HEU-LEU MIXED CORE ANALYSIS FOR TR-2

TURGUT Mehmet Hulusi

TAEK, Çekmece Nuclear Research and Training Center, İstanbul-TURKEY

Abstract

Core conversion calculations have been carried out for different core loadings of the TR-2 reactor in order to find out the optimum design for the radioisotope production. Using HEU and LEU fuel elements in the mixed core also introduced additional peaking problems to be eliminated. Five group structure is used for the burnup dependent cross-section libraries that are generated by EPRI-CELL code. 2D diffusion-depletion code GEREBUS is used for the reactivity and burnup calculations.

New graphite and Be reflectors have been added to the periphery of the core to enhance the reactivity and the discharge burnup levels. Two water boxes have been placed inside the reactor core in order to increase the radioisotope production. The activity levels of the irradiation samples, core excess reactivities, power peaking factors, and the anti-reactivities of the control blades have been calculated for various loadings. After the optimization studies, it is found that these modifications have yielded higher production rates and a uniform distribution in the activity levels of the irradiation samples.

One irradiation and two standard LEU fuel elements have already been loaded to the TR-2 core without any operational or safety related problems. The agreement between the calculations and the experiments are quite good for the operated 13 cycles.

1. Introduction

TR-2 is a plate type research reactor with an operational power of 5 MW. The initial fuel has 93 % enrichment. Core conversion calculations have been carried out at ANL-USA [1, 2]. The initial core has been modified several times according to the irradiational and operational needs [3, 4, 5, 6].

The insertion of the first LEU elements inside the core was made at the 13^{th} cycle. Two fresh standart LEU elements were placed on the opposite sides at the periphery of the core. One fresh irradiatinal LEU element was also introduced on the other side at the periphery. This mixed core has been operated for 371.9 MWD's without any operational and safety related problems.

Most of the HEU fuels have already been burned above 40 %. The aim is to increase the discharge burnup of the available HEU fuels as much as possible before the shippent to USA. So, further combinations of the mixed HEU-LEU loading were planned according to the operational needs. Many different core loadings have been tested for this purpose. The ones that have higher radioisotope production yields have been chosen for detailed studies.

2. Cross sectıon lıbrarıes and codes

Few group (5, and 10) burnup dependent cross-sections for HEU and LEU fuels were generated for different core regions using EPRI-CELL code [7]. The RABANL integral transport option of MC^2-2 code [8] was used to accurately account for the resonance self-shielding of U-238. Transport corrected effective cross-sections were used for the control rod regions [9].

Two and 3-dimensional diffusion and burnup calculations were carried out by DIF3D [10], REBUS-3 [11] and GEREBUS codes [12]. Control rods CR-1 and CR-2 were assumed to be partially inserted in the burnup calculations during each cycle in order to reflect the criticality adjustments made throughout the operations. Five group libraries were used in most of the calculations. Ten group structure was only used for the calculation of safety parameters.

3. Optımızatıon calculatıons

Optimization calculations have been carried out for the maximization of the radioisotope production, after the tracing calculations up to the $13^{\underline{th}}$ cycle. All the available 12 Be elements and some additional graphite reflectors were used around the core in order to enhance the neutron fluxes in the reactor core and the discharge burnup levels of the fuel elements. Some of the water boxes which are at the periphery were moved inside the core in order to increase the radioisotope production. MoO_3 is irradiated in order to obtain Tc-99m isotope. TeO_2 is irradiated for the production of I-131 isotope.

Many core designs have been tested in order to find an optimum loading. The proposals of the reactor operation group were also calculated. The excess reactivities and related cycle lengths, control rod anti-reactivities, the values and positions of the power peaking factors (PPF's), and Mo-99 activities were calculated for every loading. The optimum positions found for the Tc-99m isotope turned out to be again the most suitable places for the I-131 production.

4. Comparison of the results with experiments

After long discussions, most of the cases were eliminated and the experiments were made for the chosen two core loadings which are given in Figure-1 (C13K and C13AD). The Mo activities at the water boxes and irradiation elements are also included in the figure. The calculated and measured excess reactivities and the control rod worths are given in Table-1. The absolute and relative thermal flux distribution are given in Figure-2. The thermal flux profiles along the axis passed over the water boxes are given for the two cases in Figure-3. Large increase in the fluxes can be observed for the case C13K which contains 2 water boxes inside the reactor core. Relative Mo activities given in Table-2 also reflects this increase (% 66-130). As can be seen from these two tables and from Figure-2, the agreement between the calculations and the experiments are quite satisfactory. The deviations mainly come from the impossibility to reflect the control rod movements in the calculations.

5. Short discussion on the different core lodings

There are several possibilities for the TR-2 core loading and the optimum is based on the utilization of the reactor. Some of them may be eliminated due to lower activities or higher peaking values. For the moment C13K seems to be satisfactory for todays irradiational needs. C13HB is also a possibility for the increased demads due large number of irradiation positions. C13F3 is another possibility for higher activities. Decision will be made according to that days conditions.

6. Final remarks

Results of these mixed core and optimization calculations can be summarized as follows :

- The agreement between calculations and the experiments seems to be reasonable.
- There are many loading possibilities for the TR-2, and the decision can be made according to irradiational needs or other utilization factors.
- Radioisotope production can be maximized by new loading patterns. Especially insertion of water boxes inside the reactor will increase the yields up to % 66-130. This is also verified by the experiments.
- Optimization studies have yielded higher production rates and in addition a uniform distribution in the activity levels of the irradiation samples.
- Replacing Be and graphite reflectors around the core will also inrease the production rates and the discharge burnup levels.
- The discharge burnup levels of the HEU elements can further be increased only by the mixed core loading.
- The PPF’s become more important in mixed core analysis. Loading patterns should be adjusted for each step for the minimization of the peaks untill the full conversion to LEU equilibrium core.
- No operational or safety related problems were observed during the initial phase of the mixed core during 371.9 MWD’s of operation.

Table-1: Calculated and measured reactivities for the 2 core loadings

	C13K		C13AD	
	Calculations	Measurements	Calculations	Measurements
Core excess reactivity [pcm]	**3744**	**3720**	**6868**	**6867**
SR-1 worth [pcm]	5822	4503	6219	4511
SR-2 worth [pcm]	5755	5231	5936	4294
CR-1 worth [pcm]	5847	3991	6051	4402
CR-2 worth [pcm]	5748	4146	5734	4394

Table-2: Relative Mo activities for the 2 core loadings

Calculation name		% increase			
C13K	**C13AD**	Calculations	Average	Measurements	Average
WB45 /	WB25	66.0	68.2	68.2	66.1
WB65 /	WB85	70.5		64.0	
WB45 /	WB23	125.1	130.2	-	-
WB65 /	WB83	135.3		-	
IE55 /	IE55	15.7	12.0	-8.0	3.4
IE57 /	IE57	8.3		14.8	

^{22}W	^{32}WB	^{42}Be	^{52}Be	^{62}Be	^{72}DIF	^{82}W
^{23}C	^{33}Be*	^{43}S115	^{53}S113	^{63}S106	^{73}Be*	^{83}C
^{24}C	^{34}S116	C011	^{54}S104	C013	^{74}S118	^{84}C
^{25}Be	^{35}LS01	^{45}WB **16470**$^{+}$	I00200 **15094**	^{65}WB **16420**	^{75}LS02	^{85}Be
^{26}C	^{36}S105	C018	^{56}S103	C014	^{76}S117	^{86}C
^{27}C	^{37}Be*	^{47}S112	LI0100 **8120**	^{67}S110	^{77}Be*	^{87}C
^{28}W	^{38}C	^{48}Be	^{58}Be	^{68}Be	^{78}C	^{88}W

C13K

^{22}W	^{32}C	^{42}Be	^{52}Be	^{62}Be	^{72}DIF	^{82}W
^{23}WB **7316**	^{33}Be*	^{43}S110	^{53}S112	^{63}S115	^{73}Be*	^{83}WB **6979**
^{24}Be	^{34}S116	C013	^{54}S101	C017	^{74}S118	^{84}Be
^{25}WB **9921**	^{35}S117	^{45}S114	I00100 **13051**	^{65}S111	^{75}S105	^{85}WB **9628**
^{26}C	^{36}LS01	C012	^{56}S108	C015	^{76}LS02	^{86}C
^{27}C	^{37}Be*	^{47}S106	LI0100 **7501**	^{67}S104	^{77}Be*	^{87}C
^{28}W	^{38}C	^{48}Be	^{58}Be	^{68}Be	^{78}C	^{88}W

C13AD

^{28}W	^{27}C	^{26}WB **7630**	^{25}WB **9222**	^{24}Be	^{23}C	^{22}W
^{38}C	^{37}Be*	^{36}S105	^{35}LS01	^{34}S116	^{33}Be*	^{32}WB
^{48}Be	^{47}S112	--- C018 ---	^{45}S103	--- C011 ---	^{43}S115	^{42}Be
^{58}Be	LI01 0 0 **7701**	^{56}S109	I002 0 0 **12502**	^{54}S104	^{53}S113	^{52}Be
^{68}Be	^{67}S110	--- C014 ---	^{65}S102	--- C013 ---	^{63}S106	^{62}Be
^{78}C	^{77}Be*	^{76}S117	^{75}LS02	^{74}S118	^{73}Be*	^{72}DIF
^{88}W	^{87}C	^{86}WB **7570**	^{85}WB **9168**	^{84}Be	^{83}C	^{82}W

C13AB

^{28}W	^{27}C	^{26}C	^{25}Be	^{24}C	^{23}C	^{22}W
^{38}C	^{37}Be*	^{36}S105	^{35}LS01	^{34}S116	^{33}Be*	^{32}WB
^{48}Be	^{47}S112	--- C018 ---	^{45}S103	--- C011 ---	^{43}S115	^{42}Be
^{58}Be	LI01 0 0 **8875**	^{56}S109	I002 0 0 **13085**	^{54}S104	^{53}WB **14169**	^{52}Be
^{68}Be	^{67}S110	--- C014 ---	^{65}S102	--- C013 ---	^{63}S106	^{62}Be
^{78}C	^{77}Be*	^{76}S117	^{75}LS02	^{74}S118	^{73}Be*	^{72}DIF
^{88}W	^{87}C	^{86}C	^{85}Be	^{84}C	^{83}C	^{82}W

C13BB

^{28}C	^{27}C	^{26}Be	^{25}Be	^{24}Be	^{23}C	^{22}C
^{38}C	^{37}LS01	^{36}S106	^{35}WB **14057**	^{34}S112	^{33}S105	^{32}WB
^{48}Be	^{47}S115	--- C018 ---	^{45}S102	--- C011 ---	^{43}S110	^{42}Be
^{58}Be	WB **12233**	^{56}S109	I002 0 0 **12257**	^{54}S111	^{53}WB **14991**	^{52}Be
^{68}Be	^{67}S116	--- C014 ---	^{65}S103	--- C013 ---	^{63}S113	^{62}Be
^{78}C	^{77}LS02	^{76}S118	^{75}WB **14136**	^{74}S104	^{73}S117	^{72}DIF
^{88}C	^{87}C	^{86}Be	^{85}Be	^{84}Be	^{83}C	^{82}C

C13HB

^{28}C	^{27}C	^{26}Be	^{25}Be	^{24}Be	^{23}C	^{22}C
^{38}C	^{37}S106	^{36}S105	^{35}LS01	^{34}S116	^{33}S110	^{32}WB
^{48}Be	^{47}S113	--- C018 ---	^{45}WB **15756**	--- C011 ---	^{43}S102	^{42}Be
^{58}Be	S111	^{56}S107	WB **18279**	^{54}S114	^{53}S109	^{52}Be
^{68}Be	^{67}S104	--- C014 ---	^{65}WB **15755**	--- C013 ---	^{63}S103	^{62}Be
^{78}C	^{77}S115	^{76}S117	^{75}LS02	^{74}S118	^{73}S112	^{72}DIF
^{88}C	^{87}C	^{86}Be	^{85}Be	^{84}Be	^{83}C	^{82}C

C13F3

+) :	Mo activity	W:	Pool Water	S115:	HEU Standart fuel element No.115
C:	Graphite block	WB:	Water Box	LS01:	LEU Standart fuel element No.011
Be:	Be block	DIF:	Dry Irradiation Facility	I002:	HEU Irradiation fuel element No.002
Be*:	Be block with hole	C011:	HEU Control fuel element No.011	LI01:	LEU Irradiation fuel element No.001

Figure-1: TR-2 core loadings and calculated Mo activities

C13K

33 Be*	4.708 **727** 642	4.756 **734** 665	4.635 **715** 607	73 Be*
3.922 **605** 603	5.119 **790** -	5.256 **811** 707	5.066 **782** -	3.880 **599** 481
3.048 **470** 408	WB	6.479 **1000** 1000	WB	3.035 **468** 327
2.851 **440** 475	3.475 **536** -	4.027 **621** 617	3.329 **514** -	2.861 **442** 355
37 Be*	3.358 **518** 560	3.106 **479** 611	3.326 **513** 433	77 Be*

C13AD

33 Be*	5.022 **880** 612	5.080 **890** 646	4.986 **873** 611	73 Be*
4.370 **765** 511	4.933 **864** -	5.710 **1000** 752	5.685 **996** -	4.305 **754** 489
3.358 **588** 451	4.512 **790** 639	5.576 **977** 1000	4.455 **780** 533	3.227 **565** 402
2.228 **390** 258	2.775 **486** -	3.725 **652** 494	2.846 **498** -	2.172 **380** 212
37 Be*	2.772 **485** 424	2.736 **479** 535	2.792 **489** 375	77 Be*

4.708 → Thermal flux/10^{13} (Calculation)
727 → Relative thermal flux (Calculation)
642 → Relative thermal flux (Experimental)

Figure-2: Absolute and relative thermal flux distributions for the 2 core loadings

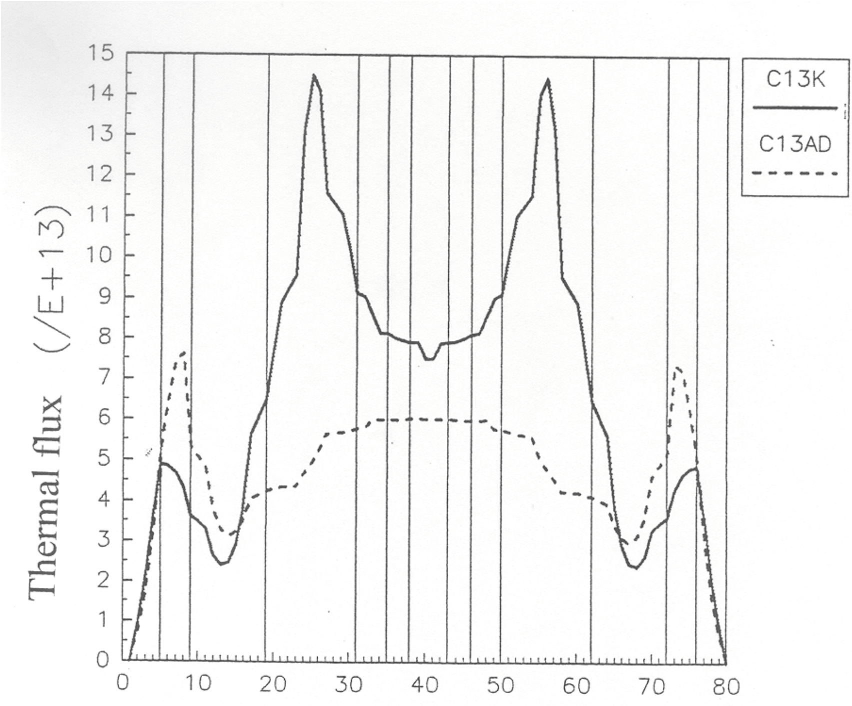

Figure-3 : Thermal flux profiles for the 2 core loadings

References

1. T. Aldemir, M.H. Turgut, M.M. Bretscher, J.L. Snelgrove, «A Feasibility Study Con-cerning the Conversion of the TR-2 Reactor from Using Highly Enriched Uranium to Light Enriched Uranium», ÇNAEM-R-217 (1982)
2. M.H. Turgut, T. Türker, «Core Conversion Calculations for the TR-2 Reactor; Part A : Neutronics Calculations», ÇNAEM-AR-308 (Feb., 1993)
3. M.H. Turgut, «Neutronic Calculations of the TR-2 Reactor Present Core», ÇNAEM Technical Report No : 30 (Sept., 1986)
4. M.H. Turgut, «Density Search Calculations for the Siliside Fuels», ÇNAEM Technical Report No : 37 (Dec., 1986)
5. M.H. Turgut, «Optimization of the Usage of the Remaining HEU Fuel», ÇNAEM Tech-nical Report No : 42 (Sept., 1987)
6. M.H. Turgut, G. Üstün, «Calibration Calculations for the TR-2 Reactor», ÇNAEM-AR-245 (Apr., 1988)

7. [B.A. Zolotar, et.al.,«EPRI-CELL Code Description», Advanced Recycle Methodology Program System Documentation, Part II, Chapter 5, Electric Power Research Institute (Sept., 1977)
8. H. Henryson III, B.J. Toppel, and C.G. Stenberg, «MC^2-2 : A Code to Calculate Fast Neutron Spectra and Multigroup Cross-Sections», Argonne National Laboratory Report, ANL-8144 (June, 1976)
9. M.M. Bretscher, «Blackness Coefficients, Effective Diffusion Parameters, and Control Rod Worths for Thermal Reactors», Argonne National Laboratory Report, ANL/RERTR /TM-5 (Sept., 1984)
10. K.L. Derstine, «DIF3D: A Code to Solve One-, Two-, and Three-Dimensional Finite-Difference Diffusion Theory Problems», Argonne National Laboratory Report, ANL-82-64 (Apr., 1984)
11. [B.J. Toppel, «A Users Guide for the REBUS-3 Fuel Cycle Analysis Capability», Ar-gonne National Laboratory Report, ANL-83-2 (March ,1983)
12. M. Console, A. Daneri and E. Salina, «EREBUS: A Multigroup Diffusion Program in two Dimension», FN-E-88 (FIAT, 1967) (GEREBUS is GKSS version of EREBUS code)