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FEASIBILITY OF CONVERTING THE WWR-M RESEARCH REACTOR IN UKRAINE FROM HEU TO LEU FUEL BY THE END OF 2010

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ABSTRACT

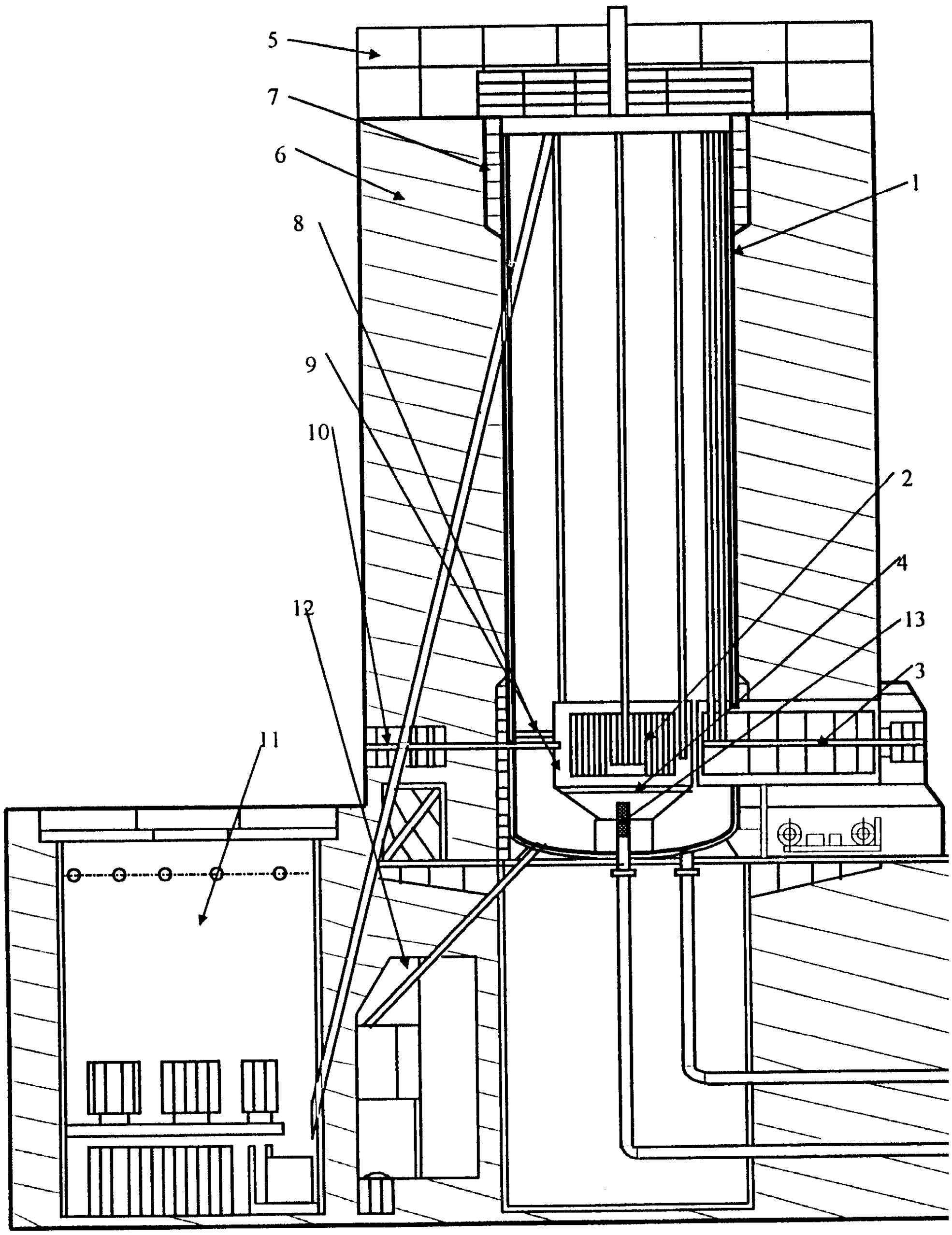
The WWR-M research reactor in Ukraine is being converted to the use of LEU fuel. In accordance with the program of pilot usage of LEU fuel approved by the Nuclear Regulatory Committee of Ukraine, most burned HEU fuel assemblies are successively replaced by fresh LEU fuel assemblies. By using this way, performance of the reactor remains almost the same as with HEU fuel but such the conversion progresses very slowly. Fast full-core conversion with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel deteriorates performance of the reactor because of considerable decrease of the number of fuel assemblies in the core with accompanying rise of fuel expenditures and reduction of total reactor power. However, this drop can be diminished using optimization of the core pattern. Feasibility of full-core conversion is analyzed by comparison to the current variant of conversion. Because of high importance of commercial applications, especially production of ^{99}Mo, it is paid main attention in selection of the most appropriate core configuration.

1. Introduction

The WWR-M reactor in Kiev (Ukraine) is a light-water cooled and moderated research reactor with beryllium reflector. Its maximal power is 10 MW. Current HEU fuel assemblies are WWR-M2 (36%). LEU replacement fuel assemblies are LEU WWR-M2 (19.75%), which have been tested successfully in the WWR-M reactor in Gatchina, Russia by irradiation to over 75% burnup [1]. The reactor and fuel assembly parameters and designs are shown in Fig.1-3 and Table 1 [1-3].

Study confirming feasibility of converting the WWR-M research reactor in Ukraine to the use of LEU fuel was completed in 2002 [4]. Safety analysis to qualify LEU WWR-M2 fuel assemblies for conversion was performed in 2004-2005 [5-6]. Safety of fresh and depleted LEU fuel storage was analyzed also [6]. The models applied for calculations were validated against measured data, which include critical experiment results for fresh fuel assemblies and measured neutronic distributions in a real WWR-M reactor core [6]. Safety documentation for LEU conversion of the WWR-M reactor was approved officially by the Nuclear Regulatory Committee of Ukraine in 2005.

In accordance with the program of pilot usage of LEU fuel approved by the Regulatory Committee, most burned HEU fuel assemblies are being successively replaced by fresh LEU fuel assemblies. By using this way, performance of the reactor remains almost the same as with HEU fuel but such the conversion progresses very slowly. Fast full-core conversion with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel deteriorates performance of the reactor because of considerable decrease of the number of fuel assemblies in the core with accompanying rise of fuel expenditures and reduction of total reactor power. However, this drop can be diminished using optimization of the core pattern. Because of high importance of commercial applications, especially production of ^{99}Mo, it should be paid main attention in selection of the most appropriate core configuration.



1 – Reactor Vessel

2 – Reactor Core

3 – Thermal Column

4 – Supporting Plate

5 – Cover

6 – Shield

7 – Cast Iron

8 – Grid for Water Flow Alignment

9 – Beryllium Reflector

10 – A Beam Tube

11 – Spent Fuel Storage

12 – Hot Cell

13 – Filter

Fig. 1. WWR-M reactor

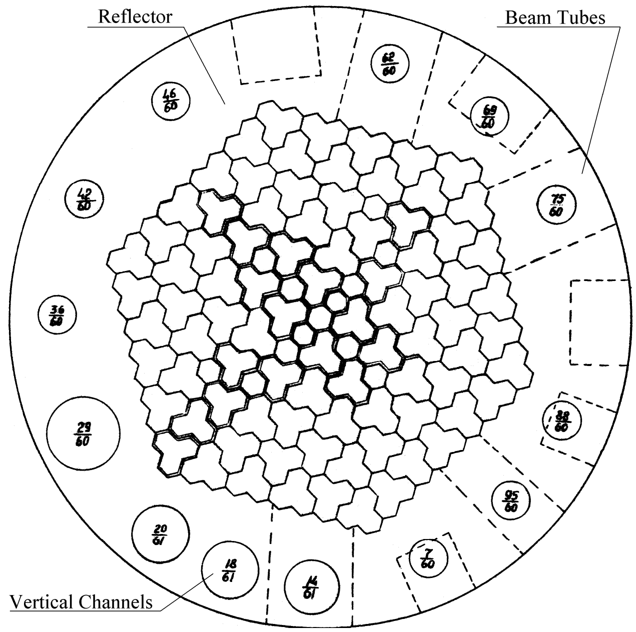


Fig. 2. Reactor Core and Beryllium Reflector

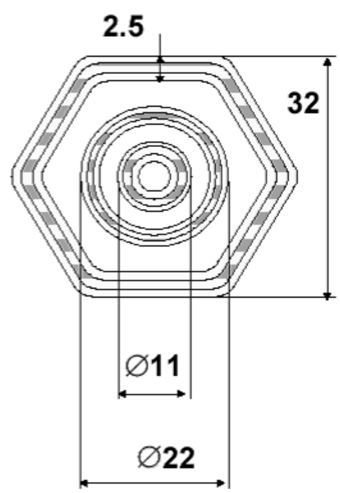


Fig.3. WWR-M2 Fuel Assembly

Table 1. Fuel Assembly Parameters

	HEU WWR-M2	LEU WWR-M2
Enrichment, %	36	19.75
Number of fuel elements	3	3
Mass of ^{235}U, g	37	41.7
Fuel meat composition	UO_2-Al 1.1 gU/cm^3	UO_2-Al 2.5 gU/cm^3
Length of fueled region, cm	50	50
Pitch/flat-to-flat, mm	35/32	35/32
Element/clad/meat, mm	2.5/0.76/0.98	2.5/0.78/0.94
Hydraulic resistance coefficient	4.35	4.35
Relative coolant velocities between fuel elements (starting from the center)	1.18;0.89;1.05;0.86	1.18;0.89;1.05;0.86

2. Mo-99 production

It is possible to produce ^{99}Mo without HEU by using ^{98}Mo(n,γ) reaction. Moreover, this process generates minimal radioactive waste. However, neutron capture-produced ^{99}Mo has low specific activity. In order to increase it, ^{98}Mo(n,γ) reaction rate should be maximized. Cross-section of this reaction calculated with NJOY [7] using ENDF/B-VII.0 data [8] is depicted in Fig.4. As calculated with MCNP [9] for the WWR-M reactor, about 60% of neutrons captured by ^{98}Mo have energy from 400 eV to 10 keV. Thus, maximization of resonance neutrons flux should be at first place. The most suitable material to increase fraction of resonance neutrons in the spectrum is aluminum. To decrease self-shielding, thin layers of highly enriched ^{98}Mo are most appropriate, as shown in Fig.5.

Because of the safety and control rods peculiarity, their location in the center of the WWR-M reactor core can not be changed. Thus, irradiation channels for ^{99}Mo production can not be placed there. However, they can be located near the center of the core and surrounded by fuel assemblies with low burnup to shift the maximum of power density toward the irradiation channels. Such the configuration of mixed HEU-LEU core is shown in Fig.6. Axial distribution of ^{98}Mo(n,γ) reaction rate is shown in Fig.7.

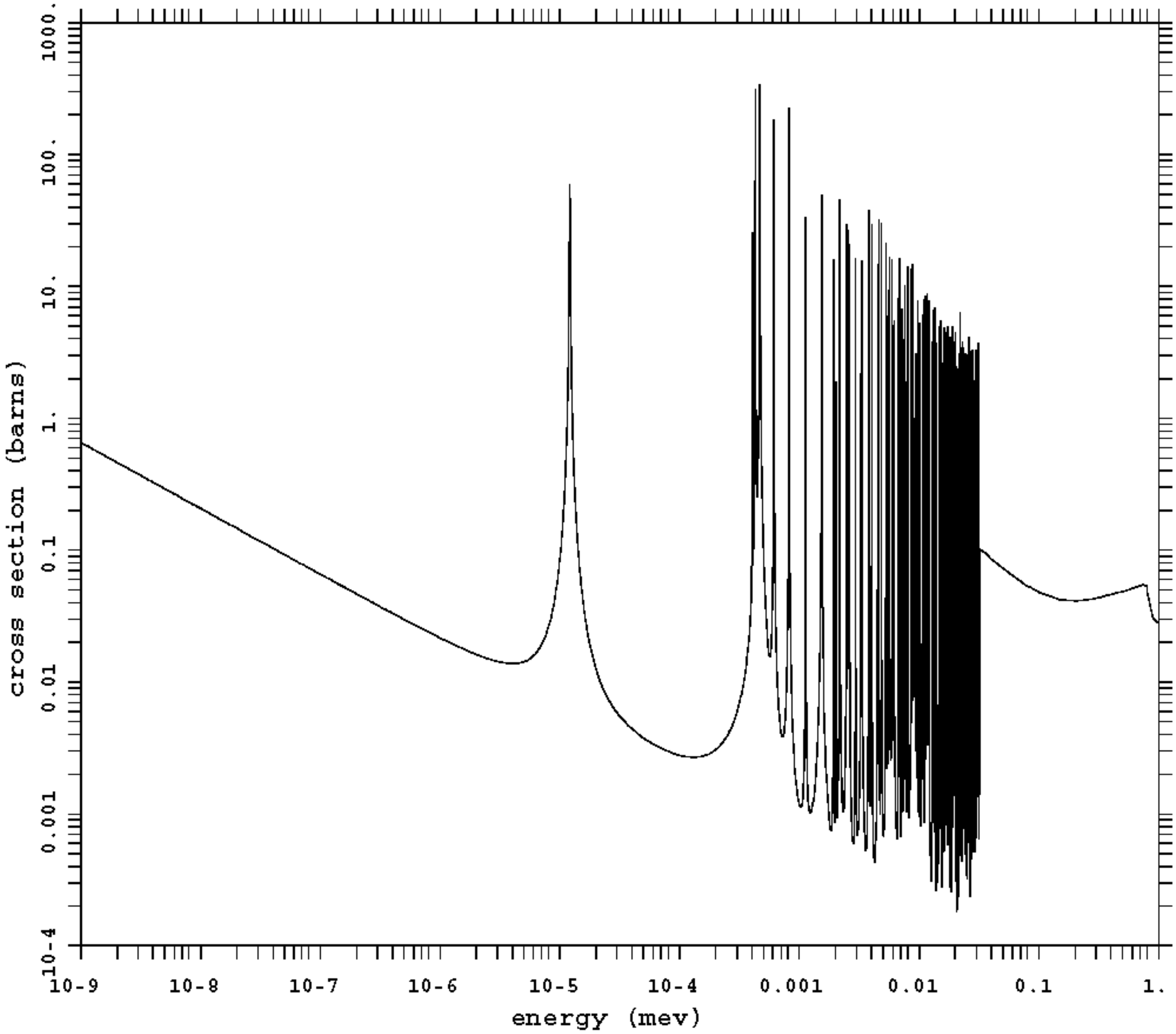


Fig.4. Cross-section of $^{98}Mo(n,\gamma)$ reaction

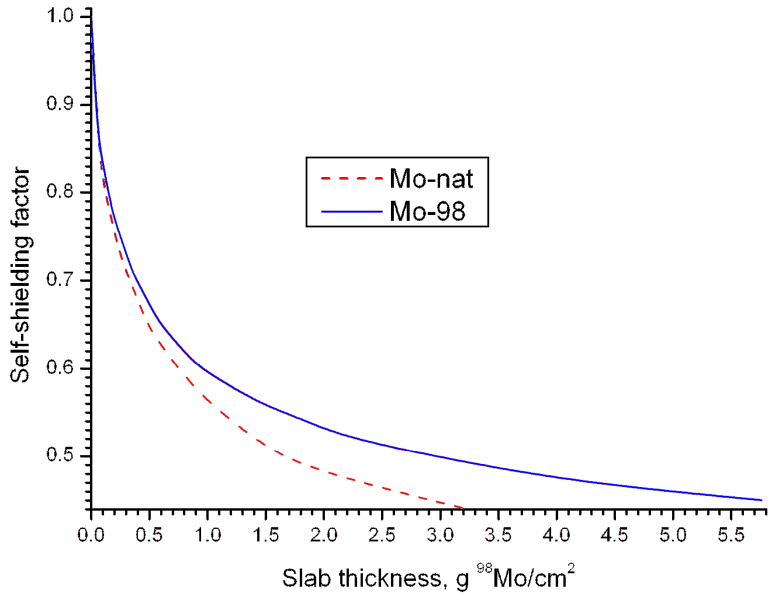


Fig.5. ^{98}Mo(n,γ) self-shielding factor for infinite slab

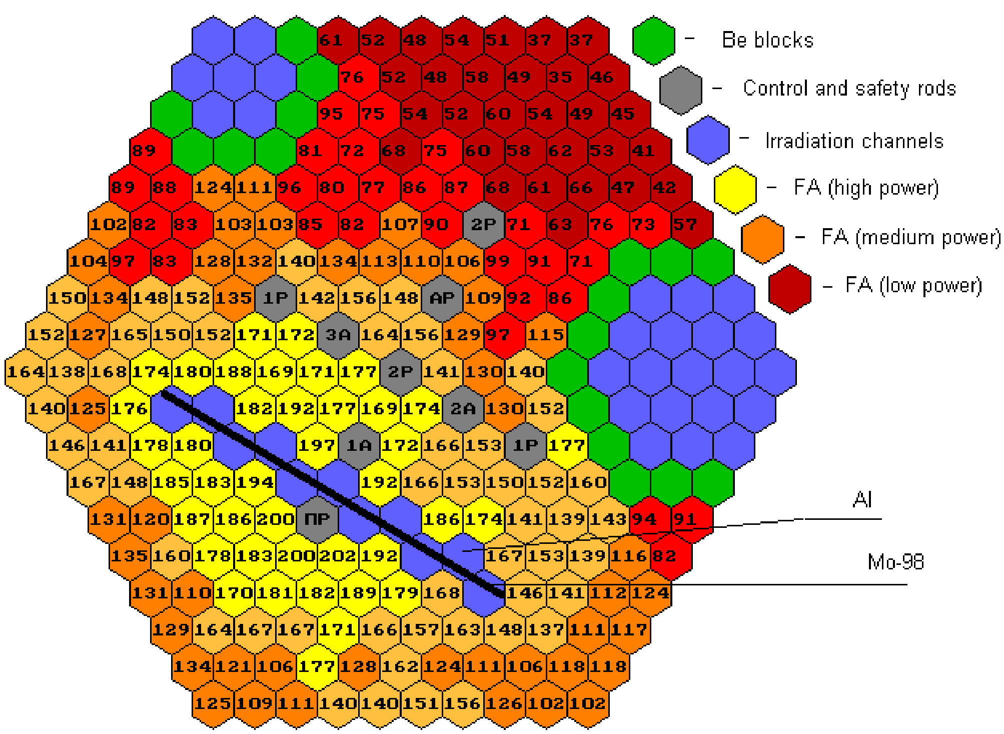


Fig.6. Power distribution for the mixed core

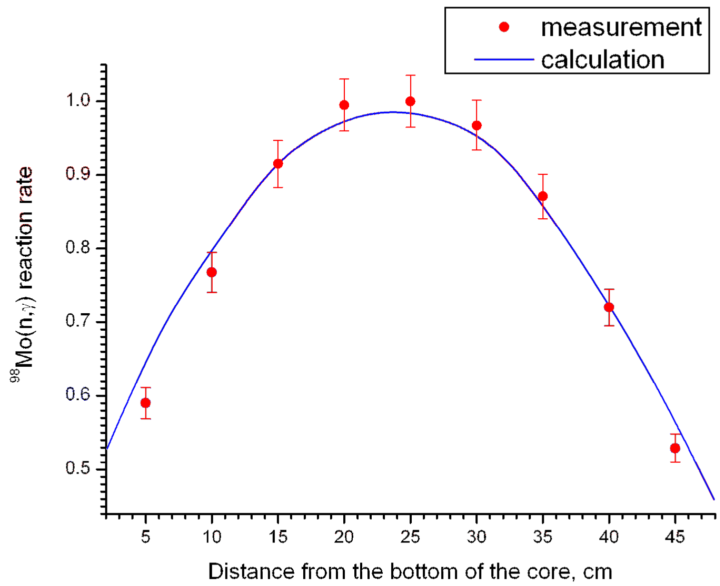


Fig.7. Axial distribution of ^{98}Mo(n,γ) reaction rate for the mixed core

3. New LEU core

Fast full-core conversion with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel deteriorates performance of the reactor because of considerable decrease of the number of fuel assemblies in the core with accompanying rise of fuel expenditures and reduction of total reactor power. Moreover, for small size of the core, it is more difficult to enhance ^{99}Mo production by increasing number of irradiation channels. Another disadvantage of such the core is very small difference in burnup of available fuel assemblies, resulting in inability to increase power density near irradiation channels by using shuffling of fuel assemblies with distinct burnups. An advantage of the small core is better cooling of fuel assemblies due to higher coolant velocity in the core.

For such the core, the best way to maximize ^{98}Mo(n,γ) reaction rate is to surround the irradiation channels by beryllium blocks. In this case, power density near irradiation channels is essentially increased, while fraction of resonance neutrons in the spectrum is not much less than for aluminum. Moreover, ^{98}Mo(n,γ) reaction rate can be increased by shifting the center of the core toward the irradiation channels for ^{99}Mo production. Such configuration of the new LEU core is shown in Fig.8. Main parameters of the mixed and LEU cores are compared in Table 2 and Fig.9. In Fig.9, total and specific activities of ^{99}Mo after 5 days (120 hours) of irradiation are depicted.

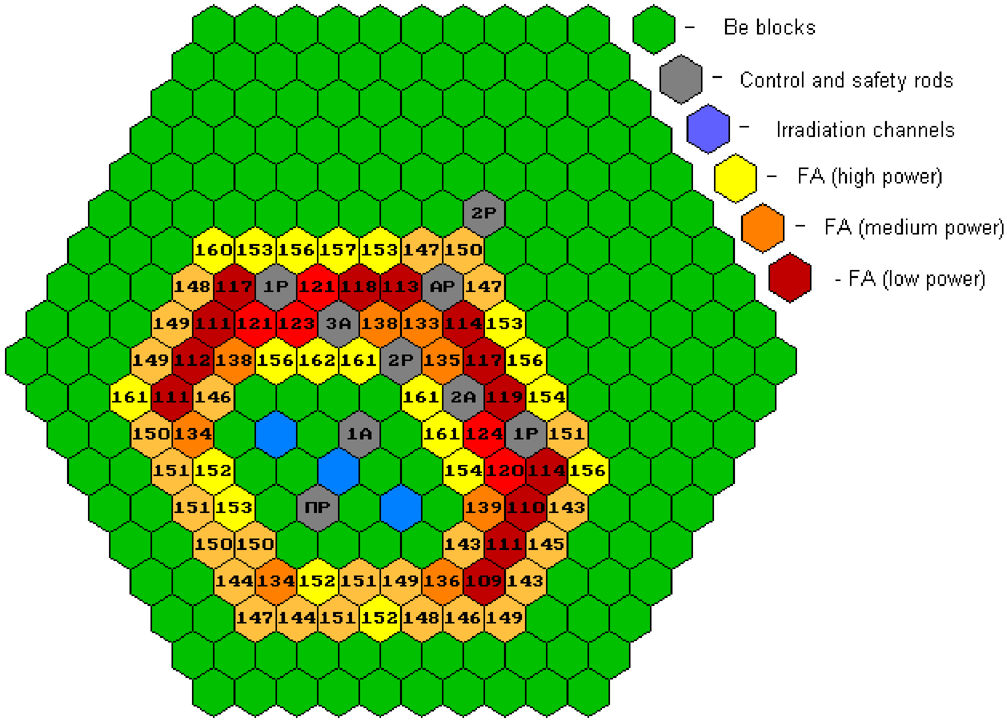


Fig.8. Power distribution for the new LEU core

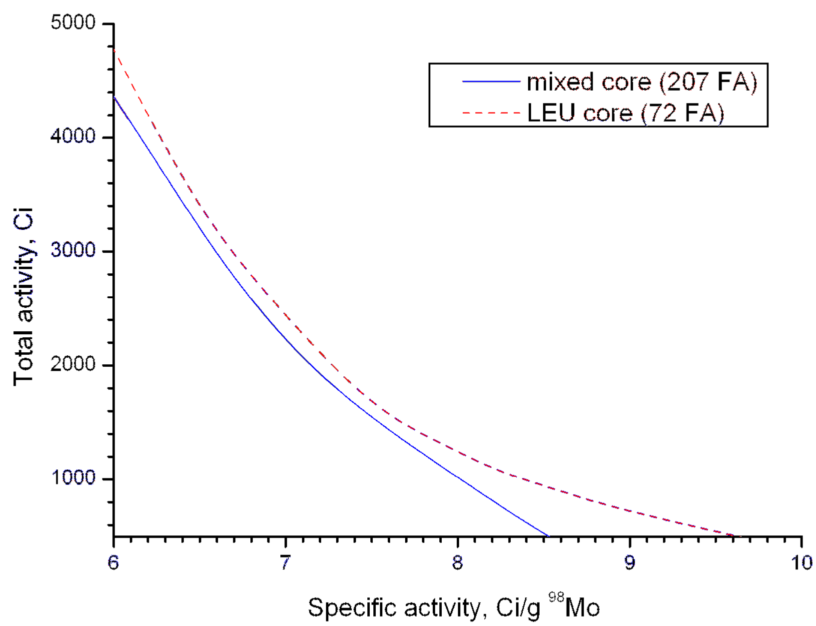


Fig.9. Potential to produce ^{99}Mo for the mixed and LEU cores

Table 2. Main parameters of the mixed and LEU cores

		Mixed core	LEU core
Power, MW		10.0	6.4
Number and type of fuel assemblies		207 (HEU and LEU)	72 (LEU)
Average fuel burnup, %		30	0.5
Maximal excess reactivity, %		5.2	5.1
Reactivity worth of control rods, %:	1P	3.0	5.3
	2P	2.4	4.0
	ПР	2.1	3.1
	AP	0.3	0.5
Reactivity worth of safety rods, %:	1A	2.2	3.6
	2A	1.7	3.1
	3A	1.8	3.2
Coolant flow in the first loop, m^3/h		1200	1000
Average power density in fuel meat, W/cm^3		530	980
Power peaking factor		2.0	1.6
Maximal fuel clad temperature, C		87	95
Maximal thermal flux, 10^{14} $n/cm^2/s$		1.2	1.3
Maximal specific activity of ^{99}Mo (without self-shielding), Ci/g ^{98}Mo		17.0	19.1

4. Conclusions

The WWR-M research reactor in Ukraine is being converted to the use of LEU fuel. In accordance with the program of pilot usage of LEU fuel approved by the Nuclear Regulatory Committee of Ukraine, most burned HEU fuel assemblies are successively replaced by fresh LEU fuel assemblies. By using this way, performance of the reactor remains almost the same as with HEU fuel but such the conversion progresses very slowly. Feasibility of fast full-core conversion is analyzed by comparison to the current variant of conversion. Because of high importance of commercial applications, especially production of ^{99}Mo, it is paid main attention in selection of the most appropriate core configuration.

Fast full-core conversion with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel deteriorates performance of the reactor because of considerable decrease of the number of fuel assemblies in the core with accompanying rise of fuel expenditures and reduction of total reactor power Moreover, for small size of the core, it is more difficult to enhance ^{99}Mo production by increasing number of irradiation channels. Another disadvantage of such the core is very small difference in burnup of available fuel assemblies, resulting in inability to increase power density near irradiation channels by using shuffling of fuel assemblies with distinct burnups. An advantage of the small core is better cooling of fuel assemblies due to higher coolant velocity in the core. For such the core, the best way to maximize ^{99}Mo production is to surround the irradiation channels by beryllium blocks and shift the center of the core toward the irradiation channels.

Due to the optimization of the new LEU core pattern, its maximal thermal neutrons flux and potential to produce ^{99}Mo are not less than for the current mixed core. Thus, the WWR-M research reactor in Ukraine is feasible to convert from HEU to LEU fuel by the end of 2010, when sufficient amount of fresh LEU fuel will be available.

5. References

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