UPDATE OF NEUTRONIC ANALYSIS OF KUCA DRY CORE USING LEU FUEL

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ABSTRACT

Recent studies on the conversion of the Kyoto University Critical Assembly (KUCA) from 93% high-enriched uranium (HEU) to low enriched uranium (LEU) have demonstrated the feasibility of the conversion without significantly changing the core characteristics.
Currently, the HEU coupons used in KUCA consist of U-Al alloy coated with a thin epoxy layer. New research by Framatome-CERCA has resulted in a novel LEU fuel coupon design in which the U7Mo-Al dispersed fuel is completely encapsulated in an aluminum case. Previous studies on the KUCA conversion did not consider the presence of an aluminum edge all around the LEU fuel. This study summarizes the updated results of the neutronic analysis of the KUCA Dry cores using the revised design of the U7Mo fuel coupon. Major core characteristics, such as critical mass, control rod worth, neutron spectrum and temperature coefficients of representative KUCA Dry cores are obtained and evaluated to verify the adequateness of the LEU conversion using the proposed fuel coupon design.

1. Introduction

Under the US Department of Energy (DOE) Material Management and Minimization Program (M^3), the Kyoto University Research Reactor Institute (KURRI) and Argonne National Laboratory (Argonne) are investigating the feasibility of converting the Kyoto University Critical Assembly (KUCA) [1] from High Enriched Uranium (HEU) to Low Enriched Uranium (LEU) fuel. Previous studies [2,3] demonstrated the feasibility of converting the 93% HEU KUCA cores to the use of 19.75% LEU fuel while preserving the same central flux spectra and about the same core size. For the conversion, the use of U10Mo fuel was initially considered. Due to the strong sensitivity of the resulting LEU loadings to tolerances of fuel fabrication (especially the thickness), the use of uranium-molybdenum fuel with 7 wt% Mo (U7Mo) dispersed in an aluminum matrix was adopted. It was demonstrated that the use of dispersed U7Mo significantly reduces the sensitivity of the LEU loadings to the fuel thickness, especially if the U7Mo density in the dispersion is decreased (e.g., from 8 to 6 gU/cc) and then increasing the thickness in order to preserve the same U7Mo mass per coupon. Previous conversion studies considered LEU fuel with a square section of 5.08 x 5.08 cm and aluminum clad on only the top and bottom surfaces, not on the edges of the fuel meat.

The encouraging results obtained from the conversion studies led to an agreement with Framatome-CERCA (France) for the development of test samples that could be evaluated for the selection of the final LEU coupon design to be adopted for the KUCA LEU cores. The research currently performed by CERCA in this testing phase, has resulted in a novel LEU fuel coupon design in which the U7Mo-Al dispersed fuel is completely encapsulated in an aluminum case.

This study summarizes the updated results of the neutronic analysis of the KUCA Dry cores using the revised design of the U7Mo fuel coupon. Major core characteristics, such as neutron spectrum, critical mass, control rod worth and temperature coefficients of representative KUCA Dry cores are obtained and evaluated to verify the adequateness of the LEU conversion using the proposed fuel coupon design. Updated results are also provided for the sensitivity of the LEU loadings to the fuel thickness. For consistency with the previous studies, all calculations are performed with tMCNP5 and ENDF\B-VII.0 data.

The goal of the present work is to identify any trend in the major neutronic features of the LEU loadings based on different coupon configurations so that a final selection can be made for the optimal coupon design that considers both neutronic and fabrication needs.

2. LEU KUCA cores

Figure 1 shows a schematic representation of the U-Al plates used in the HEU KUCA cores and of the LEU coupon developed by CERCA that has the fuel meat (dispersed U7Mo) completely encapsulated in an aluminum case. Previous studies did not consider the presence of the 3-mm aluminum edge all around the LEU fuel. In the present work, we will refer to HEU fuel as a “plate”, as appropriate for the HEU thickness (1/16 in. or 5.08 cm). With the LEU fuel, the resulting thickness will be much smaller, so that it is more appropriate to refer to LEU U7Mo fuel as “meat”. The term “LEU coupon” will be used to refer to the sandwich of fuel meat plus the entire aluminum case.

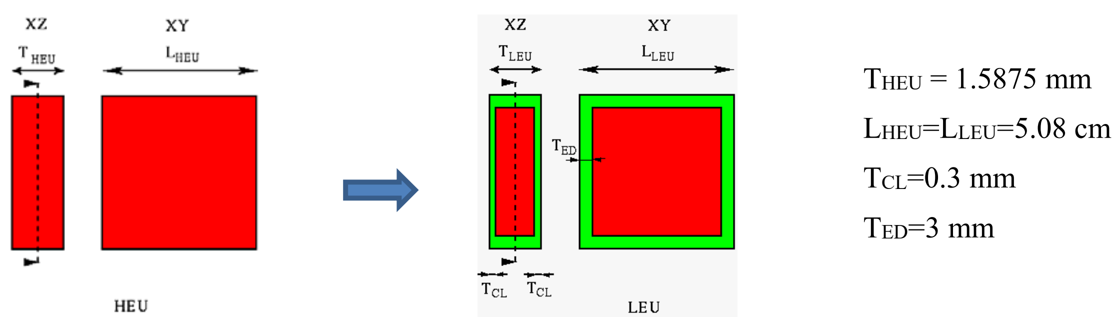

Figure 1. Configuration of HEU plate and LEU fuel coupon with aluminum edge

In addition to the revised coupon configurations, a number of updates were also introduced in the calculational model of the LEU cores. The new polyethylene plates now available at KURRI were adopted for the core loading. The LEU cores will use only 1/8-in. thick poly plates (3/8-in. thick plates were also used in the previous models) with a hydrogen number density about 4% smaller than that of the 1/8-in. plates used in the HEU cores. Similarly, for the KUCA assemblies within the core region, the upper and lower reflectors use the compositions of the new 10-in. thick polyethylene blocks. The axial extension of these reflectors will also be modified in the actual LEU configurations but for this study it has been kept the same as the LEU models previously used (i.e., the same as the HEU configurations). In fact, the impact of the likely changes in the axial reflector extension on the results of the present conversion feasibility studies is judged to be rather negligible. Finally, the aluminum-clad case containing the dispersed U7Mo fuel meat uses the standard compositions of the AG3NE aluminum alloy (2.671 g/cm^3) provided by CERCA. As an example, Figure 2 shows the axial representation of the model of a fuel assembly loaded in the L3 type LEU core (the designators used for assigning a name to the LEU cores are explained in details in Section 3.1).

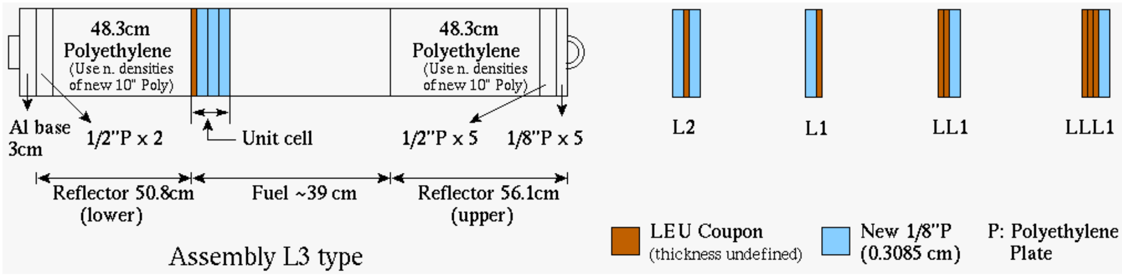

Figure 2. Axial representation of a fuel assembly model in the L3 type LEU core

3. Flux spectra

There are no specific constraints on the flux spectra of the KUCA LEU cores. It is however desired that the LEU loadings similar to the HEU cores be characterized by the same flexibility to cover a wide range of neutron spectra. For instance, in past conversion studies based on the use of dispersed U7Mo without the aluminum edge it was demonstrated that the LEU loadings are able to reproduce the same central flux spectra of five pre-selected HEU cores [3] that are representative of both thermal and fast reactors. The same capability is demonstrated in the present study for the LEU cores based on the revised design of the fuel coupons. As discussed in detail in Section 3.1, it is found that the preservation of flux spectra between the HEU and LEU cores can be achieved with the use of LEU coupons, each containing about 10 g of U7Mo. However, the LEU cores are not required to exactly reproduce the flux spectra of specific HEU cores. Thus, a parallel conversion study was performed with the use of LEU coupon configurations that are characterized by a larger content of dispersed U7Mo in an attempt to reduce the number of fuel assemblies needed to attain the desired core reactivity.

Flux spectra are all calculated in a central assembly and are determined as average values in a specific region of the LEU meat (or HEU plate) closest to the core midplane. This region is 1 cm × 1 cm with an axial extension that corresponds to the thickness of the LEU meat (or HEU plate). All flux spectra are obtained in 53 energy groups. The calculations are performed in "homogeneous" mode, i.e. in absence of the external (D-T) neutron source usually present in these configurations.

3.1. LEU cores reproducing the HEU flux spectra

As done in the previous conversion studies, calculations were performed to identify the LEU cores that preserve about the same central flux spectra of five pre-selected HEU cores characterized by different H/U5 atom ratios (or moderator to fuel volume ratios, V_m/V_f) in the fuel unit cell (see Figure 2 for the definition of unit cell and Ref. 3 for more details on the five HEU cores). As reminder, the flux spectra in the KUCA cores are strictly dependent on the H/U5 atom ratio in the core zone and the five HEU cores were selected with the purpose of considering a wide range of neutron spectra representative of both fast and thermal reactors.

For the conversion, the unit cells of the LEU cores have the same total thickness (and thus the same volume) of polyethylene moderator as the corresponding HEU cores. Thus, for each HEU configuration, several LEU cores can be found that preserve the same central flux spectra simply by using different configurations of LEU fuel coupons that contain the same U-235 (or U7Mo) mass. Practically, this can be achieved by simultaneously modifying the fuel thickness and U7Mo density in the dispersion fuel, since the X-Y dimension (2.48 cm) of the fuel as well as AG3NE clad thickness (0.3 mm) and edge extension (3 mm) are fixed.

For the coupon configurations considered in the past without the aluminum edge, it was determined that the preservation of the central flux spectra between the HEU and LEU cores was attained by the use of LEU coupons containing about 12.6 g of dispersed U7Mo. Thus, two coupon configurations were investigated: 8 gU/cc dispersed U7Mo of 22 mils thickness and 6 gU/cc dispersed U7Mo of 30 mils thickness. Adjusting for the change in the hydrogen number density of the new 1/8 in. polyethylene plates, the target U7Mo mass per LEU coupon would have to be revised to about 12 g when no aluminum edge is used to preserve the central flux spectra between the HEU and LEU cores. Through a parametric study, it was found that to preserve the same central flux spectra of the corresponding HEU cores the presence of the 3 mm AG3NE edge around the LEU fuel requires that the U7Mo mass per coupon be reduced from 12 g to 10 g. This change in the U7Mo mass per coupon corresponds approximately to the variation of the XY surface of the fuel between the two coupon configurations with and without the aluminum edge.

For the modeling of the LEU cores, different coupon configurations were investigated with the purpose of considering specific thicknesses or U7Mo densities in the dispersion fuel. In one case, LEU loadings were defined by progressively increasing the thickness of the fuel meat (0.06 cm, 0.075 cm and 0.1 cm) and adjusting the U7Mo density in the dispersion fuel in order to preserve the 10 g of U7Mo per coupon. This approach aims at identifying a range of fuel thicknesses that can be successively fabricated for testing. The final selection of the fuel thickness will be made by identifying an optimal value that fits best with both neutronic and fabrication needs. In a parallel approach, the conversion feasibility was investigated by assigning the fuel meat a specific U7Mo density of 6 gU/cc and a corresponding thickness of 0.077 cm to preserve the 10 g U7Mo per coupon. As done in the past conversion studies, once the LEU coupon configuration that generates the desired central flux spectra is defined, the target reactivity value is simply attained by adding (or removing) a number of peripheral fuel assemblies. In this conversion study the target reactivity doesn't translate to a specific reactivity value but it is simply required that an excess reactivity (less than 1000 pcm) be assured when all control rods are completely withdrawn. As in previous studies, the axial extension of the LEU cores is kept the same as the HEU cores.

For all coupon configurations discussed above (the cases of three specific thicknesses and the specific dispersion fuel densities), it was possible to define an LEU loading that satisfies the conversion requirements for both central flux spectra and excess reactivity. This confirms the flexibility of the KUCA cores for the conversion from HEU to LEU fuel. As an example, Figure 3 shows the final layout for the LEU configurations that preserve the same central flux spectra as the HEU cores of largest (KUCA A3/8"P36HEU [3]) and lowest (KUCA A1/8"P48HEU-HEU-HEU [3]) V_m/V_f.

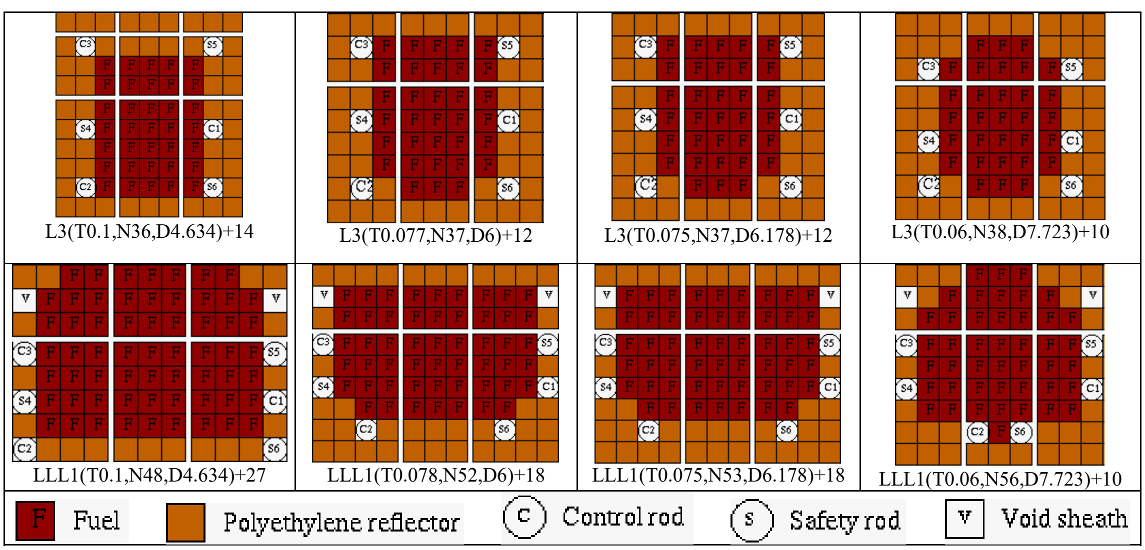

Figure 3. L3 and LLL1 type core configurations

In the core identifiers, e.g., “L3(T0.1,N36,D4.634)+14”, the following conventions are used. The number of times the designator “L” appears indicates the number of LEU coupons in the unit cell; the number “3” denotes the number of 1/8-in. polyethylene plates in the unit cells; “T0.1” specifies the thickness in cm of the fuel meat; “N36” indicates the number of unit cells loaded along the axial extension of the core; “D4.634” denotes the U7Mo density in the dispersion fuel in gU/cc; “+14” specifies the number of peripheral fuel assemblies that had to be added with respect to the HEU cores to meet the excess reactivity requirements. Note that the presence of the Al edge requires the loading of a larger number of extra fuel assemblies with respect to the case of no aluminum edge to achieve the excess reactivity requirements, especially for larger values of the fuel thickness. Particularly, in the case of 0.1 cm fuel thickness a considerable number of fuel assemblies need to be added especially (up to 27) in the case of configurations of low V_m/V_f. Figures 4 through 8 show that the central flux spectra of the defined LEU cores match quite well the central flux spectra of the corresponding HEU cores. As expected, by maintaining the same U7Mo mass per coupon the neutron spectrum is preserved for each LEU core type.

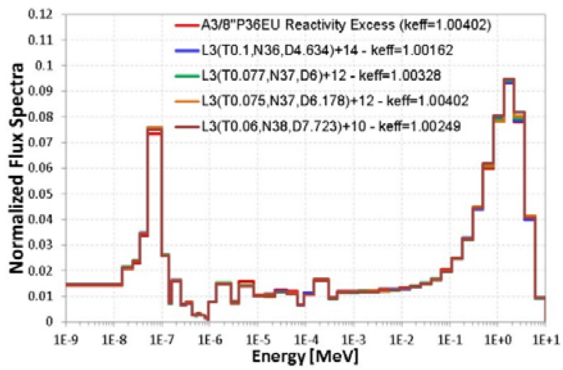

Figure 4. Central flux spectra of A3/8”P36HEU and L3 type LEU cores

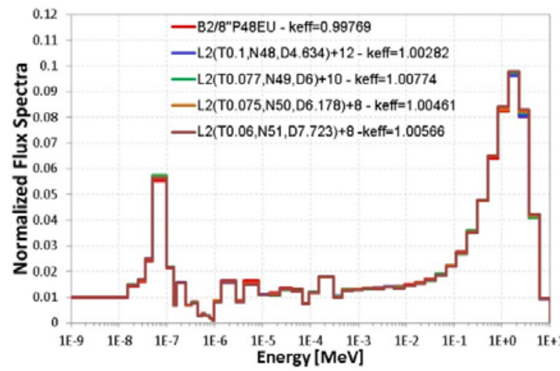

Figure 5. Central flux spectra of B2/8”P48HEU and L2 type LEU cores

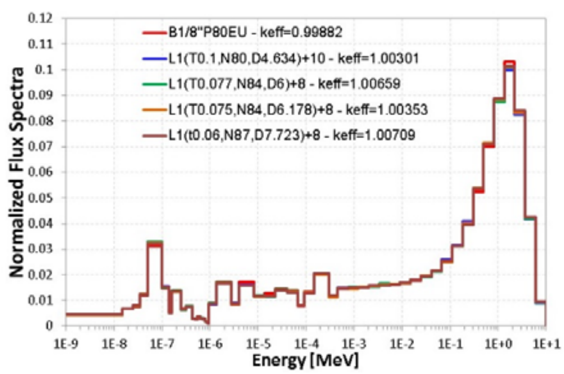

Figure 6. Central flux spectra of B1/8”P80HEU and L1 type LEU cores

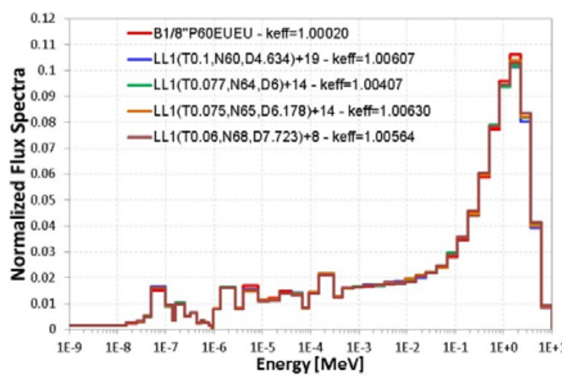

Figure 7. Central flux spectra of B1/8”P60HEU-HEU and LL1 type LEU cores

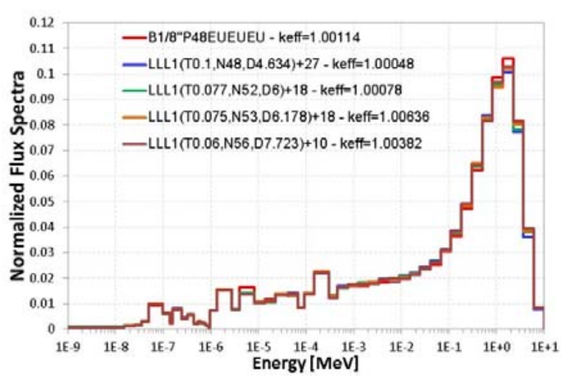

Figure 8. Central flux spectra of B1/8”P48HEU-HEU-HEU and LLL1 type LEU cores

3.2. LEU cores using 12g dispersed U7Mo per coupon

A parallel conversion study was performed using LEU coupon configurations that are characterized by a larger mass of U7Mo in an attempt to reduce the number of fuel assemblies needed to attain the desired core reactivity. More precisely, the U7Mo mass per coupon was increased from 10 to 12 g. Also in this case different coupon configurations were considered, characterized by an increasing thickness of the fuel meat (0.06 cm, 0.075 cm and 0.1 cm) and by a specific U7Mo density of 6 gU/cc in the dispersion fuel. Figures 9 through 13 show that by increasing the U7Mo mass per coupon, harder flux spectra are obtained from the LEU loadings, due to the reduced moderator to fuel atom ratio in the unit cell. For the configurations of low V_m/V_f however, the change in the flux spectra is less important since these configurations are less sensitive to the H/U5 atom ratio in the fuel unit cell.

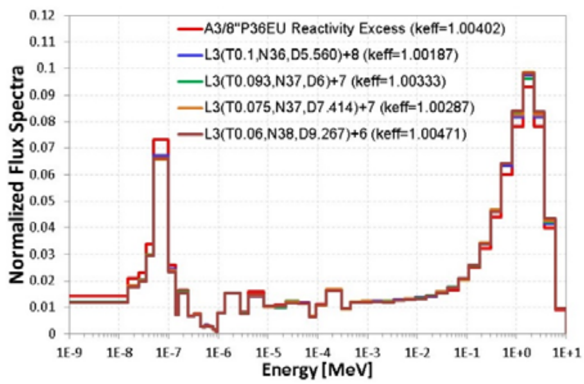

Figure 9. Central flux spectra of A3/8"P36HEU and L3 Type LEU cores

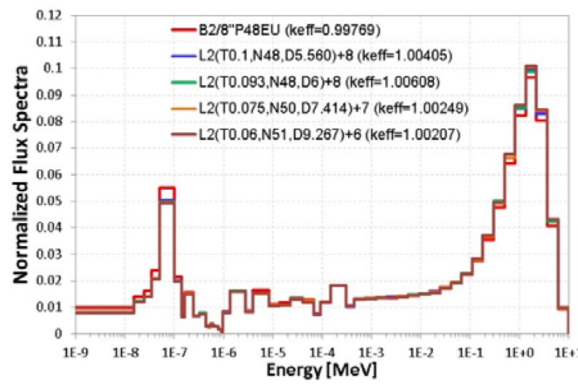

Figure 10. Central flux spectra of B2/8"P48HEU and L2 type LEU cores

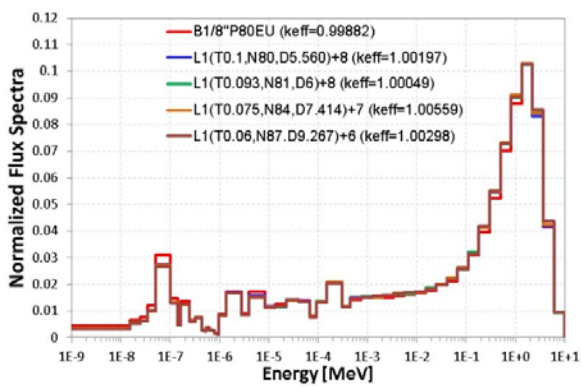

Figure 11. Central flux spectra of B1/8"P80HEU and L1 type LEU cores

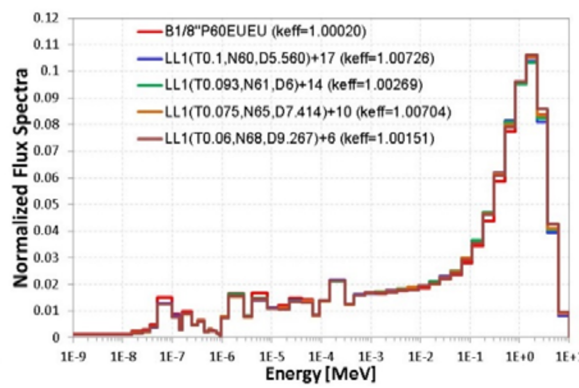

Figure 12. Central flux spectra of B1/8"P60HEU-HEU and LL1 type LEU cores

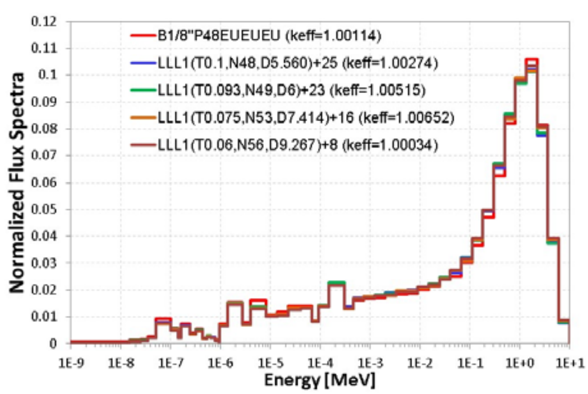

Figure 13. Central flux spectra of B1/8"P48HEU-HEU-HEU and LLL1 type LEU cores

Comparing Figures 4 through 8 with Figures 9 through 13 it can also be noted that for the same fuel thickness, increasing the U7Mo mass per coupon from 10 to 12 g reduces the core size by an average of just a few assemblies in the case of configurations with low V_m/V_f. The reduction in core size becomes greater for configurations of large V_m/V_f (i.e., L3 cores).

4. Control rod worth

For the KUCA cores it is required that the total control rod worth be at the least equal to the excess reactivity of the core +1% dk/k. In other words, with the three control rods fully inserted the core multiplication factor should not exceed the value of ~0.99. Additionally, the worth of a single control rod should not exceed about 1/3 of the total control rod worth. Table 1, shows how these constraints were met in the design of the five selected HEU cores. Specifically, with the HEU cores, the total control rod worth was significantly above the desired minimum value.

	Excess Reactivity	Total CR Worth	C1 Worth	C2 Worth	C3 Worth
A3/8"p36EU	400	-1901	-474	-679	-1364
B2/8"P48EU	-232	-1545	-702	-200	-617
B1/8"P80EU	-118	-2175	-926	-417	-784
B1/8"P60EU-EU	20	-1783	-846	-199	-670
B1/8"P48EU-EU-EU	114	-1592	-394	-580	-577

Table 1: Excess reactivity [pcm] and control rod reactivity worths [pcm] of HEU cores

Tables 2 and 3 show the total control rod worths for the LEU cores that were identified in Section 3 based on neutron spectra considerations. It is observed that none of those LEU cores meets the requirement for minimum total control rod worth. The loadings of Section 3 were defined in an attempt to minimize the number of assemblies required for the excess reactivity requirement. Thus, control (and safety) rods were moved to increased distances from the core center with respect to the original location in the corresponding HEU cores.

L3(T0.1,N36,D4.634)+14	L3(T0.075,N37,D6.178)+12	L3(T0.077,N37,D6)+12	L3(T0.06,N38,D7.723)+10
162 / -541 [(a)]	400 / -567	327 / -562	248 / -593
L2(T0.1,N48,D4.634)+12	L2(T0.077,N49,D6)+10	L2(T0.075,N50,D6.178)+8	L2(T0.06,N51mD7.723)+8
281 / -1223	768 / -825	459 / -365	563 / -592
L1(T0.1,N80,D4.634)+10	L1(T0.075,N84,D6.178)+8	L1(T0.077,N84,D6)+8	L1(T0.06,N87,D7.723)+8
300 / -784	352 / -843	655 / -729	704 / -1867
LL1(T0.1,N60,D4.634)+19	LL1(T0.077,N64,D6)+14	LL1(T0.075,N65,D6.178)+14	LL1(T0.06,N68,D7.723)+8
603 / -1574	405 / -1268	626 / -1336	561 / -897
LLL1(T0.1,N48,D4.634)+27	LLL1(T0.077,N52,D6)+18	LLL1(T0.075,N53,D6.178)+18	LLL1(T0.06,N56,D7.723)+10
48 / -673	78 / -795	632 / -789	381 / -1451

[(a)] a/b: a is the reactivity excess (i.e., the core reactivity with all control rods fully withdrawn); b is the total control rod reactivity worth. All values are in pcm.

Table 2: Excess reactivity [pcm] and total control rod reactivity worths [pcm] of LEU cores using 10 g U7Mo/coupon

L3(T0.1,N36,D5.560)+8	L3(T0.075,N37,D7.414)+7	L3(T0.0927,N37,D6)+7	L3(T0.06,N38,D9.267)+6
187 / -660	286 / -953	332 / -671	469 / -834
L2(T0.093,N48,D6)+8	L2(T0.1,N48,D5.560)+8	L2(T0.075,N50,D7.414)+7	L2(T0.06,N51,D9.267)+6
604 / -717	403 / -647	248 / -1171	207 / -991
L1(T0.1,N80,D5.560)+8	L1(T0.093,N81,D6)+8	L1(T0.075,N84,D7.414)+7	L1(T0.06,N87,D9.267)+6
197 / -536	49 / -952	556 / -1345	297 / -1427
LL1(T0.1,N60,D5.560)+17	LL1(T0.093,N61,D6)+14	LL1(T0.075.N85,D7.414)+10	LL1(T0.06,N68,D9.267)+6
721 / -1427	268 / -1208	699 / -1075	151 / -816
LLL1(T0.1,N48,D5.560)+25	LLL1(T0.093,N49,D6)+23	LLL1(T0.075,N53,D7.414)+16	LLL1(T0.06,N56,D9.267)+8
273 / -728	512 / -717	648 / -838	34 / -1093

Table 3: Excess reactivity [pcm] and total control rod reactivity worths [pcm] of LEU cores using 12 g U7Mo/coupon

Using the same coupon configurations considered in Section 3, the total control rod worth requirements can be still satisfied by moving the rods closer to the core center and loading additional peripheral fuel assemblies to compensate for the subsequent loss of reactivity. The suggested changes in the core loadings would not affect the central flux spectra identified in Section 3. As an example, for the case of a fuel coupon with 10 g U7Mo and 6 gU/cc new LEU loadings were defined as shown in Figure 14 by moving the control rods to the original locations of the corresponding HEU cores. As can be observed in Table 4, the total and single rod worth requirements are satisfied for each core type but an average of 5 extra assemblies had to be loaded at the core boundary with respect to the loadings defined in Section 3.1. The total number of fuel assemblies needed to achieve the excess reactivity requirements could be eventually reduced by increasing the axial core extension. As an example, it was found that for the L3 core type with 10 g U7Mo and 6 gU/cc [L3(T0.077,N37,D6)+18 in Figure 14], increasing the axial extension of the core by ~5 cm (i.e., loading axially 5 additional unit cells) allows the desired reactivity to be attained by reducing by 4 the total number of fuel assemblies. Similarly, for the LLL1 core type with 10 g U7Mo and 6 gU/cc [LLL1(T0.077,N52,D6)+21 in Figure 14] increasing the axial extension of the core by ~5 cm (i.e., loading axially 7 additional unit cells) allows the desired reactivity to be attained by reducing by 8 the total number of fuel assemblies. However, despite the use of longer assemblies, the total loading of U-235, and hence the number of coupons, in the critical assembly remains fairly constant within a few percent).

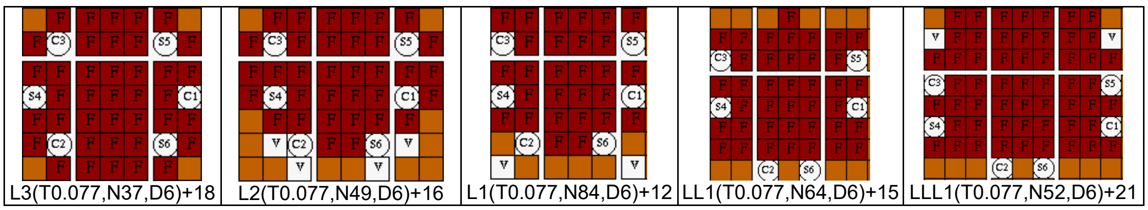

Figure 14. LEU cores configurations satisfying CR worth requirements (with coupons of 6 gU/cc and 10 g U7Mo/coupon)

	Excess Reactivity	Total CR Worth	C1 Worth	C2 Worth	C3 Worth
L3(T0.077,N37,D6)+18	635	-3278	-783	-1137	-1101
L2(T0.077,N49,D6)+16	964	-3023	-1194	-345	-1238
L1(T0.077,N84,D6)+12	176	-3084	-1105	-820	-977
LL1(T0.077,N64,D6)+15	305	-2381	-945	-542	-758
LLL1(T0.077,N52,D6)+21	464	-1515	-402	-475	-572

Table 4: Excess reactivity [pcm] and control rod reactivity worths [pcm] of LEU cores satisfying the CR requirements (with coupons of 6 gU/cc and 10 g U7Mo/coupon)

5. Temperature feedback coefficients

Temperature feedback coefficients were evaluated for the configurations of largest and lowest V_m/V_f presented in Section 3.1, i.e. L3(T0.077,N37,D6)+12 and LLL1(T0.077,N52,D6)+18. In both cases, the change in core reactivity was determined by increasing the fuel temperature up to 100 C (calculations were performed at 20, 40, 60, 80, 100 C). The temperature increase was modeled by weighting the number densities with respect to the ENDF\B-VII.0 cross section libraries evaluated at 20 C (70c) and 327 C (71c). For simplicity, the temperature change was limited to the fuel meat only. There are no specific requirements on the temperature feedback coefficients of the KUCA LEU cores, except of course that they be negative. As can be seen in Table 5, the temperature feedback coefficients are larger for the configuration of low V_m/V_f. The reference reactivity values at 20 C are taken from the calculations described in Section 3.1.

Temperature (C)	L3(T0.077,N37,D6)+12	LLL1(T0.077,N52,D6)+18
20	326	84
40	300	1
60	262	-64
80	238	-139
100	213	-203

Table 5: L3 and LLL1 LEU core excess reactivity [pcm] for different fuel temperatures (case of coupons of 6 gU/cc and 10 g U7Mo/coupon)

6. Sensitivity to fuel fabrication tolerances

One of the major concerns of the KUCA LEU cores is the sensitivity to potential tolerances on the fuel fabrication, particularly to the thickness of the fuel meat. From Ref 3, it was concluded that using more lower U7Mo densities in the dispersed fuels (thus, increasing the thickness to preserve the fuel mass per coupon) has the advantage of reducing the sensitivity to thickness tolerances but requires more fuel to attain the desired reactivity. This conclusion is expected to be the same with the new design of the fuel coupon. As an example, sensitivity to the fuel thickness was investigated for the loadings of largest and lowest V_m/V_f in Figure 14 [i.e., L3(T0.077,N37,D6)+18 and LLL1(T0.077,N52,D6)+21]. As done in past studies, the sensitivity was estimated in terms of reactivity change due to a 1-mil increase in the fuel thickness of all coupons loaded in the core. It is found that 1-mil increase in the thickness of fuel meat produces a reactivity change of 583 pcm in the case of L3(T0.077,N37,D6)+18 and 60 pcm in the case of LLL1(T0.077,N52,D6)+21. Even if these estimates are very conservative because they assume that all fuel coupons in the cores are affected by the same 1-mil increase, the results need to be considered when developing fabrication techniques for the LEU coupons.

Another concern for the use of LEU fuel is the potential sensitivity to the homogeneity of the dispersed fuel. CERCA has suggested that the inhomogeneity of the dispersion may be greater for thinner fuel meat. Preliminary investigations [4] performed at KURRI, however, indicate that any inhomogeneity of the dispersed U7Mo would have only a minor impact on the reactivity of the KUCA Dry cores.

7. Conclusions

This study summarizes the updated results of the conversion analyses of the KUCA Dry cores using the revised design of the LEU fuel coupon with complete aluminum encapsulation. Major core characteristics, such as neutron spectrum, critical mass, control rod worth and temperature coefficients of representative KUCA Dry cores were obtained and evaluated to verify the acceptability of the LEU conversion using the proposed fuel coupon design.

Concerning the flux spectra, it was confirmed that the LEU cores are able to produce a wide range of neutron spectra with the revised design of the fuel coupon. With the use of fuel coupons containing 10 g of dispersed U7Mo, it was demonstrated that the LEU loadings are able to reproduce the same central flux spectra of five pre-selected HEU cores that are representative of both thermal and fast reactors. Since the LEU cores are not required to exactly reproduce the flux spectra of specific HEU cores, a parallel conversion study was performed with the use of LEU coupon configurations that are characterized by a larger content of dispersed U7Mo (12 g) in an attempt to reduce the number of fuel assemblies needed to attain the desired core reactivity. In both cases (i.e., 10 and 12 g U7Mo/coupon), different coupon configurations were investigated with the purpose of considering specific thicknesses or densities of U7Mo in the dispersion fuel. In one case, LEU loadings were defined by progressively increasing the thickness of the fuel meat (0.06 cm, 0.075 cm and 0.1 cm) and adjusting the dispersion fuel density in order to preserve the U7Mo mass per coupon and thus the flux spectrum of each LEU loading type. This approach was aimed at identifying a range of fuel thicknesses that can be successively tested. The final selection of the fuel thickness will be made by identifying an optimal value that fits best with both neutronic and fabrication needs. In a parallel approach, the conversion feasibility was investigated by assigning the fuel coupon a specific U7Mo dispersion density of 6 gU/cc and a corresponding thickness for the preservation of the U7Mo mass/per coupon. As done in the past conversion studies, once the LEU coupon configuration that generates the desired central flux spectra was defined, the target reactivity value (i.e., an excess reactivity less than 1000 pcm with all control rods completely withdrawn) was simply attained by adding (or removing) to the LEU cores a number of peripheral fuel assemblies. It is found that coupon configurations with smaller thicknesses require fewer assemblies to attain the desired reactivity. Particularly, in the case of 0.1 cm fuel thickness a considerable number of fuel assemblies need to be added especially (up to 27) in the case of configurations of low V_m/V_f. For the same fuel thickness, increasing the U7Mo mass per coupons from 10 to 12 g reduces the core size by an average of just a couple of assemblies in the case of configurations with low V_m/V_f. The reduction in core size becomes more important for configurations of large V_m/V_f (i.e., L3 cores). However, since the low V_m/V_f cores require the most assemblies the change from 10 to 12 g does not reduce assembly requirements across the analyzed range by more than two assemblies. The range of V_m/V_f analyzed covers, and significantly exceeds, the expected range of utilization of the critical assembly which is useful in the final selection of the fuel that fits best with both neutronic and fabrication needs.

For the KUCA cores it is required that the total control rod worth be at least equal to the excess reactivity of the core +1% dk/k. Additionally, the worth of a single control rod should not exceed approximately 1/3 of the total control rod worth. It was found that the LEU cores determined by neutron spectra considerations did not meet the requirement of minimum total control rod worth. These loadings were defined in an attempt to minimize the number of assemblies required for the excess reactivity requirement. Thus, control (and safety) rods were moved to matrix locations farther from the core center with respect to the original locations in the corresponding HEU cores. Using the same coupon configurations based on neutron spectra considerations, the total control rod worth requirements can be still satisfied by moving the rods closer to the core center and loading additional peripheral fuel assemblies to compensate for the subsequent loss of reactivity.

Temperature feedback coefficients were evaluated for the configurations of largest and lowest V_m/V_f and shown to be sufficiently negative for all LEU cases.

Revised results were also provided for the sensitivity of the obtained LEU loadings to the fuel thickness of the U7Mo meat in the fuel coupon.

8. Acknowledgements

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9. References

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