kept for 48 hours and then the power is changed to 5MW. The 5MW operation is continued for about 4 hours. The total operation hours for one cycle is about 52 hours. The 1MW thermal power is for general experiments and irradiations, whereas the 5MW operation for 4 hours is dedicated for the BNCT treatment. The operational history during FY2010 is shown in Fig. 6.

The utilization status of KUR at FY2010 is shown in Fig. 7. Due to the decrease in the average thermal power, the beam experiments have been decreased; however, the overall utilization of the KUR LEU has been shown to be still successful compared to the previous operation using HEU fuels.

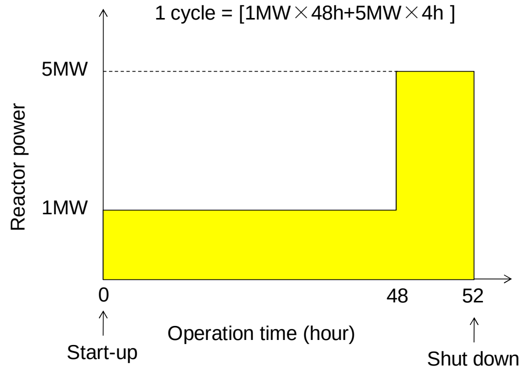


Figure 5: Operating pattern of KUR LEU core

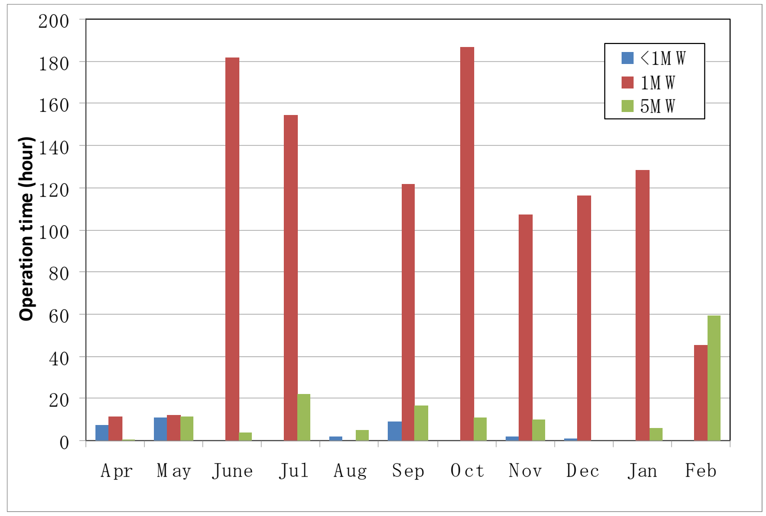


Figure 6: Operational history for FY2010 (Apr. 2010 - March 2011). Only maintenance operation has performed in March 2011.

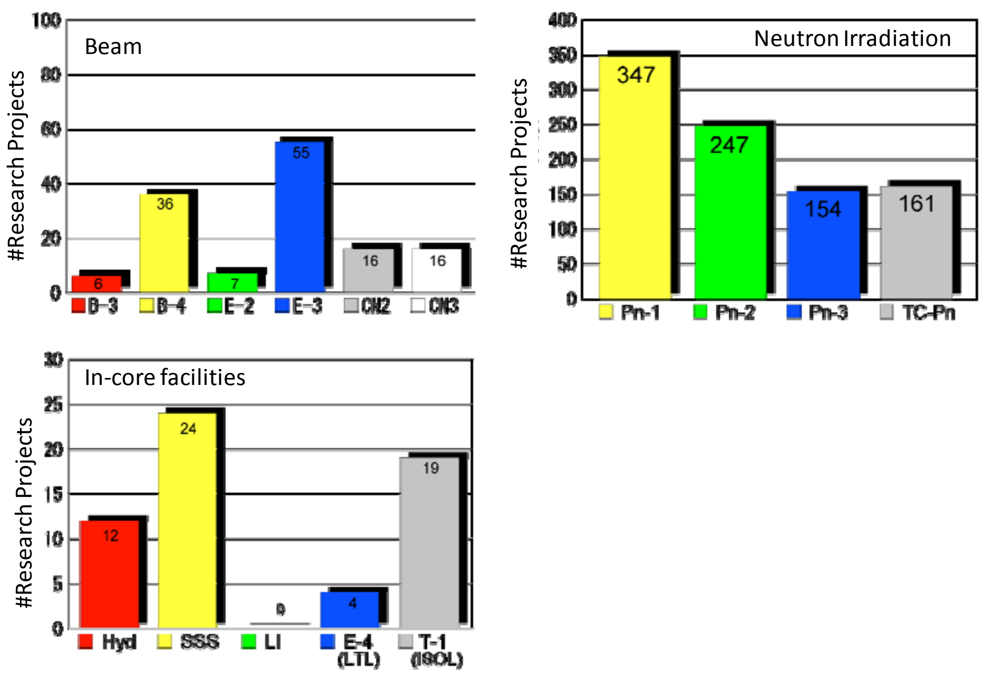


Figure 7: Utilization Status of KUR LEU at FY2010

The status of BNCT treatment since the restart of KUR is shown in Fig. 8. Despite the limitation in the operation time with 5MW thermal power, over 60 treatment of various tumor (mainly brain tumor and melanomas) have been successfully operated since last May. This alone would show the significance and importance to continue the operation of research and test reactors for scientific use.

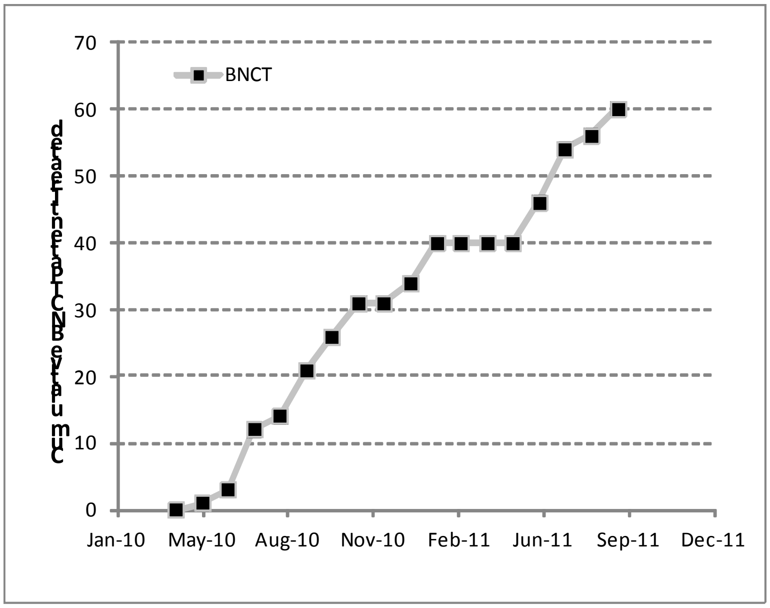


Figure 8 : Evolution of BNCT Treatments after KUR restart

4. Core Management System for KUR

4.1 Nuclear Design Calculation Scheme and its Verification

The nuclear design calculation system for the KUR LEU core[3] was constructed based on SRAC2006 code system [4] and JENDL-3.3 nuclear data library [5] to analyze the neutronics characteristics and to perform the fuel management of initial core configuration of KUR LEU core. Figure 9 shows the flow chart of the nuclear design calculation.

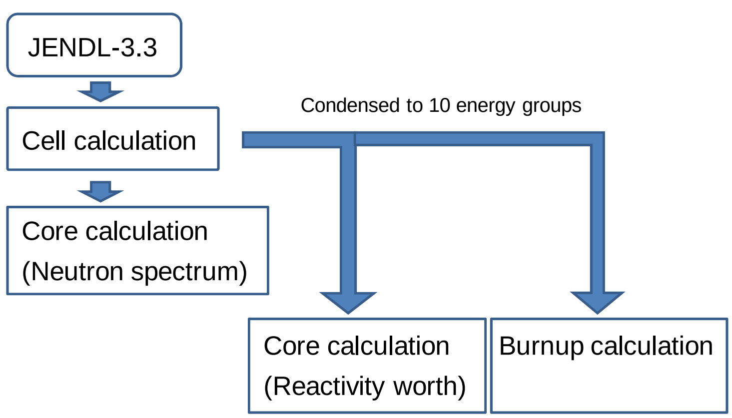


Figure 9: Calculation flow of KUR nuclear design

To analyze the neutronics characteristics in KUR core, the 107-gourps cross section set processed by SRAC2006 with JENDL-3.3 was utilized in the cell calculation step. After the processing, the core calculations were performed using SRAC2006/CITATION to evaluate the neutron flux spectrum and the reactivity worth. The Burnup calculations were used by

SRAC2006/CORBN code. A three-dimension (X-Y-Z) model was utilized for the core calculations and the burnup calculation. In the cell calculation step, the collision probability method with 107 energy groups is used. In resonance energy region, ultra fine lethargy meshes are employed by the PEACO routine in SRAC code. The calculation geometry is a two-dimension (X-Y) model. The core calculations are performed with three-dimension (X-Y-Z) model. In the neutron spectrum calculations, 107 energy groups are employed and 10 energy groups are employed for the reactivity worth calculation. In the burnup calculation step, the same geometry of core calculation is used. The energy groups are 10 groups. In order to perform the fuel management, the time dependency of 214 nuclides inventory (21 heavy nuclides and 193 F.P nuclides) are evaluated in the burnup model of KUR LEU core.

The accuracy of this calculation scheme has been verified through analysis of the initial loading configuration of the KUR LEU core shown in Fig. 10. The predicted excess reactivity of LEU initial core and the time dependency of burnup reactivity worth in 1 cycle operation of LEU initial core showed satisfactory agreement with measurement as shown in Table 4 and Fig. 11.

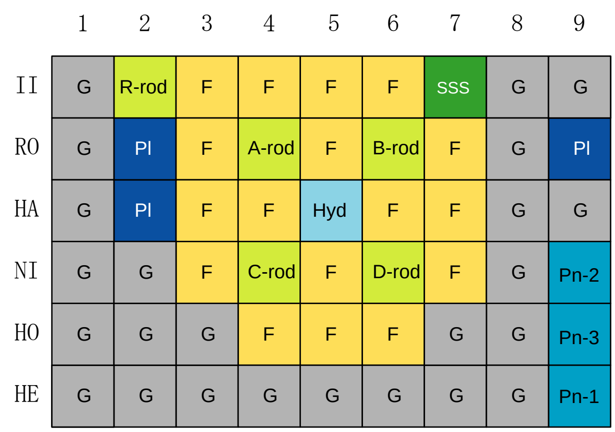


Figure 10: Fuel loading of KUR LEU initial core

F: Standard fuel, G: Graphite reflector, Pl: Water plug
A-D: Special fuel for Shim rods, R: Special fuel for Regulation rod
Hyd, SSS: Irradiation hole, Pn: Pneumatic tube

Table 4: Comparison of excess reactivity, KUR LEU initial core

Calculation (%Δk/k)	Measurement (%Δk/k)	C/E
3.93	3.96	0.99

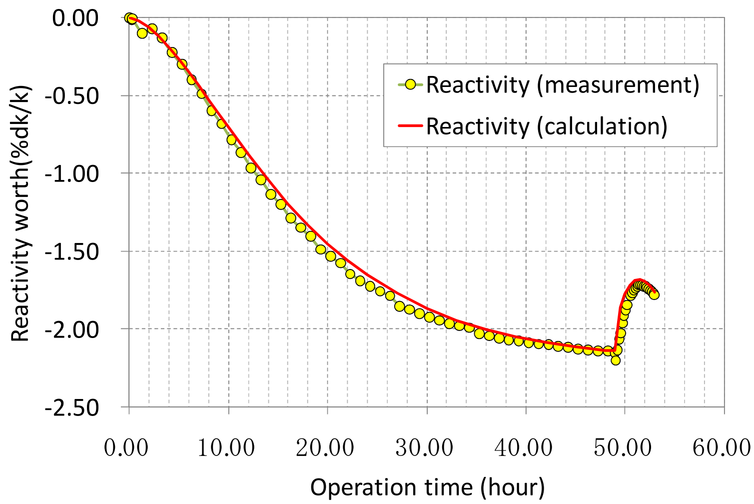


Figure 11: Burnup reactivity worth in 1 cycle operation

4.2 Development of Core Management System and its Verification

Based on the successful experience on the nuclear design scheme, the core management system has been developed to further improve the prediction accuracy of the KUR LEU core. The overall structure of the core management system is shown in Fig. 12. The system consists of basic cell calculation, core calculation using diffusion and transport codes, burnup calculation and sensitivity analysis for evaluating the uncertainty in the prediction accuracy. The collision probability routine PIJ of SRAC code system is used to generate the effective cross sections for fuel element and structural materials. The effective cross section is then collapsed to 10 energy groups using SRAC ANISN and TWOTRAN. The effective cross section of control rods are obtained and collapsed into 10 energy group using SRAC PIJ. The neutron flux distribution, reactivity worth and kinetic parameter are obtained by SRAC CITATION, whereas the excess reactivity, control rod worth and isotopic evolution with burnup is obtained using COREBN module[6].

The prediction accuracy of the excess reactivity is updated based on the following scheme;

1) calculate the excess reactivity of new core using predicted number density data (burnup calculation),
2) adjust the calculated excess reactivity using bias factor method,
3) for the excess reactivity at BOC, compare the predicted value with the results of detailed Monte Carlo calculation using MVP code.

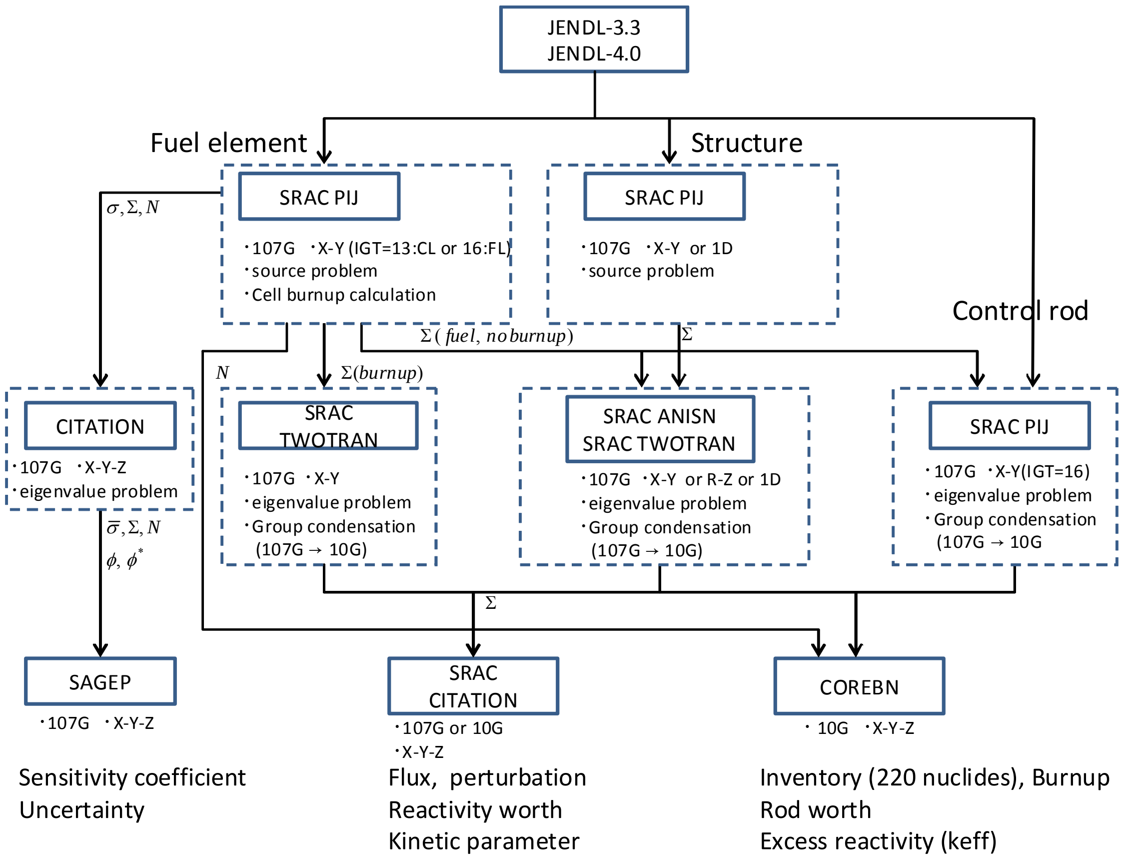
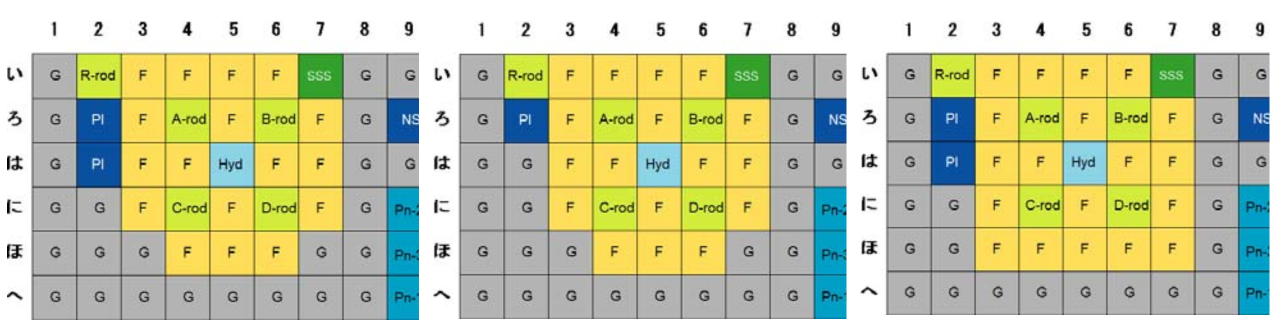


Figure 12: Detailed Calculation flow of KUR core management

The accuracy of this core management system is currently being verified based on the operating experience of the KUR LEU core. Figure 13 shows the fuel loading pattern of the KUR LEU core up to present. Since the startup at May 2010, two modifications in the fuel loading pattern has been made to account for the degradation of the excess reactivity due to fuel burnup. The corresponding excess reactivity and the predicted values are shown in Fig. 14, where satisfactory agreement has been achieved.



LEU17F-P13 **LEU17F-P12** **LEU19F-P13**

Figure 13: Core Fuel Loading of KUR LEU, May 2011 - Present

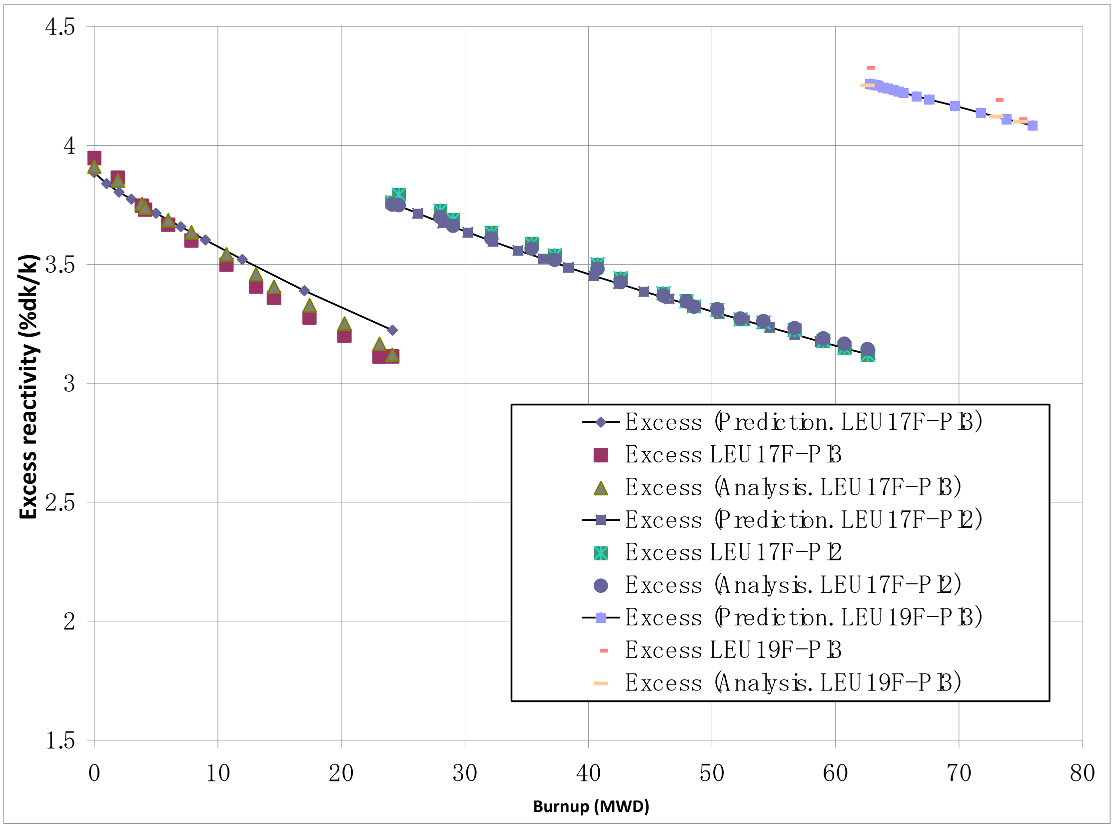


Figure 14: Burnup Dependence of Excess Reactivity

5. Conclusion

The operational experiences of LEU fueled KUR since the conversion on March 2010, mainly focusing on the prediction accuracy of the reactor core characteristics, together with the present status of the utilization of KUR, especially for the BNCT have been described. Despite of the limitation in operation power due to the limitation of fuel inventory, KUR has achieved successful operating experience since the startup using LEU, especially in the field of BNCT. The performance of the newly developed core management system is continuously being improved based on operating experiences.

Although the present status of KUR is quite satisfactory, the spent fuel problem remains as the most significant problem to be solved in the near future for the continuation of KUR. It is expected that the back-end issues of research reactor spent fuel, including both development on reprocessing technologies and possible disposal pathway, be accelerated in the very near future.

References

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