Full-Core Conversion of the WWR-M Research Reactor in Ukraine to the Use of LEU Fuel

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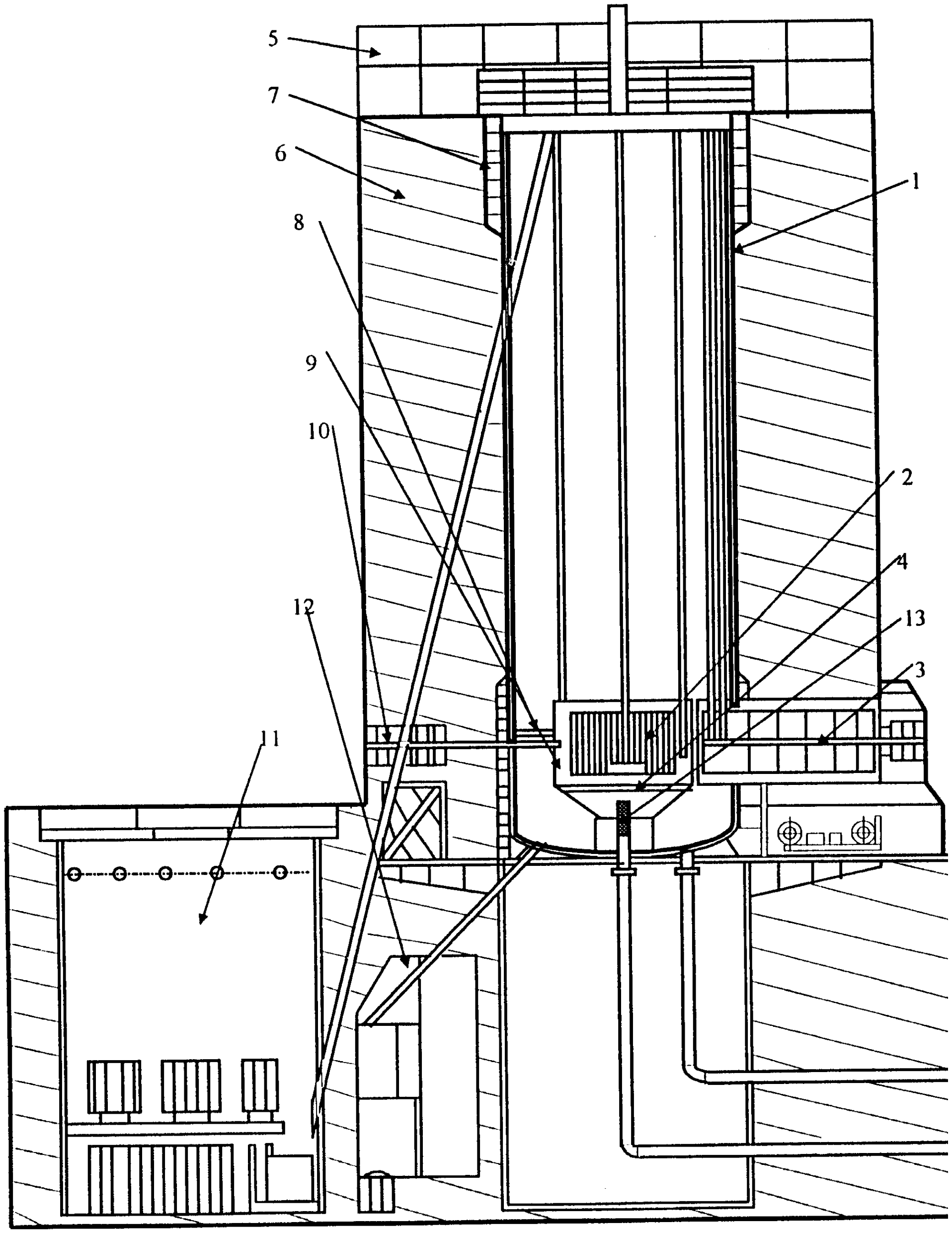
WWR-M reactor



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

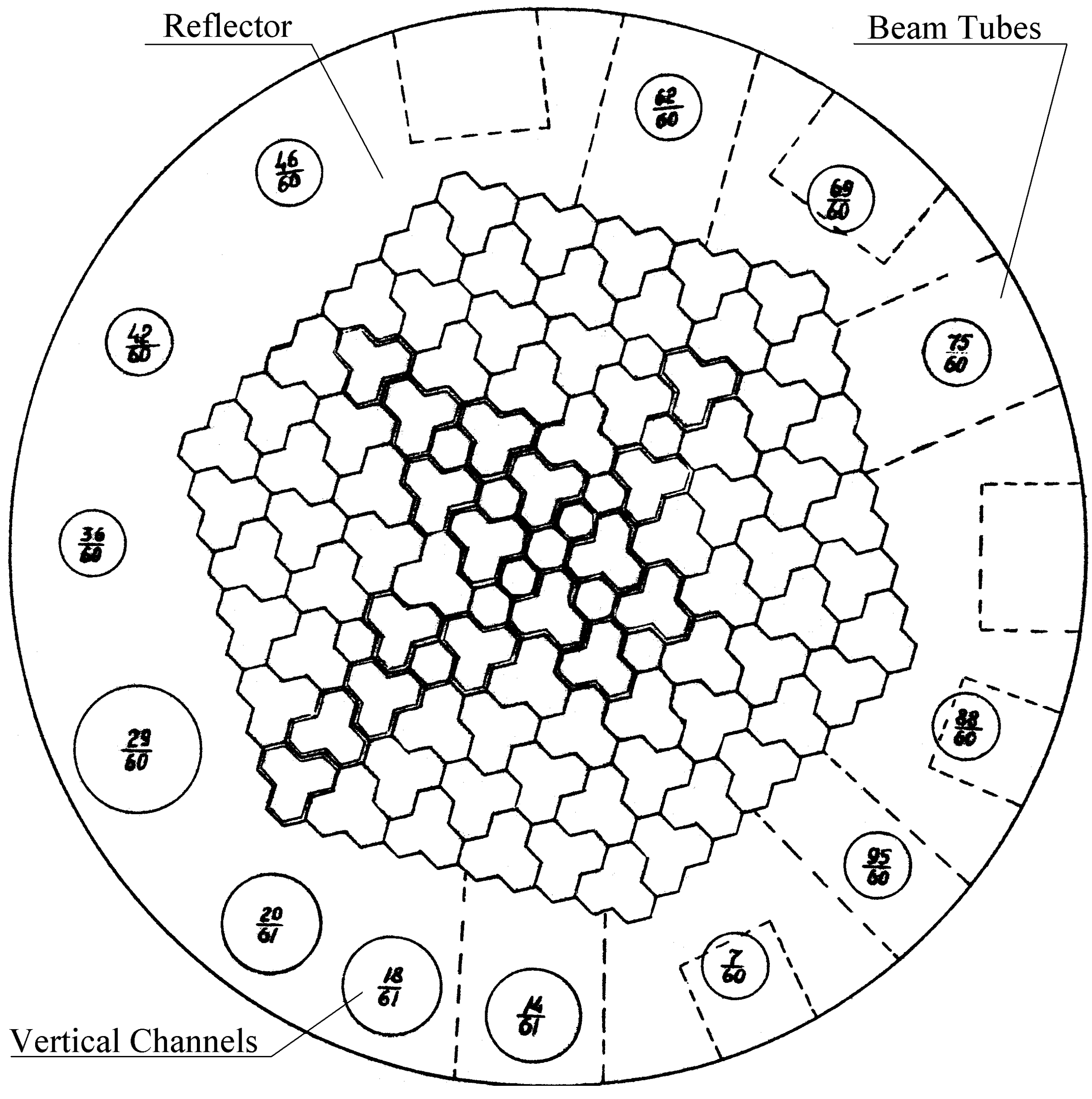
10 – A Beam Tube

11 – Spent Fuel Storage

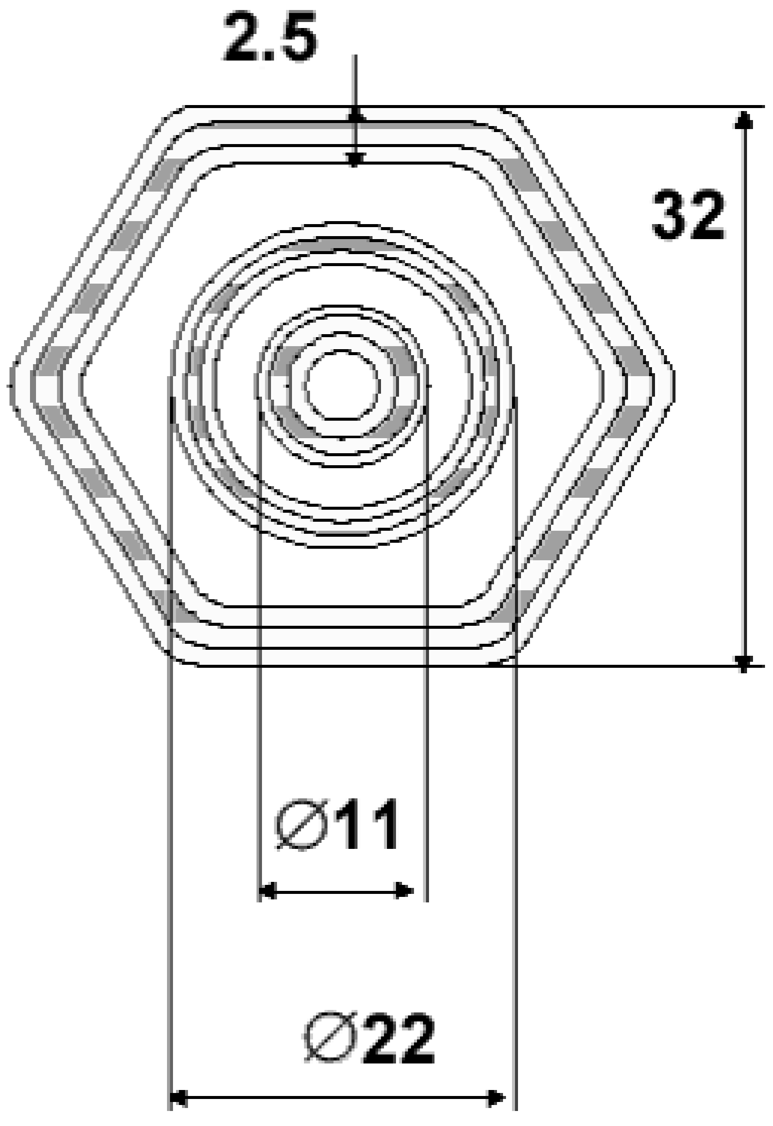
12 – Hot Cell

13 – Filter

Reactor Core and Beryllium Reflector



WWR-M2 Fuel Assembly



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

Feasibility Study

Study confirming feasibility of converting the WWR-M research reactor in Ukraine to the use of LEU fuel was completed in 2002. Candidate LEU WWR-M2 replacement fuel assemblies were tested successfully in the similar WWR-M reactor in Gatchina (Russia) by irradiation to over 75% burnup.

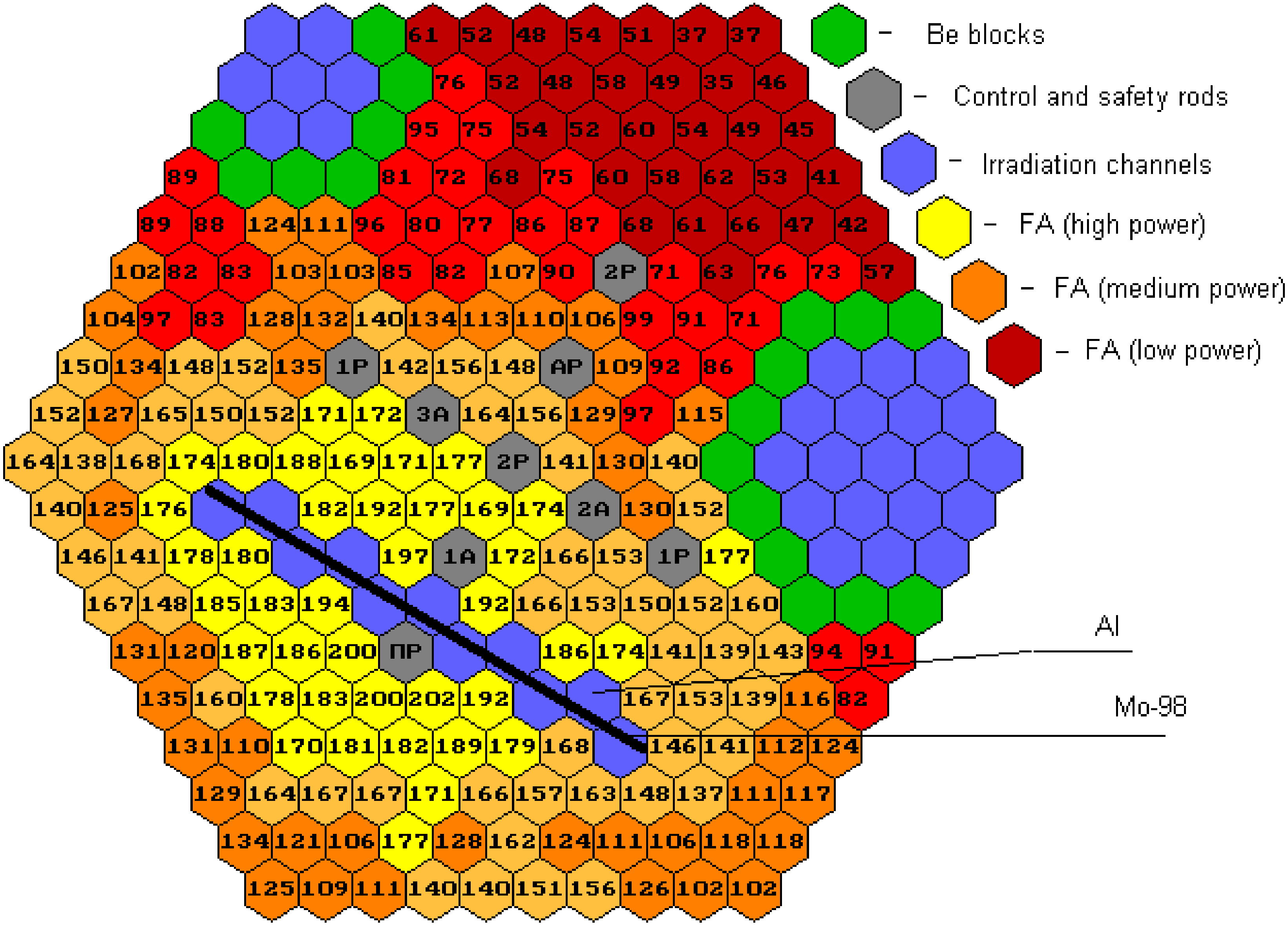
Safety analysis to qualify LEU WWR-M2 fuel assemblies for conversion was performed in 2004-2005. Safety documentation for LEU conversion of the WWR-M reactor was approved officially by the Nuclear Regulatory Committee of Ukraine in 2005.

Pilot Usage of LEU Fuel

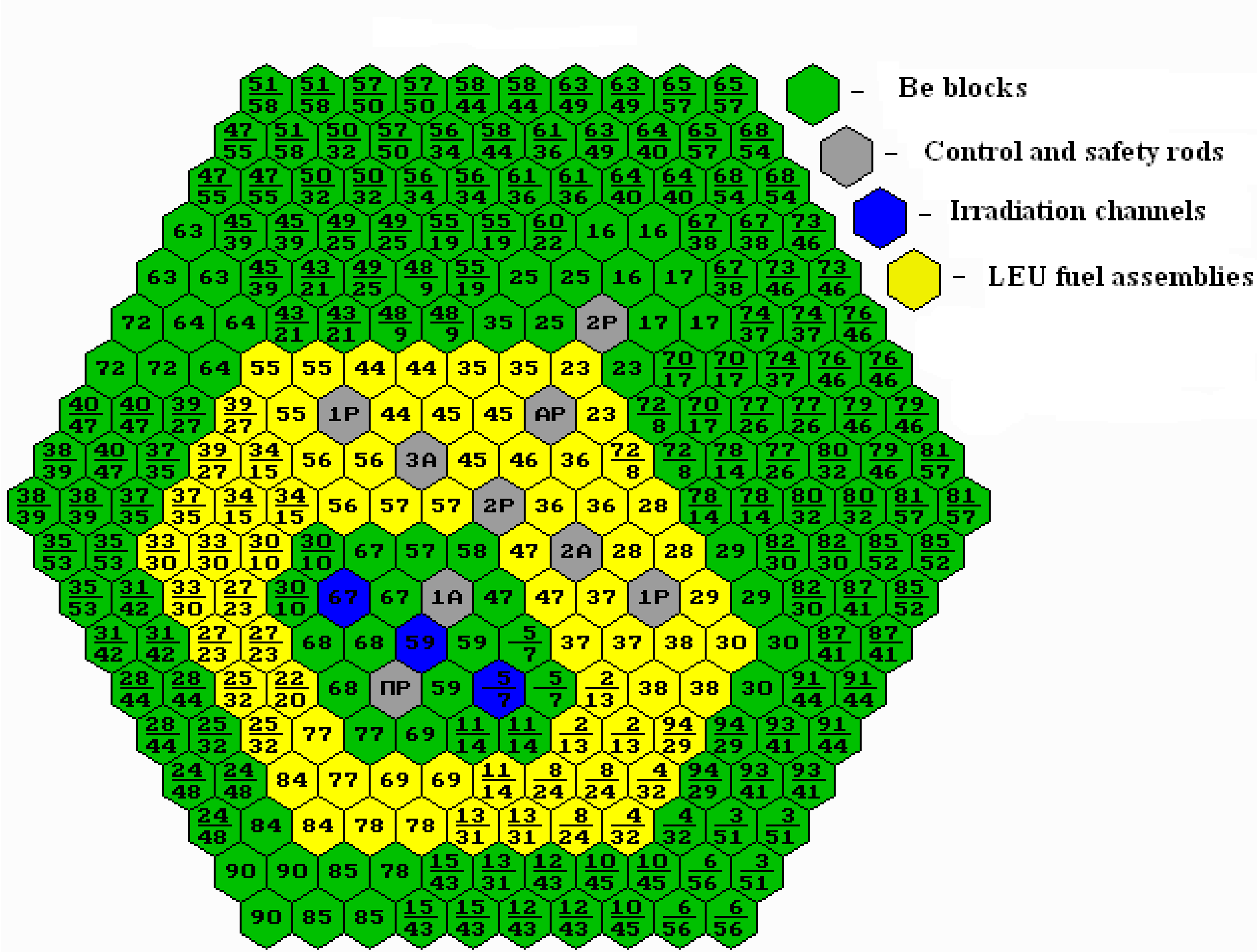
In accordance with the program of pilot usage of LEU fuel approved by the Ukrainian Regulatory Committee, most burned HEU fuel assemblies of the WWR-M reactor were successively replaced by fresh LEU fuel. By using this way, neutronic performance of the reactor remained almost the same as with HEU fuel but such the conversion progressed very slowly.

Thus, the new full-core conversion program with simultaneous replacement of all remaining HEU fuel by fresh LEU fuel was developed .

HEU-LEU Mixed Core



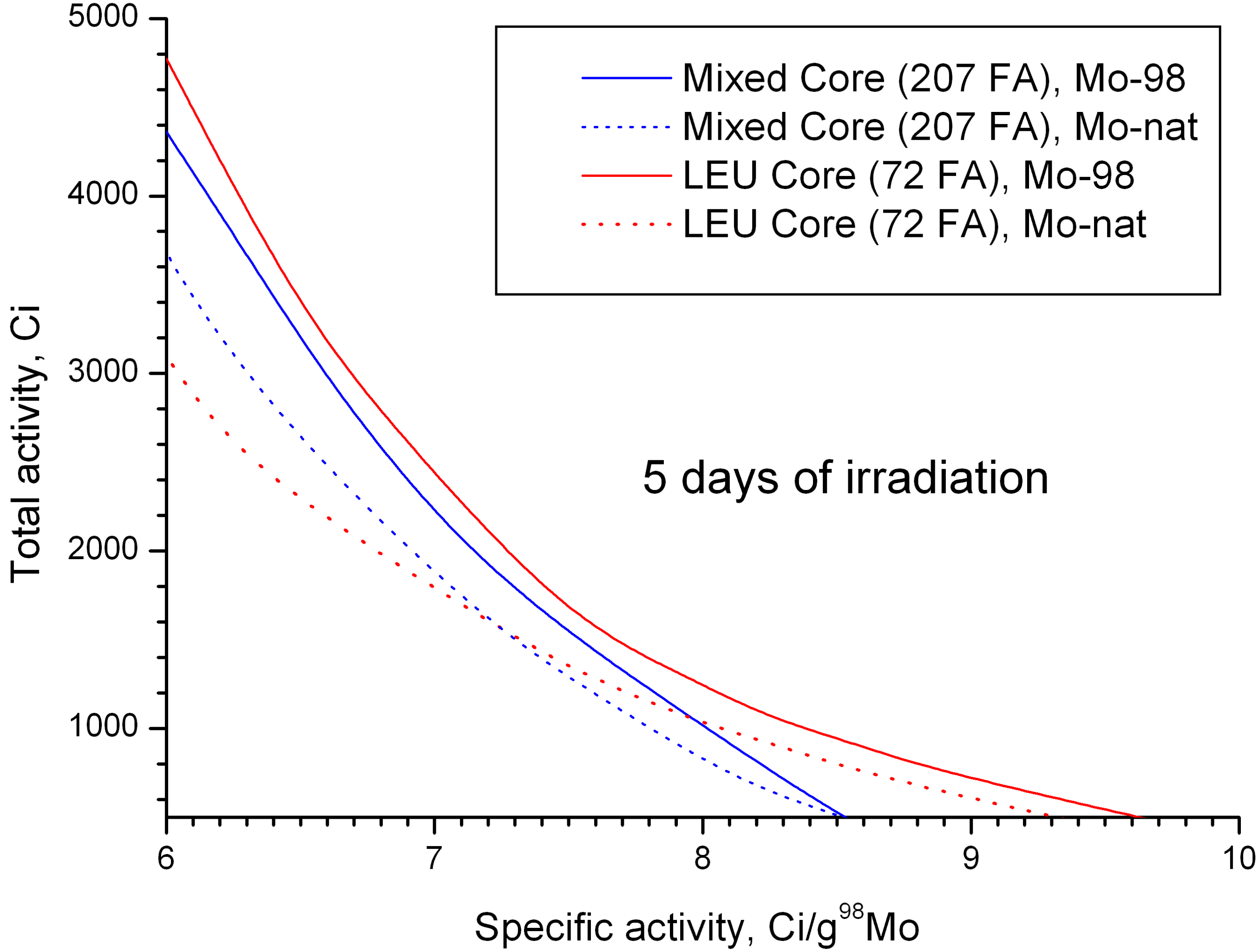
New LEU Core


– Be blocks
– Control and safety rods
– Irradiation channels
– LEU fuel assemblies

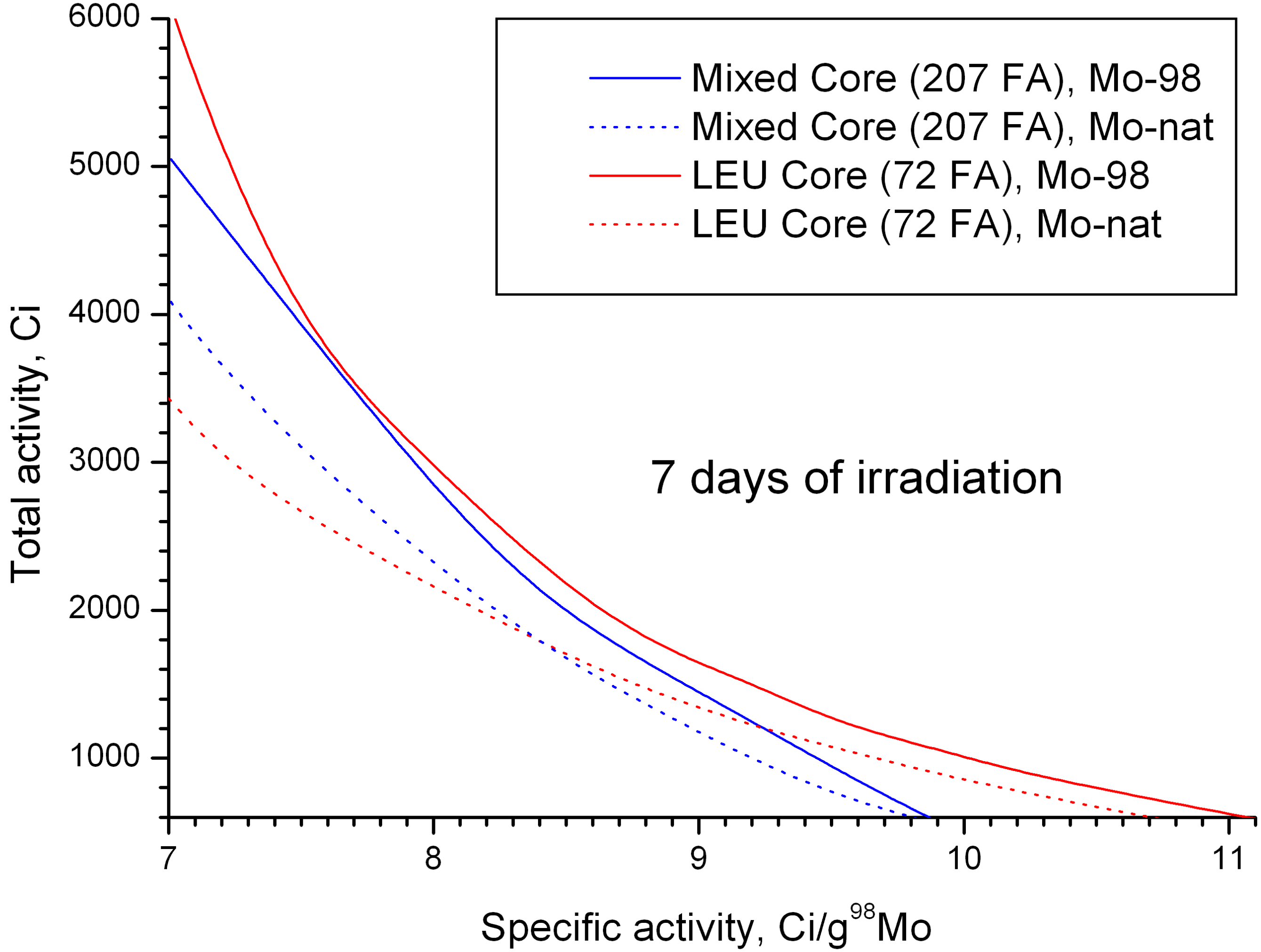
Main Parameters of the Mixed and LEU Cores

		Mixed core	LEU core
Power, MW		10.0	7.0
Number and type of fuel assemblies		207 (HEU and LEU)	72 (LEU)
Average fuel burnup, %		30	0.5
Reactivity worth of control rods, $	1P	4.2	7.6
	2P	3.8	6.0
	ПР	2.6	3.9
	AP	0.5	0.7
Reactivity worth of safety rods, $	1A	2.5	4.6
	2A	2.0	4.3
	3A	2.5	4.6
Minimal sub-criticality when all control rods are fully in and all safety rods are fully out, %		2.5	7.3
Maximal reactivity due to loading a fuel assembly in a cell of the core, %		1.1	2.2
Power peaking factor		2.0	1.6
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

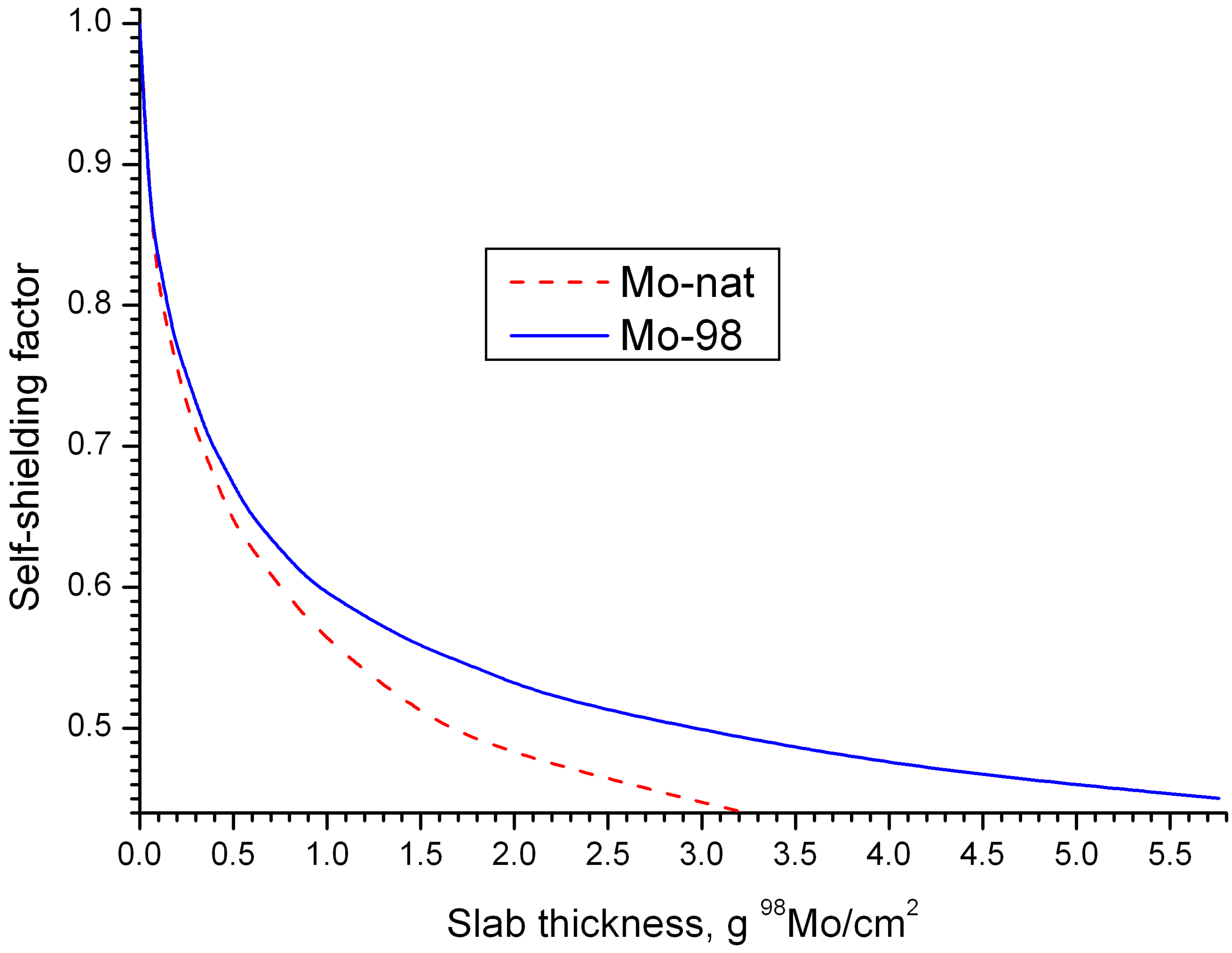
Potential to Produce ^{99}Mo for the Mixed and LEU Cores



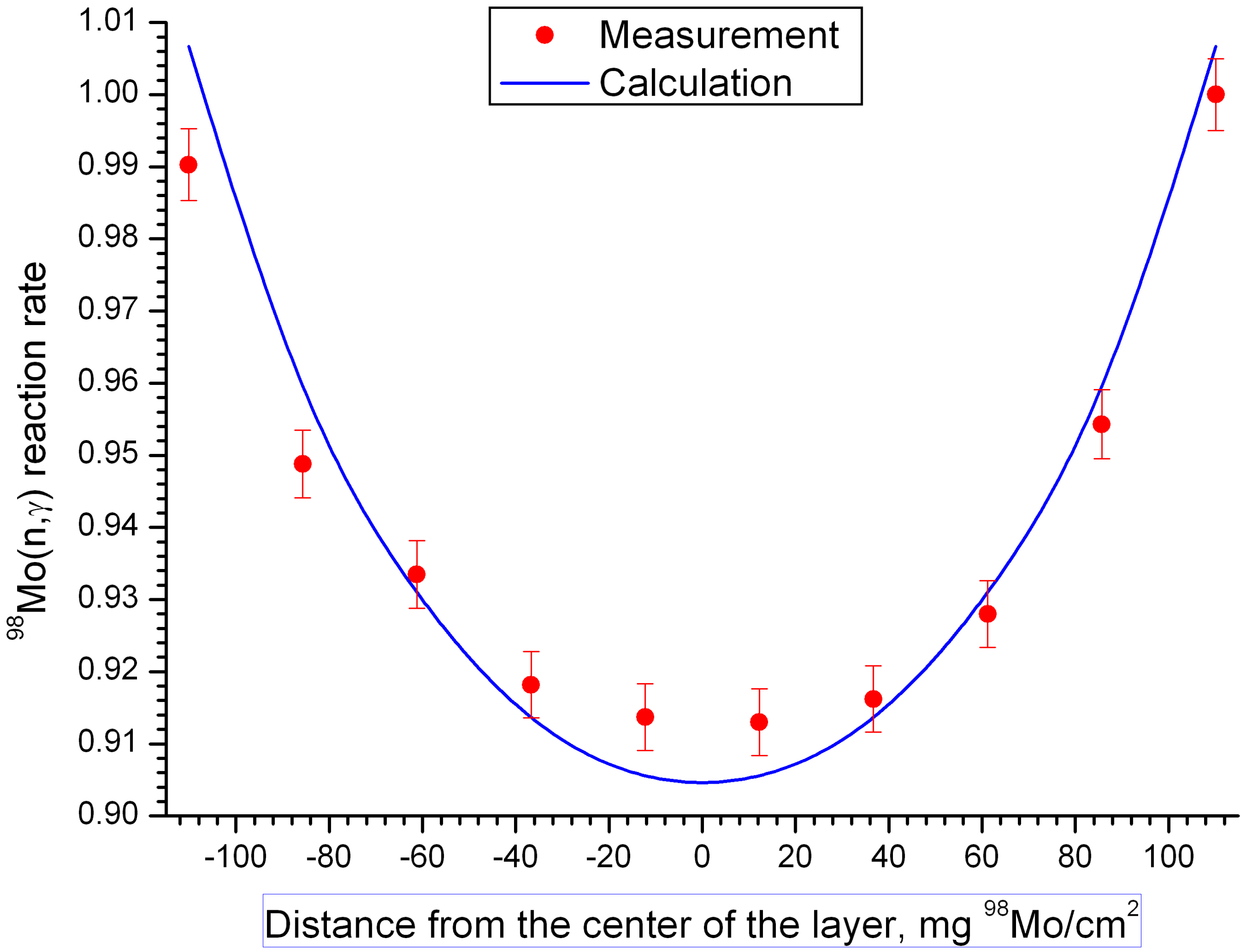
Potential to Produce ^{99}Mo for the Mixed and LEU Cores



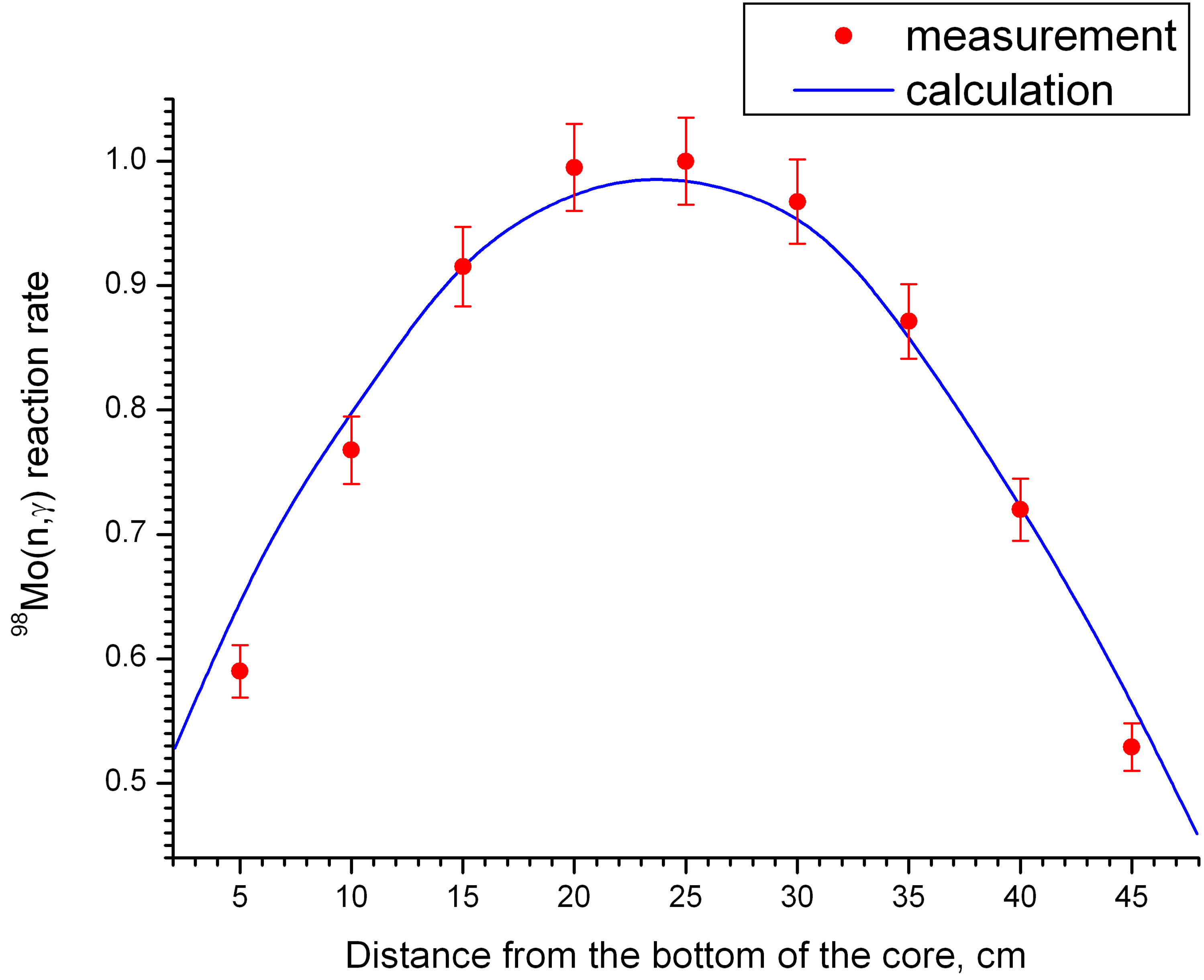
^{98}Mo(n,γ) Self-Shielding Factor for Infinite Slab



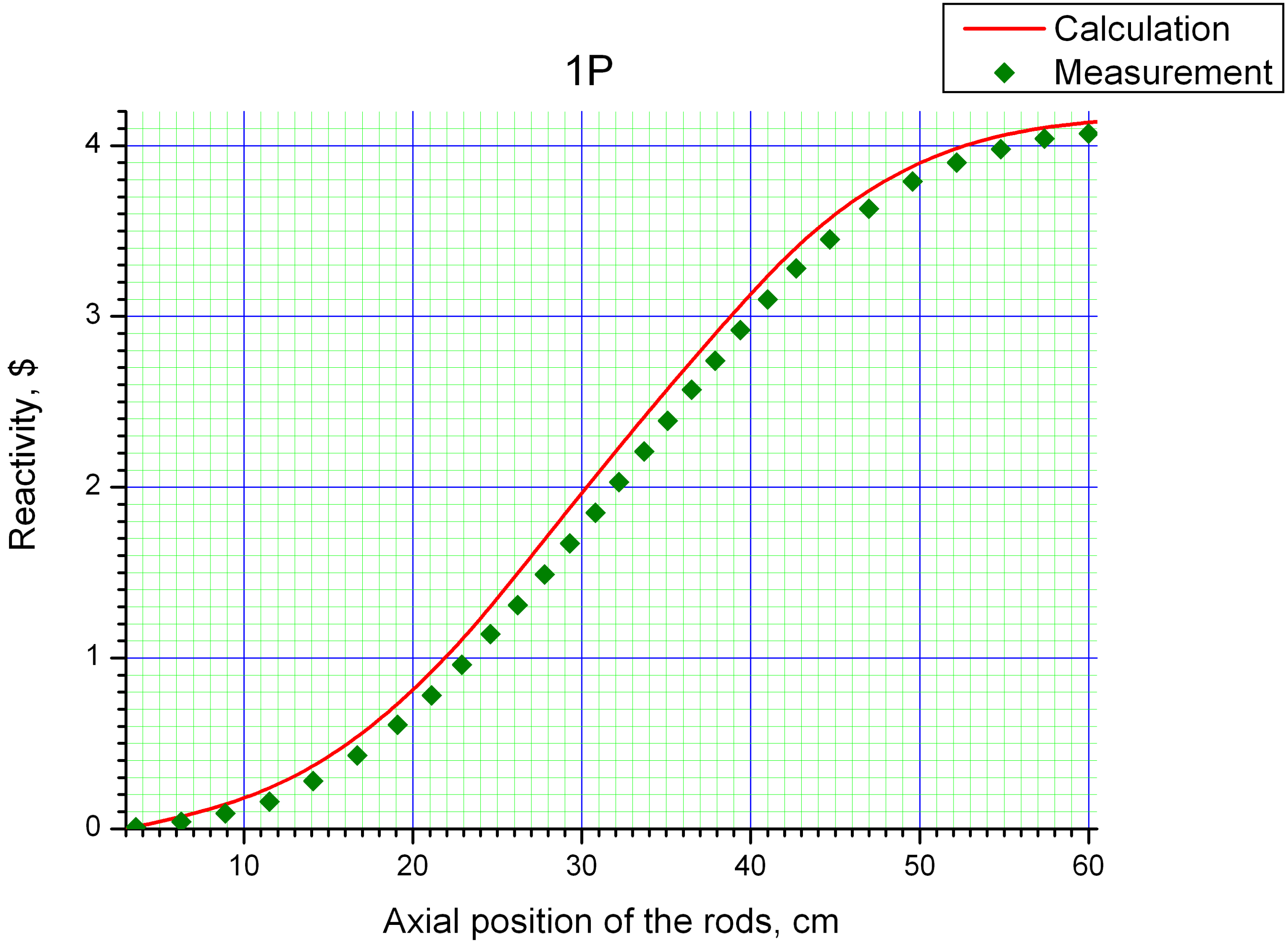
Distribution of $^{98}Mo(n,\gamma)$ Reaction Rate through the Natural Molybdenum Layer



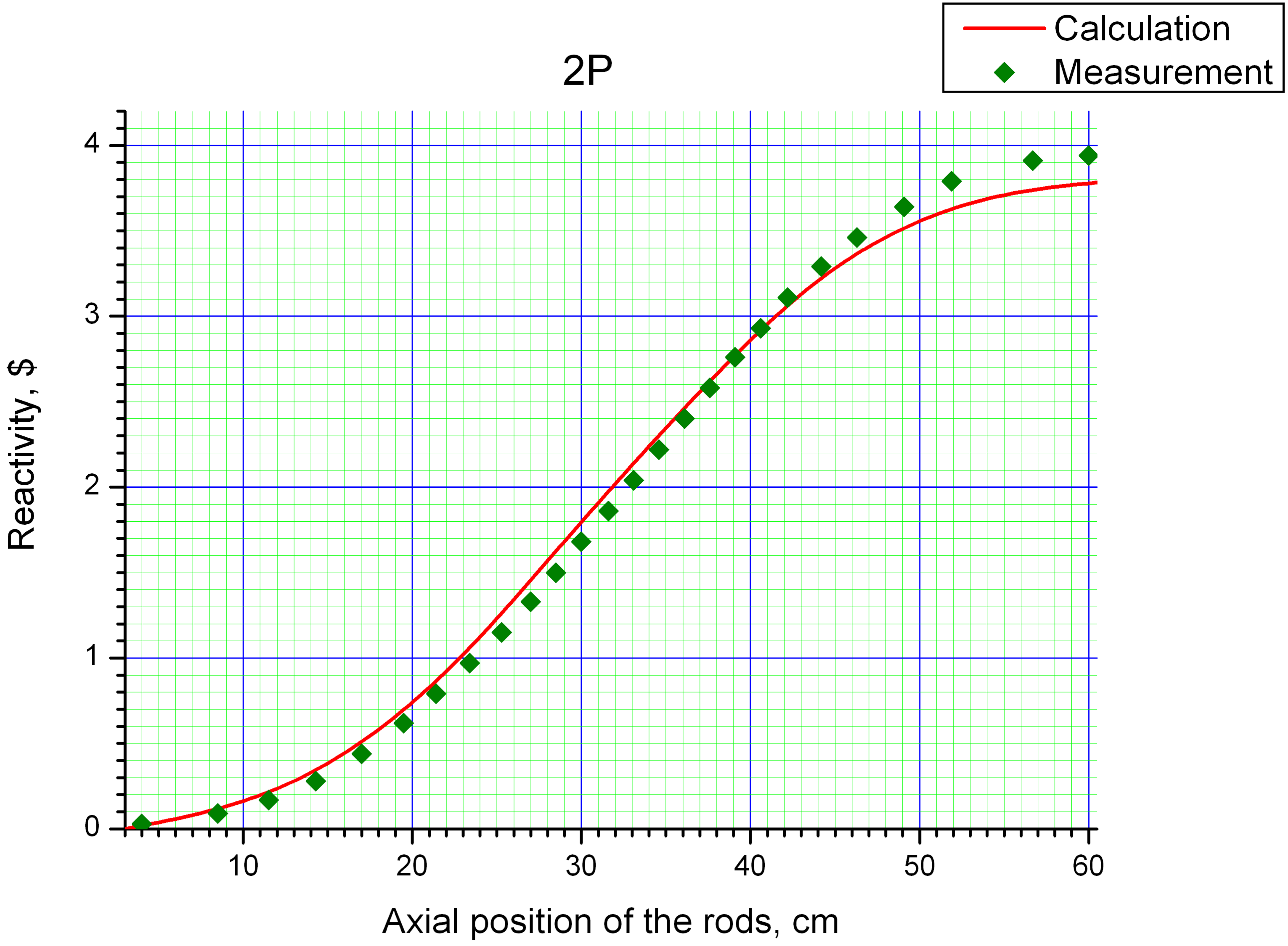
Axial Distribution of $^{98}Mo(n,\gamma)$ Reaction Rate



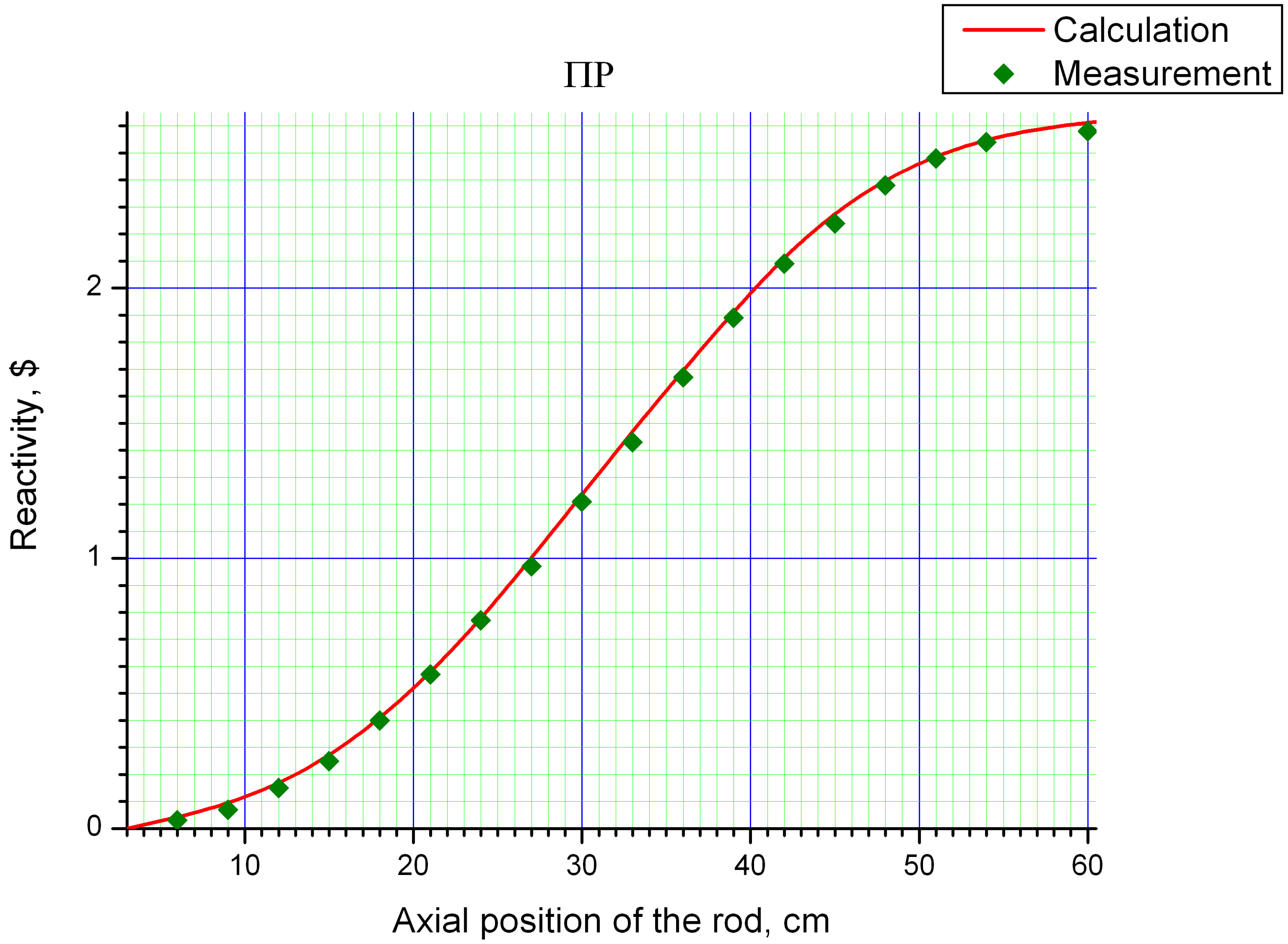
Reactivity Worth of the 1P Rods for the Mixed Core



Reactivity Worth of the 2P Rods for the Mixed Core



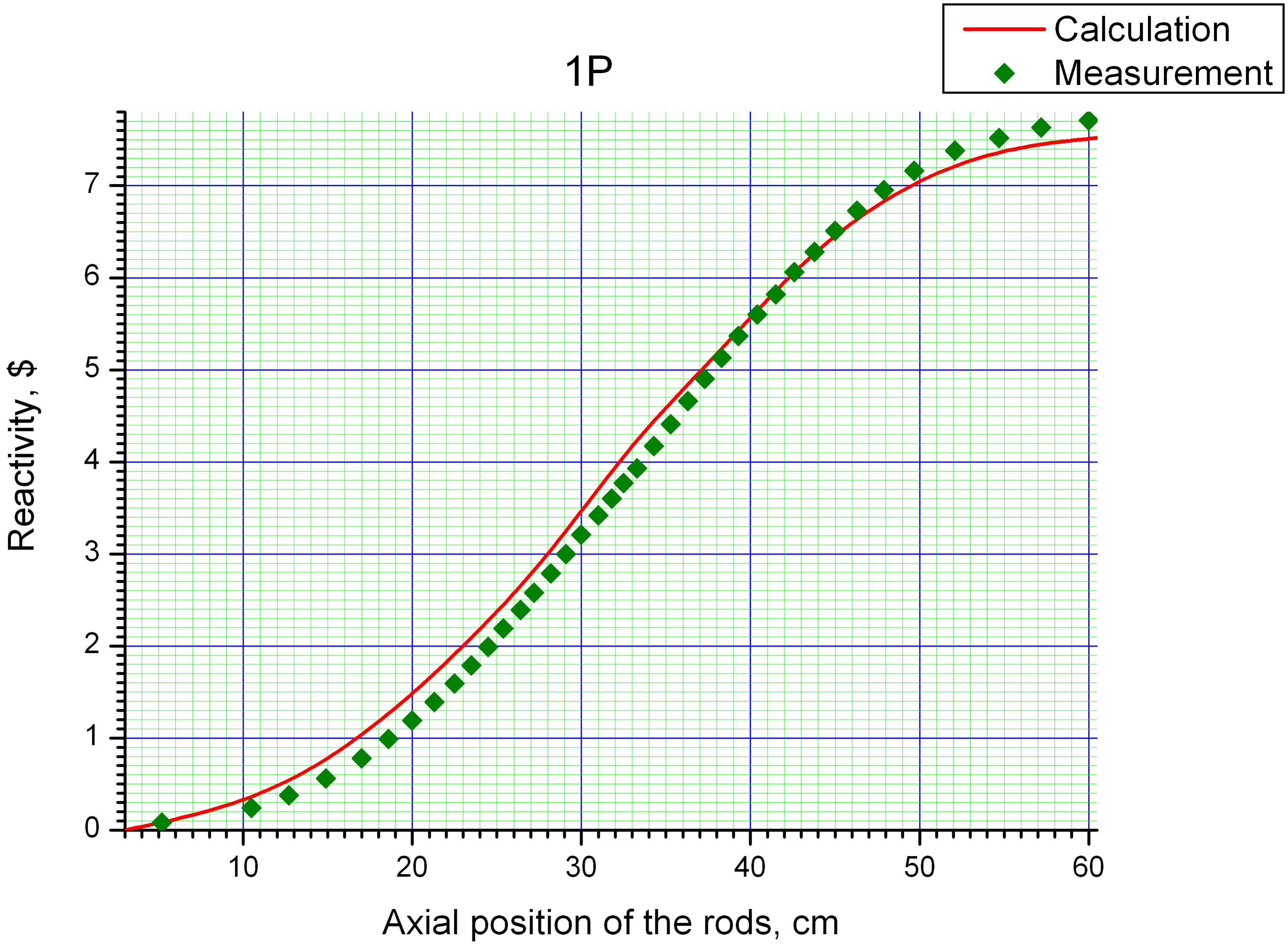
Reactivity Worth of the ΠP Rod for the Mixed Core



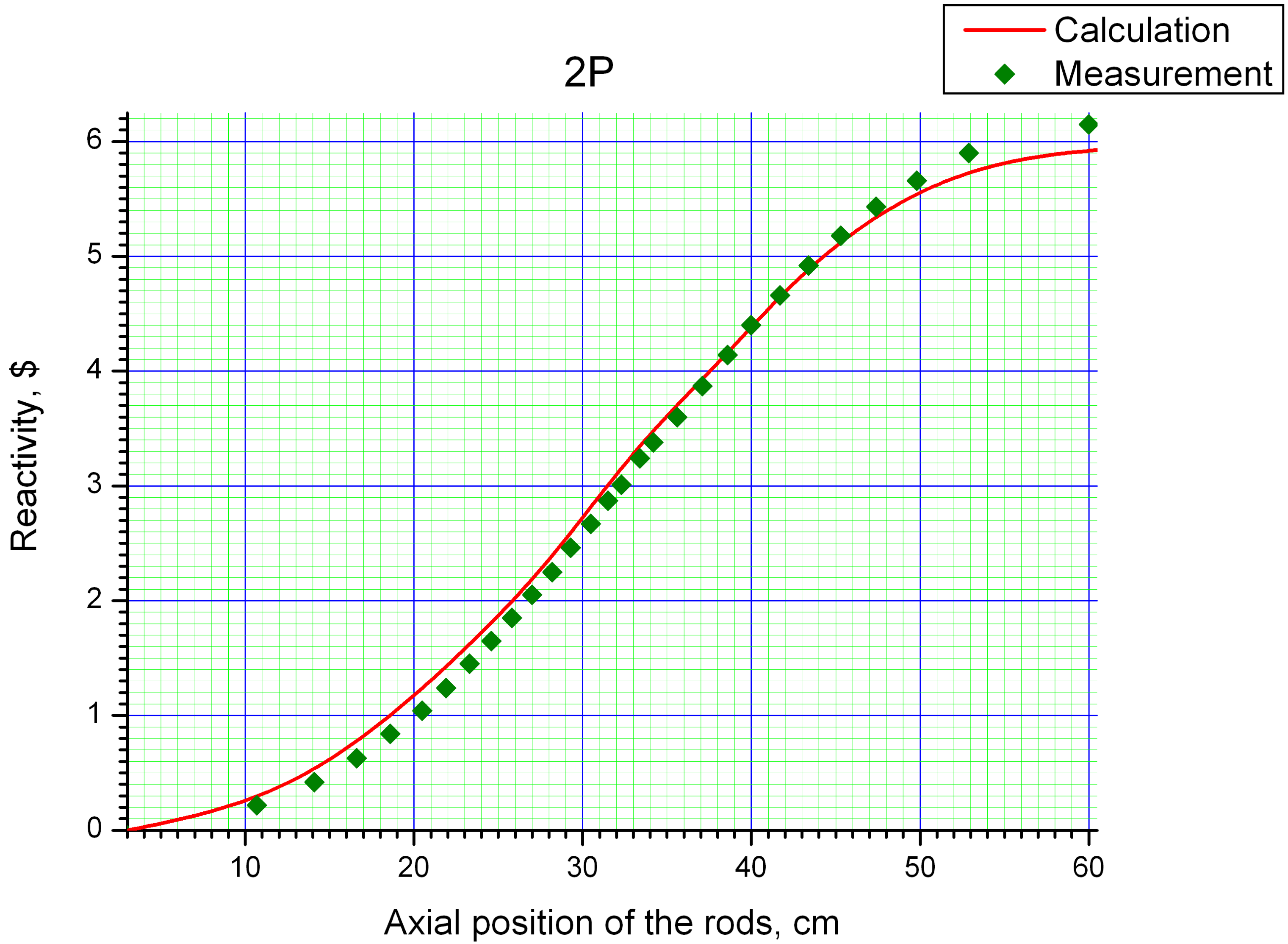
Reactivity Worth of the Control and Safety Rods for the LEU Core, $

	Calculation	Measurement
1P	7.55	7.71
2P	5.95	6.15
ПР	3.88	3.97
AP	0.70	0.73
1A	4.61	4.9
2A	4.26	4.0
3A	4.57	4.9

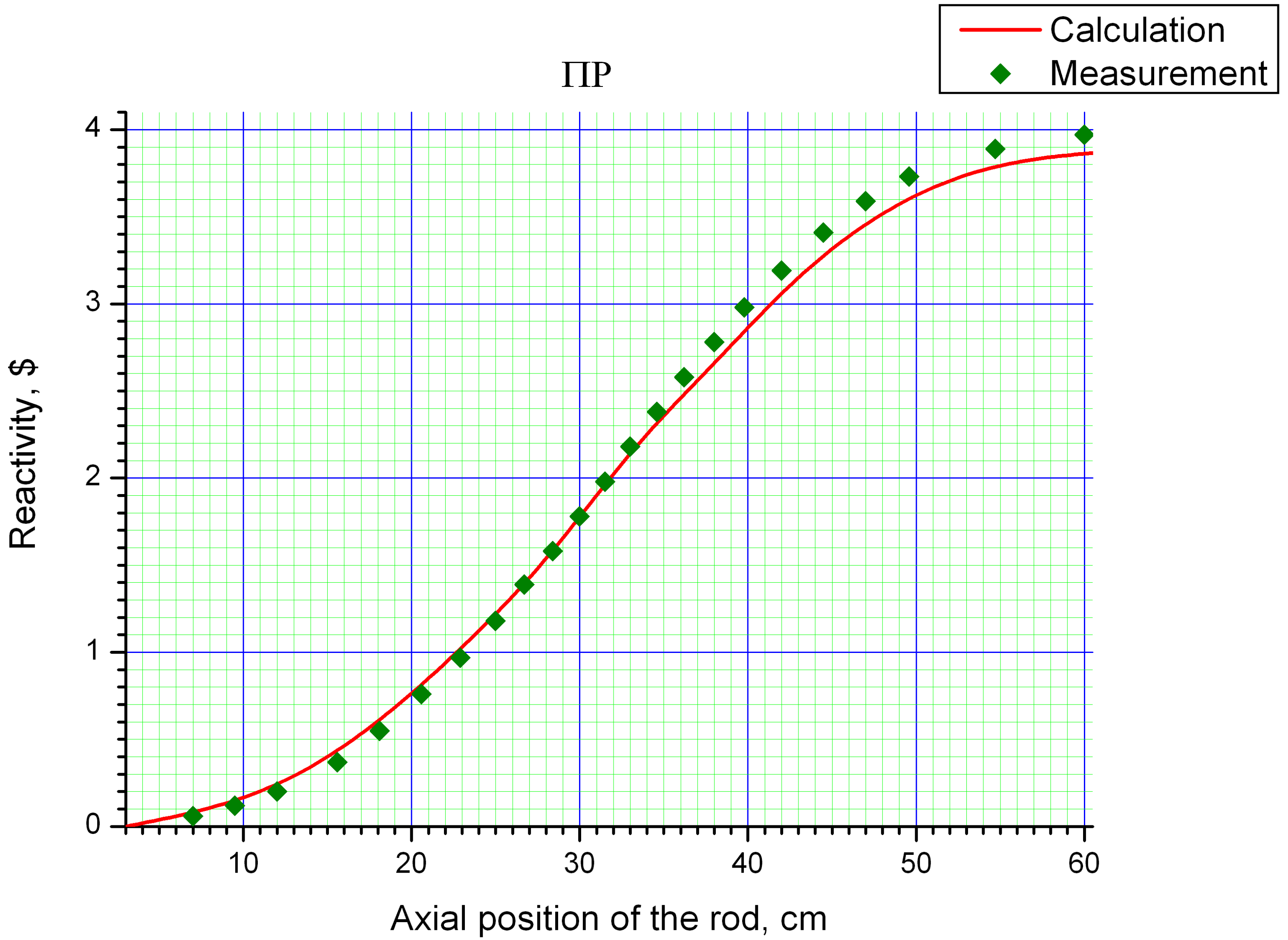
Reactivity Worth of the 1P Rods for the LEU Core



Reactivity Worth of the 2P Rods for the LEU Core



Reactivity Worth of the ПР Rod for the LEU Core



Accidents Analysis for the LEU Core

Because of considerable increase of reactivity due to loading a fuel assembly into the core and reactivity worth of control rods, the following potential accidents are analyzed for the new LEU core:

- incidental falling of a fuel assembly in a cell of the core;

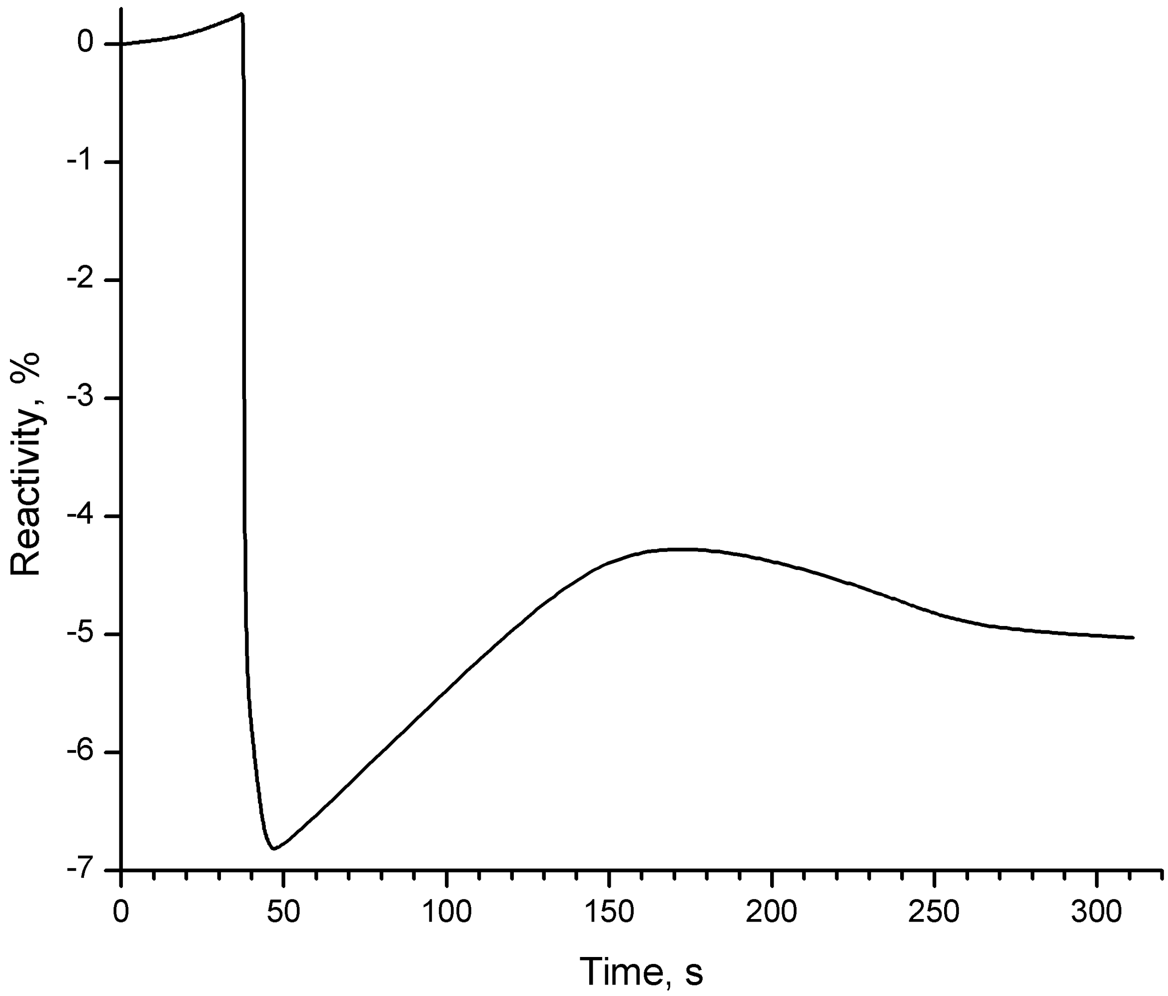
- spontaneous withdrawal of a control rod group because of malfunction of electronic equipment.

Accidents Analysis for the LEU Core

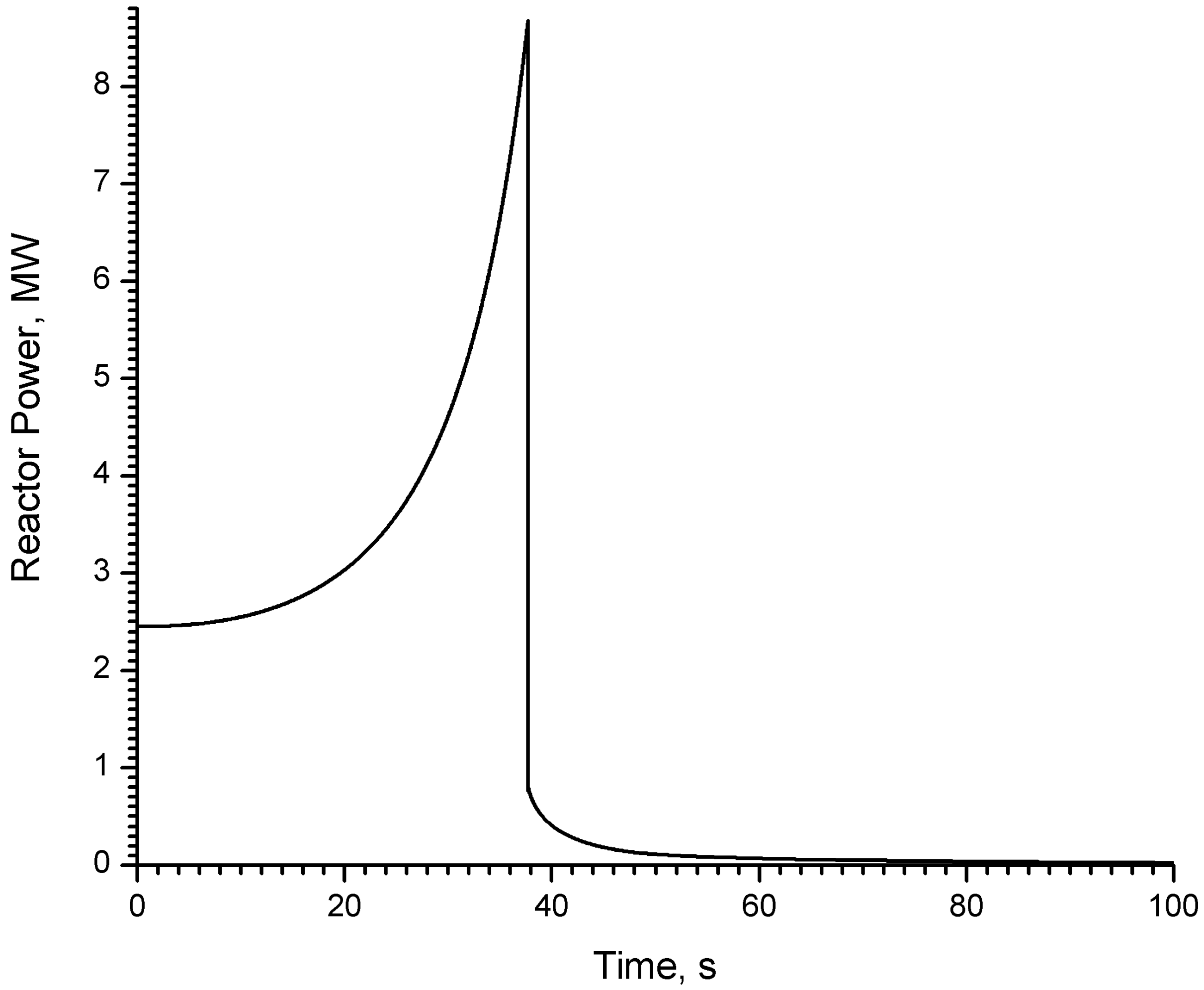
To provide safety of the reactor, some limiting conditions for operation are revised. In particular, maximum allowed effective multiplication factor when all control rods are fully in and all safety rods are fully out is decreased from 0.988 to 0.977, and maximum allowed power of the reactor is decreased from 10 MW to 7 MW.

The safety analysis confirms that with the revised limiting conditions for operation, such the events with accompanying one additional equipment malfunction and one error of personnel do not lead to damage of fuel elements and release of radioactivity exceeding allowed level.

Reactivity for spontaneous withdrawal of a control rod group



Reactor power for spontaneous withdrawal of a control rod group



Conclusions

Full-core conversion of the WWR-M research reactor in Ukraine 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, due to optimization of the new LEU core pattern, its maximal thermal neutrons flux and potential to produce Mo-99 are higher than for the old mixed core.

To provide safety of the reactor, some limiting conditions for operation are revised. In particular, maximum allowed effective multiplication factor when all control rods are fully in and all safety rods are fully out is decreased from 0.988 to 0.977, and maximum allowed power of the reactor is decreased from 10 MW to 7 MW.

Conclusions

The safety analysis shows that with the revised limiting conditions for operation, such the events with accompanying one additional equipment malfunction and one error of personnel do not lead to damage of fuel elements and release of radioactivity exceeding allowed level.

At this moment, the power of the reactor is 7 MW, while the number of fuel assemblies in the core is 85. With fuel burnup, the number of fuel assemblies in the core will be increased and the reactor power will reach 10 MW.