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The Most Efficient Target Development to Increase the ^{99}Mo Production Using the VVR-ts Reactor Core

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Abstract

The article shows the possibility of increasing the ^{99}Mo production using the modifyed target. It was shown that there is a significant reserve for increasing the production of the ^{99}Mo isotope without a significant change in the core.

Keywords: VVR-ts, ^{99}Mo production, modified target

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1. Introduction

The development of nuclear medicine is associated with radionuclide diagnostics and treatment of oncological diseases. In connection with this, the issue of special isotopes obtaining is becoming strongly important. The need for such isotopes is growing all over the world. The procedure for obtaining them is specific and laborious. It depends on many factors that require knowledge of the nuclear installation itself and the neutron-physical processes occurring in the reactor core and the target. At the same time, the main problem is the most efficient production of radionuclides. This immediately implies both the nomenclature of manufactured preparations, and the products price.

Recently, both in Russia and in the whole world, a radionuclide such as ^{99}Mo, which is produced in JSC NIFKhI "Karpov Institute of Physical Chemistry", is in demand. The production of this radionuclide is carried out in special experimental channels of the reactor VVR-ts. At the same time, the ^{99}Mo production efficiency strongly depends on two main factors. Firstly, this is the operating conditions of the reactor. Secondly, the isotopes production efficiency depends on the target characteristics and methods of its placement in the experimental channels. Thus, an important part of the work is the investigation of various special conditions that can be created for the target, in order to increase the yield of nuclides [3, 4].

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2. Methodology

We have used the previously created model of the VVR-ts reactor core [1], which makes it possible to carry out corresponding estimations, as well as carry out computational studies to improve radionuclides production in experimental channels. In particular, it became possible to compare different targets in terms of their effectiveness for various radionuclides production.

The developed input file was used to calculate single-group reaction rates, neutron flux densities, and energy-release estimates in experimental channels under consideration. The file takes into account the reactor core, as well as the design of the experimental channels under consideration. To calculate the change in the nuclide composition of the targets, the VisualBurnOut code was used.

To assess the possibility of increasing the production level of ^{99}Mo, a radiochemical yield of ^{99}Mo was considered for each of the proposed options for the modernization of the target design. After that, obtained indicators were compared with those for the standard target. It should be noted that the comparison was made for the total yield of the nuclide. According to expert estimates, the real amount of the isotope is approximately 70% of the total amount of ^{99}Mo produced in the target.

3. Results

For all type of targets neutron fluxes, energy-release and the ^{99}Mo yield were evaluated for the standard and modified target (Figure 1) placed in the experimental channel (4-1 on the cartogram) during the campaign. This experimental channel was chosen, because of the most accurate coincidence of the calculated neutron-physical characteristics with the experimental data was obtained.

The primary modifying of the target was to create a quick-disconnect target in the form of a "pipe in a pipe". In this case, a mixture of U_3O_8 and ZnO is placed between the inner and outer tubes. Simultaneously two modified targets were installed in the channel, while for the standard target this number was equals four. The modified target is cooled with water flowing through it and the space of the experimental channel is used in the fullest possible way [2].

The length of the campaign was 72 hours at a nominal power of 10 MW with subsequent excerpt of the target for 24 hours.

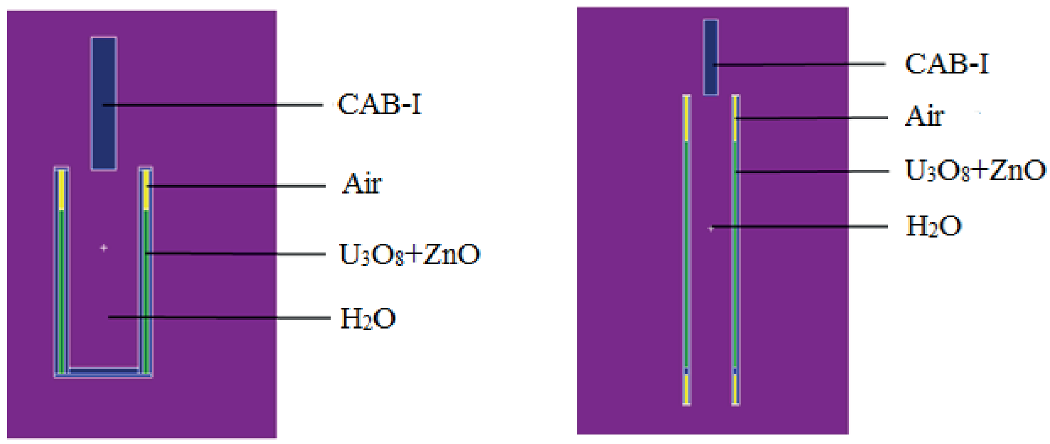

Figure 1: Standard target ("glass in glass", left) and modified target ("pipe in pipe", right) for the ^{99}Mo production..

Table 1 shows the results of the ^{99}Mo yield for the standard and modified targets (the uncertainty was estimated by taking into account the neutron flux error by 10%).

Table 1: Comparison of the standard and modified targets for ^{99}Mo production.

Standard target				
The ^{99}Mo yield, Ci				
The 1st target (counting from the bottom)	The 2nd target (counting from the bottom)	The 3rd target (counting from the bottom)	The 4th target (counting from the bottom)	Total ^{99}Mo yield
125+/-2	143+/-2	110+/-2	62+/-1	440+/-6
Modified target				
The ^{99}Mo yeild, Ci				
The 1st target (counting from the bottom)		The 2nd target (counting from the bottom)		Total ^{99}Mo yield
373+/-5		355+/-5		728+/-9

The results show, that the modified target gives the ^{99}Mo yield about 1.7 times greater.

Then the method of implementing the "activation" technology for the ^{99}Mo production was considered (Figure 2) for the same campaign but without subsequent excerpt of the target.

Table 2 shows the results of the ^{99}Mo yield applying the modified target (the uncertainty was estimated by taking into account the neutron flux error by 10%).

The results show, that the modified target gives the ^{99}Mo yield about 2.5 times greater, due to use of "activation" technology.

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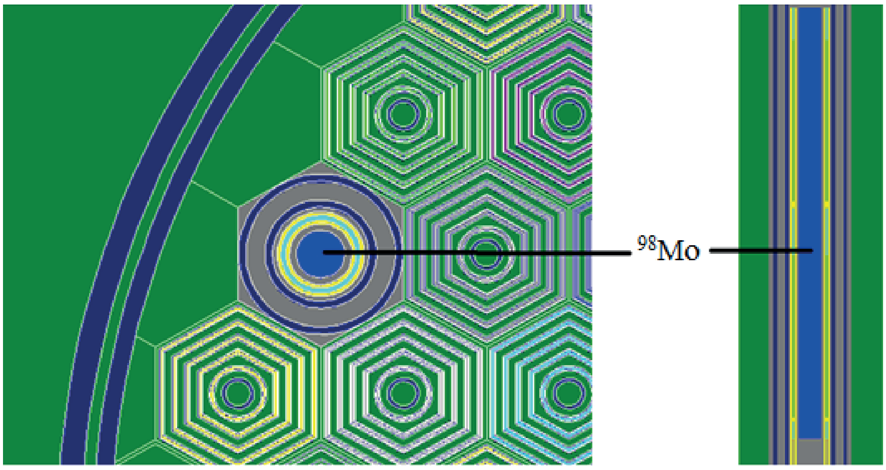

Figure 2: Placement of ^{98}Mo into the modified target for the ^{99}Mo production.

Table 2: Estimation of the ^{99}Mo yield in the modified target.

	Neutron flux, $\frac{n}{cm^2 s}$	Energy-release, kW	The ^{99}Mo yield, Ci
The central element consisting of ^{98}Mo	$1{,}32 \cdot 10^{14}$	$3.45 \cdot 10^{-2}$	749+/-11
Lower target	$1{,}31 \cdot 10^{14}$	23.53	536+/-8
Upper target	$1{,}39 \cdot 10^{14}$	24.47	584+/-8

It should be noted that when developing and implementing an alternative production technology for the ^{99}Mo, a number of problems arise, so at present it is not widely used.

When using the modified target shown in Figure 1, the central part of the pipe is not used. Therefore a new upgraded version of the target (Figure 3) was subsequently considered in which the central rod was installed. Also, in order to increase the ^{99}Mo yield, a variant with an increased duration of the reactor company and reactor power was considered, which is quite feasible in view of the forthcoming reconstruction of the reactor VVR-ts core.

The length of the campaign was 120 hours at a nominal power of 15 MW without subsequent excerpt of the target.

Table 3 shows the results of the ^{99}Mo yield by applying the modified target with central rod (the uncertainty was estimated by taking into account the neutron flux error by 10%).

The results show that this type of target together with a change in the irradiation conditions make it possible to increase the ^{99}Mo yield by 20%, relative to the target without the placement of a central rod. The first problem with using such a modified

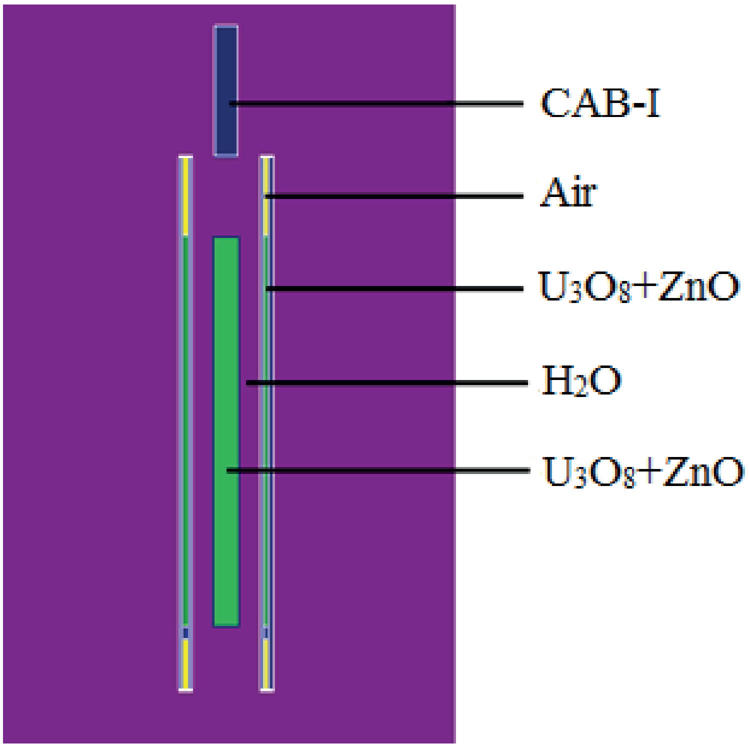

Figure 3: Modified target with central rod.

Table 3: Estimation of the ^{99}Mo yield for the modified target with central rod.

	Neutron flux, $\frac{n}{cm^2 s}$	Energy-release, kW	The ^{99}Mo yield, Ci
Upper target	$2.09 \cdot 10^{14}$	24.47	1006 +/-15
Central rod of the upper target	$2.14 \cdot 10^{14}$	5.43	231+/-3
Lower target	$2.04 \cdot 10^{14}$	24.01	992+/-15
Central rod of the lower target	$1.97 \cdot 10^{14}$	5.22	225+/-3

target is associated with an increasing of energy release in the target (about 18%). The second problem is a decrease in the cross-sections, which also leads to an increase in the water temperature in the target. As calculations have shown, an increase in the radius of the central rod of more than 3 mm leads to a decrease in the ^{99}Mo yield in the target, and therefore a further increase in the radius is not advisable.

In order to avoid these problems we proposed the variant of placing an additional internal element in the form of a ring (Figure 4) instead of a rod.

Calculations were carried out with the same irradiation conditions.

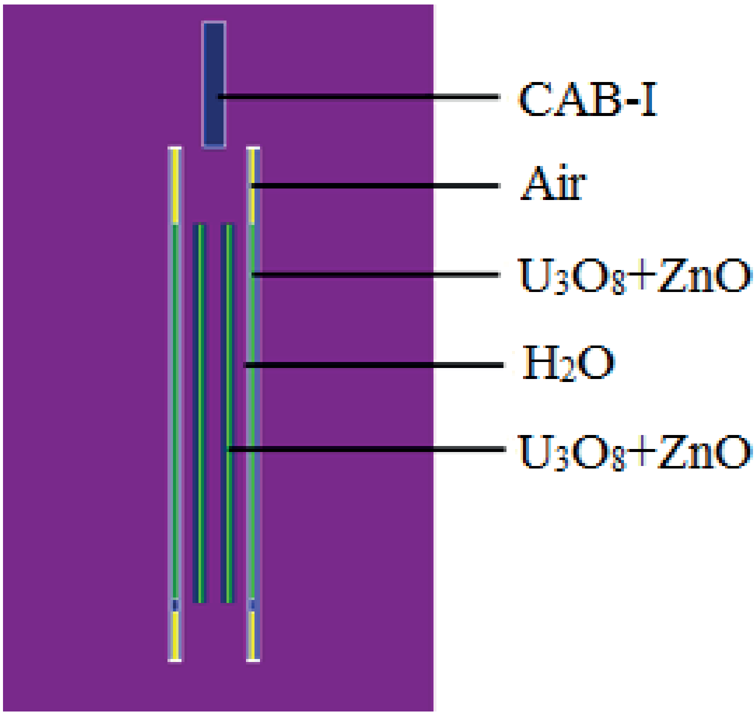

Figure 4: Modified target with a ring.

Table 4 shows the results of the ^{99}Mo yield by applying the modified target with a ring (the uncertainty was estimated by taking into account the neutron flux error by 10%).

Table 4: Estimation of the ^{99}Mo yield for the modified target with a ring.

	Neutron flux, $\frac{n}{cm^2 s}$	Energy-release, kW	The ^{99}Mo yield, Ci
Upper target	$2.04 \cdot 10^{14}$	20.76	889 +/-13
The ring of the upper target	$1.98 \cdot 10^{14}$	7.77	341+/-5
Lower target	$2.00 \cdot 10^{14}$	20.96	895+/-13
The ring of the lower target	$1.98 \cdot 10^{14}$	8.01	349+/-5

Above results show the possibility of achieving the ^{99}Mo yield similar to the rod element. Also, there is a redistribution of energy release by the volume of the target, which leads to a decrease in operating temperatures.

The last variant of the modified target represents a set of rod elements (Figure 5) filled with fuel with a radius of 3 mm.

Calculations were carried out with the same irradiation conditions.

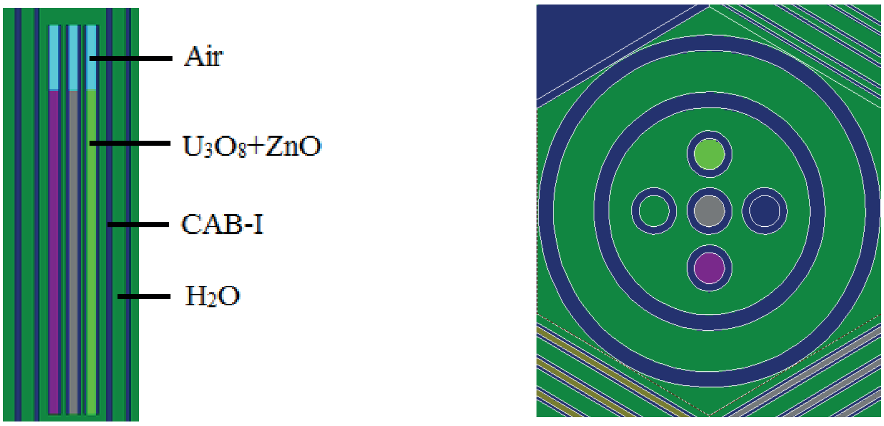

Figure 5: The model with a set of rod elements filled with fuel.

Table 5 shows the results of the ^{99}Mo yield by applying the modified target with a set of rod elements filled with fuel (the uncertainty was estimated by taking into account the neutron flux error by 10%).

TABLE 5: Estimation of the ^{99}Mo yield for the modified target with a set of rod elements filled with fuel.

	Neutron flux, $\frac{n}{cm^2 s}$ (mean value per target)	Energy-release, kW (mean value per target)	The ^{99}Mo yield, Ci
Upper target	$2.05 \cdot 10^{14}$	17.74	729+/-10
Lower target	$2.03 \cdot 10^{14}$	17.46	720+/-10

For the considered variant of the construction, a decrease in the ^{99}Mo yield is noticeable. However, the very idea of such arrangement of the fuel composition will allow increase the number of placed rod elements in the experimental channel, and consequently, the ^{99}Mo production.

4. Conclusions

Calculated studies have shown a noticeable increase in the ^{99}Mo yield in the different types of targets. The main problem is associated with a change in the energy release in the target and consequently in the values of operating temperatures. In the future will address more complex geometry and additional work will done on the substantiation of a thermal-hydraulic parameters of new targets for the ^{99}Mo production.

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