Core Configuration of the Syrian reduced enrichment fuel MNSR

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Abstract:

The possibility of substituting the actual HEU by a LEU or MEU in the Syrian MNSR is investigated through a pre-constructed 3-D detailed model of the reactor.
Core configuration does not change if a reduced enrichment fuel (20% u-235, with the same percentages of impurity and eliminating aluminum) is used. The required density for the reactor to be critical in this case would be 7.29 g/cm^2.
If a specific fuel is used (20 w/o U235, 72 w/o U), the reactor may not go critical at all. When a MEU fuel is used (45 w/o U235, 40 w/o U), the reactor will restore the same actual initial excess reactivity if 2 standard fuel rods are added to each fuel circle.

1. Introduction

The actual Syrian Miniature Neutron Source Reactor (MNSR) is loaded with HEU fuel rods (i.e 89.97 w/o U-235). These fuel rods [5] are distributed on ten circles (see Tab. 1). Three dummy elements are distributed almost symmytrically in the tenth fuel circle, and 4 tie rods are symmytrically distributed in the 8th fuel circle (see Fig.(1)).

Table 1. Actual Core configuration of the Syrian MNSR.

Fuel Circle	1	2	3	4	5	6	7	8	9	10
No. of Fuel Rods	6	12	19	26	32	39	45	48	58	62
No. of Dummy Rods										3
No. of Tie Rods								4		

The core configuration of Tab.1 enables the reactor to have the neutronic characteristics shown in Tab.2 [1].
The actual load is the first one. It is expected to be exhausted within 10 years beginning from 1996 [4]. The following loads should be a reduced enrichment uranium to be within international rules. The reactor core contaions 347 standard fuel rods, each of them is 23 cm high, and has an external radius of 0.275 cm of which 0.06 cm is the cladding thickness.
Dummy elements (rods) are aluminum rods having the same length and external radius of the standard fuel rod. Tie rods are also a sort of dummy elements made of aluminum or stainless steel, but serve as junctions between the upper and lower fuel Grids. The upper and lower Grids are grids accommodating the fuel rod ends, the former allowing the fuel rod ends to expand freely when heated during reactor operation.

The fuel is surrounded by a thick Beryllium reflector which defines quite well the limits of the core being a rigid block. This constrains to modify the reactor core configuration, when a new fuel will substitute the actual one, in a way that the new fuel will stay within the internal diameter of the reflector.

Table 2. Some neutronic characteristics of MNSR.

Item	Meas. value
Initial excess reactivity (mk)	3.94
Effective control rod worth(mk)	6.43
Reactivity Regulator worth (mk)	0.41
Shut down margin(mk)	-3.06
Maximum Operable Time(min)	350-400

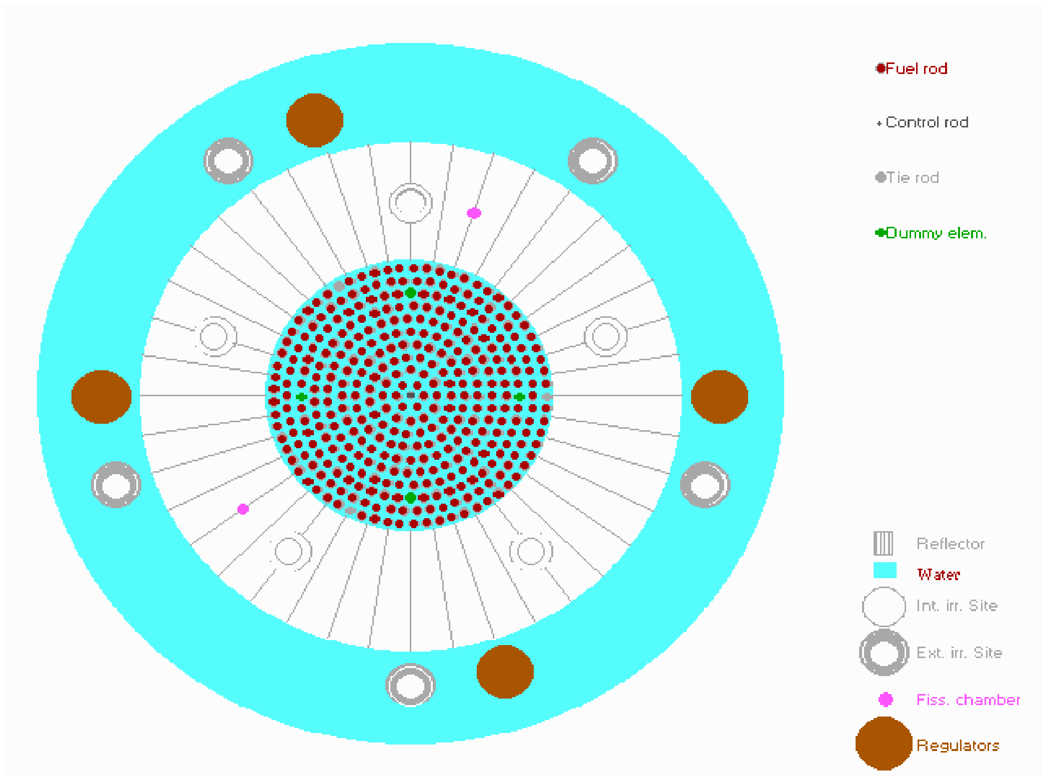

Figure 1. A cross section in the Syrian MNSR showing the core, reflector and the surrounding water

The new fuel will be of the type LEU or MEU, so calculations should show which type of these two fuels would be better to use. In the following the methodology will be illustrated concisely.

2. Methodology

The model for the calculation of the new fuel has been already elaborated [2]. Details can be found also in [2]. The model however used the cell code WIMSD4 [3] coupled with the core calculations code CITATION [6], in three dimensions (r, ϑ , z).

About 15 slices in the z dimensions, 25 circular sectors in the r dimension, and 20 angular sectors in the ϑ dimension were used.
Cross Sections and Group Constants have been generated with WIMSD4 for the various zones, and calculations were achieved with CITATION.
Calculations have been carried out in the following cases:
1-The actual fuel (see composition in Tab.3), when density is conserved (3.405 g/cm^3) and enrichment is reduced to 20% .

Table 3. MNSR's actual fuel composition

Element	%	ppm	Type of Fuel	Density(g/cm^3)
Al	72.2964		UAl_4-Al	3.403
U-235	24.8310			
U-238	2.7989			
B		0.01		
Li		0.80		
Cd		0.01		
Cr		140.		
Fe		100.		
Ni		150.		
C		200		

2-The LEU fuel used for the benchmarck of IAEA TEC-DOC 233 (see composition in Tab.4), in the case of 20% enrichment (CNF20).

Table 4. The fuel composition of the 10 Mw reactor used for the benchmark of IAEA TEC-DOC 233 (Enrichment= 20%)

Element	%	Type of Fuel	Density(g/cm^3)
Al	28.	UAl_x-Al	6.108
U-235	14.4		
U-238	57.8		

3-The MEU fuel used for the benchmark of IAEA TEC-DOC 233 (see composition in Tab.5), in the case of 45% enrichment (CNF45).

Table 5. The fuel composition of the 10 Mw reactor used for benchmark in IAEA TEC-DOC 233 (Enrichment= 45%)

Element	%	Type of Fuel	Density(g/cm^3)
Al	60.02111	UAl_x-Al	4.0107
U-235	17.99051		
U-238	21.98837		

The final proposed configuaration of the core is established according the the results coming out from the core calculations.

3. Results and discussion

As described above, calculations have been executed for the case of the actual fuel type (Tab.3) with the actual density (3.403 g/cm^3), but for the reduced enrichment (20%). The resulting initial excess reactivity is –31.4904 mk. This means that the reactor cannot go critical if the actual fuel (UAl_4-Al) will still be used, and only the enrichment is reduced to 20% conserving the actual density. The required density for the reactor to have the actual characteristics shown in Tab. (2) is 7.29 g/cm^3 in this case. If the CNF20 fuel is used the reactor will not go critical anyway (see Tab.s 6-10).

Table 6. Multiplication factor in the case of CNF20 fuel, and unchanged rod dimensions.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	0.969471
No. of Fuel Rods	6	12	19	26	32	39	45	48	58	62	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.215										
Clad external radius (cm)	0.275										

Table 7. Multiplication factor in the case of CNF20 fuel, with increased rod dimensions.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	0.716228
No. of Fuel Rods	6	12	19	26	32	39	45	48	58	62	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.415										
Clad external radius (cm)	0.475										

Table 8. Multiplication factor in the case of CNF20 fuel, and reduced rod dimensions.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	0.941986
No. of Fuel Rods	6	12	19	26	32	39	45	48	58	62	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.175										
Clad external radius (cm)	0.235										

Table 9. Multiplication factor in the case of CNF20 fuel, reduced rod dimensions and increased number of rods.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	0.949016
No. of Fuel Rods	8	14	21	28	34	41	47	50	60	64	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.175										
Clad external radius (cm)	0.235										

Table 10. Multiplication factor in the case of CNF20 fuel, reduced rod dimensions and furtherly increased number of rods.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	0.951418
No. of Fuel Rods	10	16	23	30	36	43	49	52	62	66	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.175										
Clad external radius (cm)	0.235										

Table 11. Multiplication factor in the case of CNF45 fuel, and increased number of rods.

Item	Fuel Circle										K_{eff}
No.	1	2	3	4	5	6	7	8	9	10	1.003965
No. of Fuel Rods	8	14	21	28	34	41	47	50	60	64	
No. of Dummy Rods										3	
No. of Tie Rods								4			
Fuel meat radius (cm)	0.215										
Clad external radius (cm)	0.275										

If the CNF45 fuel is used, the reactor can restore its actual characteristics if two other standard fuel rods are added to each fuel circle and the actual dimensions of the rod are conserved (see Tab. 11).

Reactor core configuration may appear as in Fig. (2); spaces between fuel rods may reduce, but rod power reduces too. Calculations should be made to confirm the better neutronic situation of the reactor. However the only fuel grids need to be change to accommodate the 20 additional rods.

6. Conclusions

The Core configuration of the Syrian MNSR cannot remain the same as the actual one if the fuel enrichment is to be reduced. The reactor cannot go critical neither in the case the actual UAl4-Al fuel is used with 20% enrichment only, nor in the case the CNF20 is used. The only suitable fuel for the reactor is the CNF45 one. In this case a couple of standard fuel rods need to be added to each fuel circle.

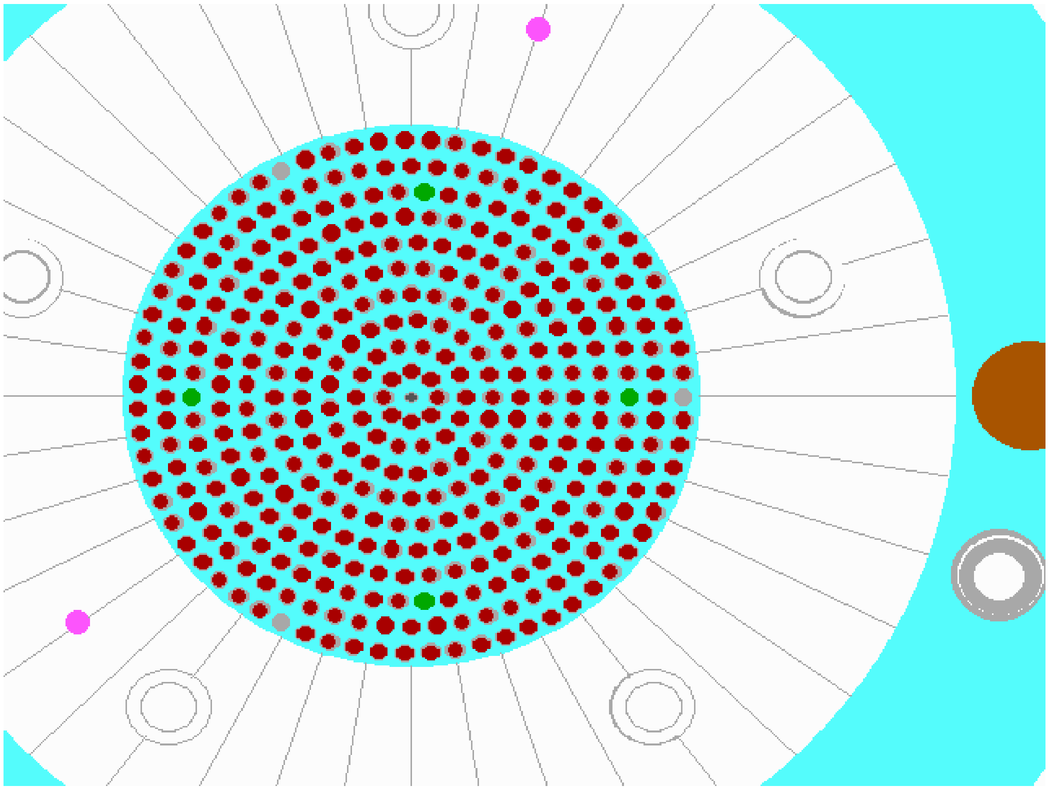

Fig. (2) The final core configuration of the Syrian MNSR after reduction of its fuel enrichment

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