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THE USE OF ^{252}Cf NEUTRON SOURCES IN THE USSR

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As atomic science and engineering and atomic energetics develop it becomes more and more possible to obtain a number of isotopes of the transuranium elements and in particular, californium-252 in rather large quantities. Due to its high specific yield of neutrons (2.34×10^{12} n/s per g of ^{252}Cf) which are emitted during spontaneous nuclear fission and its relatively long half-life (2.65 yr) this isotope is quite attractive for the fabrication of neutron sources especially those having a yield of 10^9 n/s or more.[1]

The availability of such sources enables one to increase the number of practical problems which may be effectively solved with the help of the isotope neutron sources as well as increase the efficiency of using such sources in the traditional areas. In this connection it appears necessary to carry out studies such as the development and improvement of the fabrication techniques and designs of sources using ^{252}Cf, studies of their radiation-physical and other characteristics, development of methods and means for certification, determination of conditions of the use and requirements for source parameters when solving specific problems, and the creation of the necessary equipment, etc.

Carrying out these and other studies made it possible to solve a number of primary problems of the practical use of ^{252}Cf neutron sources and to determine trends for further studies.

At present in the USSR the production and supply of ^{252}Cf sources having general commercial application to the user is handled through V/O IZOTOP. These sources with external sizes 8mm diameter x 10 mm long have a neutron yield from 1×10^6 to 1×10^9 n/s. Also, sources for interstitial and intracavitary therapy as well as sources for experimental studies are produced and supplied.

The active part of ^{252}Cf neutron sources which are supplied to the users is usually put in succession into two stainless steel capsules sealed by means of argon-arc welding. The source surface is then thoroughly decontaminated and leak-tested.

At present in the USSR ^{252}Cf neutron sources are used in the following applications:

- geological prospecting and in particular, neutron logging and fast activation analysis to determine

elemental composition of geological samples;

- medical-biological studies - interstitial and intracavitary therapy;

- neutron injection into neutron breeders-special subcritical reactor assemblies for elemental activation analysis;

- studies on non-destructive testing of materials and finished products using neutrons, in particular by neutron radiography;

- studies on elemental activation analysis of samples and moving media;

- studies on dosimetry, protection, metrology.

Data on using ^{252}Cf neutron sources for some studies and the results of those studies are listed below.

Elemental Activation Analysis of Moving Media

In order to control continuous processes effectively it is often necessary to get constant information on the elemental or isotope composition of a substance in the relevant process stream (solution, pulp, or other media). Activation analysis is one of the prospective methods for obtaining such information. In the present case the activation of the moving substance and measurements of the quantity of radioactive isotopes formed in this substance can be carried out directly in the corresponding pipes or in special on-stream activation and measurement chambers.

Clearly the optimum mode of analysis and the parameters of the relevant equipment depend on the composition of solutions being controlled, the velocity of their movement, the half-lives and energies of the radiation from the radioisotopes and a number of other factors that must be determined for each specific problem.

Table 1

Thresholds of Detectability of Some Elements in Aqueous Solution, g/ℓ^3

Neutron Yield of source n/s	Element						
	Al	F	Se	Cl	Na	Y	Mn
5×10^8	1.4×10^2	0.4	1×10^{-2}	-	-	-	-
1.5×10^9	-	-	3.6^{-3}	0.12	0.1	10^{-3}	2.6×10^{-3}

For this purpose a "Rastvor"-type special plant was developed and used. Its principle scheme is shown in Fig. 1.[2] The plant consists of a number of tanks with capacities of about 100 ℓ each provided with mixers and electric heaters, a pump for transferring solutions with a maximum throughput of 1000 ℓ/h, activation and measurement assemblies having a set of removable on-stream chambers with various volumes, and electronic registering apparatuses.

The plant makes it possible to use different isotope neutron sources, including ^{252}Cf sources, with yields up to 5×10^9 n/s. During the studies carried out, sources having neutron yields 5×10^8 and 1.5×10^9 n/s were used. In Table 1 observed thresholds of detectability are listed for a number of elements in water solutions. The effects of solution flow rate, activation chamber volume and radioactive isotope characteristics on the value of the solution activity are shown in Fig. 2.

The studies demonstrated that the use of ^{252}Cf neutron sources for the activation analysis of the elemental composition a moving medium can solve a number of practical problems.

Results of the studies were used when constructing industrial plants for analysis of Al, F, and In contents in industrial streams.[4,5]

Use of ^{252}Cf Sources in Neutron Multipliers

When solving some problems of activation analysis special subcritical reactor assemblies called neutron multipliers usually are used as a source of slow neutrons. Their advantages are simplicity of design and operation, high reliability, operational stability, and the possibility of obtaining relatively high slow-neutron flux densities in substantial volumes.

The principle scheme of one of the neutron multipliers used in our studies[6] is shown in Fig. 3. The multiplier core is a homogeneous mixture of polyethylene and uranium enriched to 35% in the isotope ^{235}U. A ^{252}Cf source with a yield of 1.5×10^9 n/s is used as a neutron source in the multiplier. The slow neutron flux density in the experimental channels as measured by the activation of the gold foils was 2×10^8 n/cm^2·s. The slow neutron flux density in the hydrogenous moderator, e.g., in the paraffin wax was a maximum of about 3×10^7 n/cm^2·s and decreased rapidly as the distance from the source increased.

The multiplier equipment allows activation analysis to be carried on solid and liquid samples as well as on industrial streams.

Fig. 4 and Fig. 5 show the scheme of carrying out such analyses.

In Table 2 and Fig. 6 there are given some results which show the potentialities of the multiplier for elemental analysis of samples of biological soil and their water extracts and of moving plant solutions as well.[7]

The neutron multipliers are of interest as sources of slow neutrons for the non-destructive testing of materials and products using neutron radiography.[8] For such tests the multiplier design described above is provided with a horizontal channel for extracting the slow neutron beam from the core surface. With a collimating beam of 2° the density of the slow neutron flux at the exit of the channel from the shielding was 1.4×10^{5} n/cm^2 as measured by activation of gold foils.

Neutron Radiography

At present various types of nuclear reactors are used in most cases as neutron sources for the non-destructive testing of materials and products by means of neutron radiography.[8,9] In general, reactor sources make it possible to obtain slow neutron beams for testing which usually have better parameters than do other types of sources so that a rather wide range of testing problems are possible with the method. However, these neutron sources have some essential shortcomings. One of these is the stationary arrangement of the nuclear reactor and the accompanying experimental techniques for carrying out neutron radiography.

The above shortcoming essentially restricts the use of neutron radiography for testing commercial products because the products must be transported to the testing point. In this connection there is also a problem of creating simple transportable facilities which can be used for neutron radiography of materials and products directly under manufacturing conditions.

Along with neutron multipliers one may also use some types of isotope neutron sources for this purpose especially ^{252}Cf sources. A facility using ^{252}Cf sources in its simplest case can be a tank of about 1m^3 volume filled with a hydrogenous moderator such as H_2O and having a collimator for extracting a neutron beam.

The effect of the sizes of H_2O moderator on the spatial distribution of thermal and epicadmium neutrons from a ^{252}Cf source is illustrated in Fig. 7. The distributions were measured by activation of indium foils.

Fig. 8 shows the effect of the distance between the collimator base having the form of a truncated cone and the Cd plating of its walls on the slow neutron flow at the collimator exit.

A facility for our experimental studies of the characteristics of the neutron radiography method using ^{252}Cf sources is shown in Fig. 9.

Evaluations and experiments showed that for obtaining neutron beams having acceptable parameters ^{252}Cf neutron sources with the yield in the order of $10^9 - 10^{10}$ n/s were preferable. In this case one may obtain slow neutron beams with the flux densities in the order of $10^3 - 10^4$ n/cm^2·s when collimating the beam from 2-5°. Though the use of sources with yields in the order of 10^{12} n/s or greater permits better beam parameters, it is considered inexpedient, however, because the corresponding facilities for neutron radiography are bulky and of high cost.

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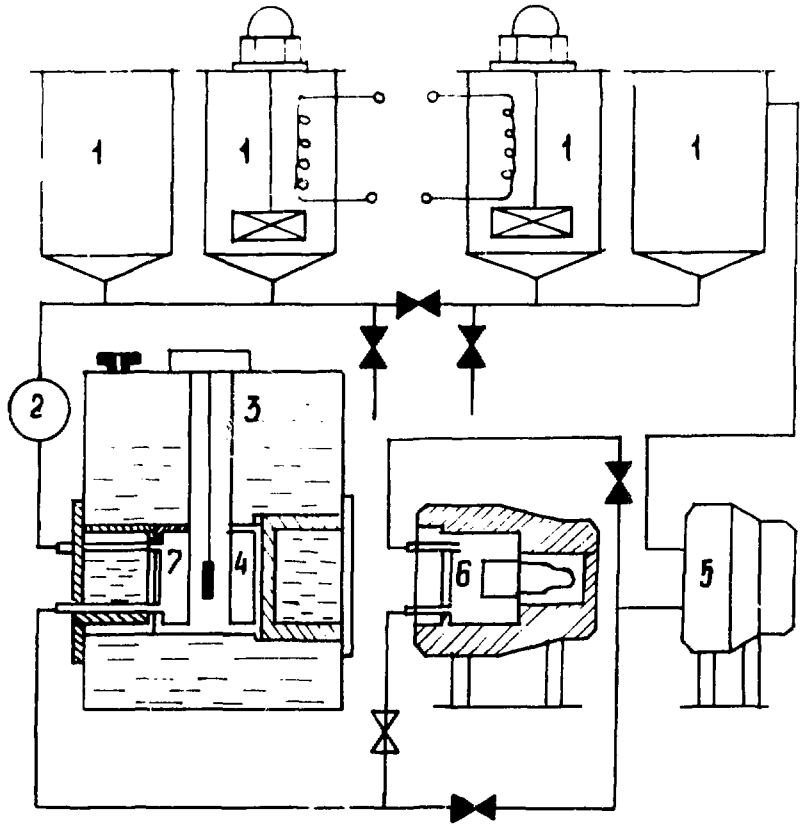

Fig. 1. "RASTVOR" type experimental plant:
1 - tanks for solutions to be analyzed
2 - pump-doser
3 - activation assembly
4 - activation chamber
5 - measurement assemblies
6 - measurement chamber
7 - isotope neutron source

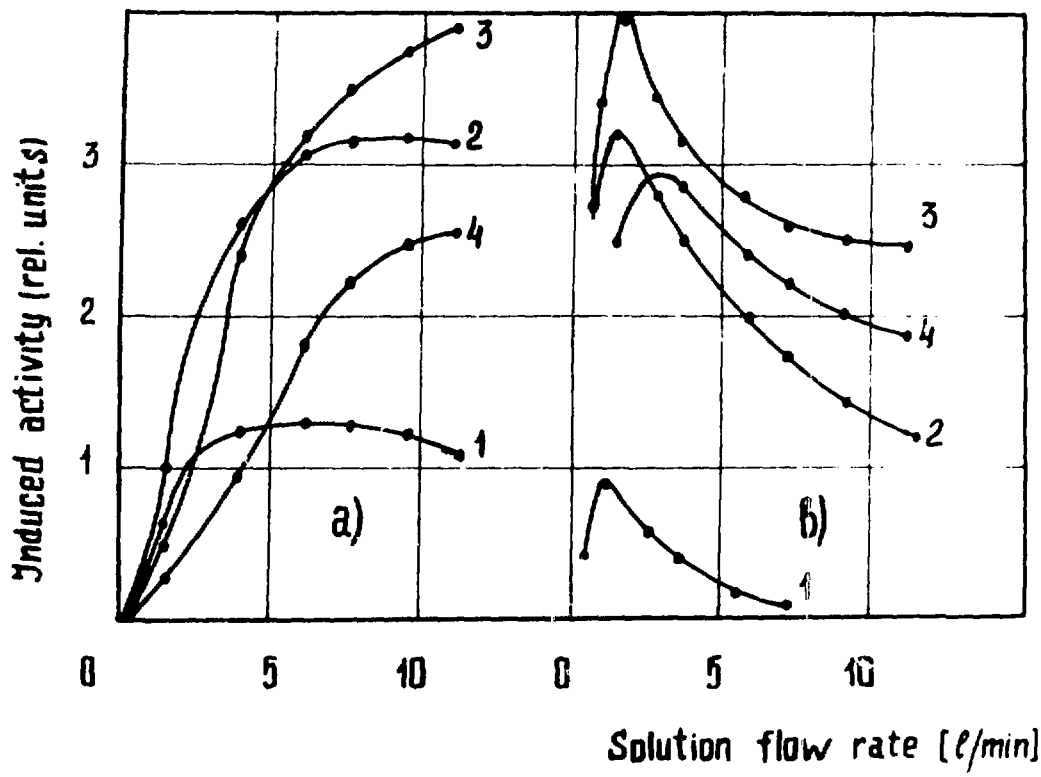

Fig. 2. The dependence of the induced activity on the solution flow rate and activation chamber volume (1 to 0.5 l, 2 to 2 l, 3 to 5 l, 4 to 15 l). The measurement chamber volume is 3 l. ^{252}Cf neutron source. a) - isotope ^{77m}Se; b) - isotope ^{28}Al.

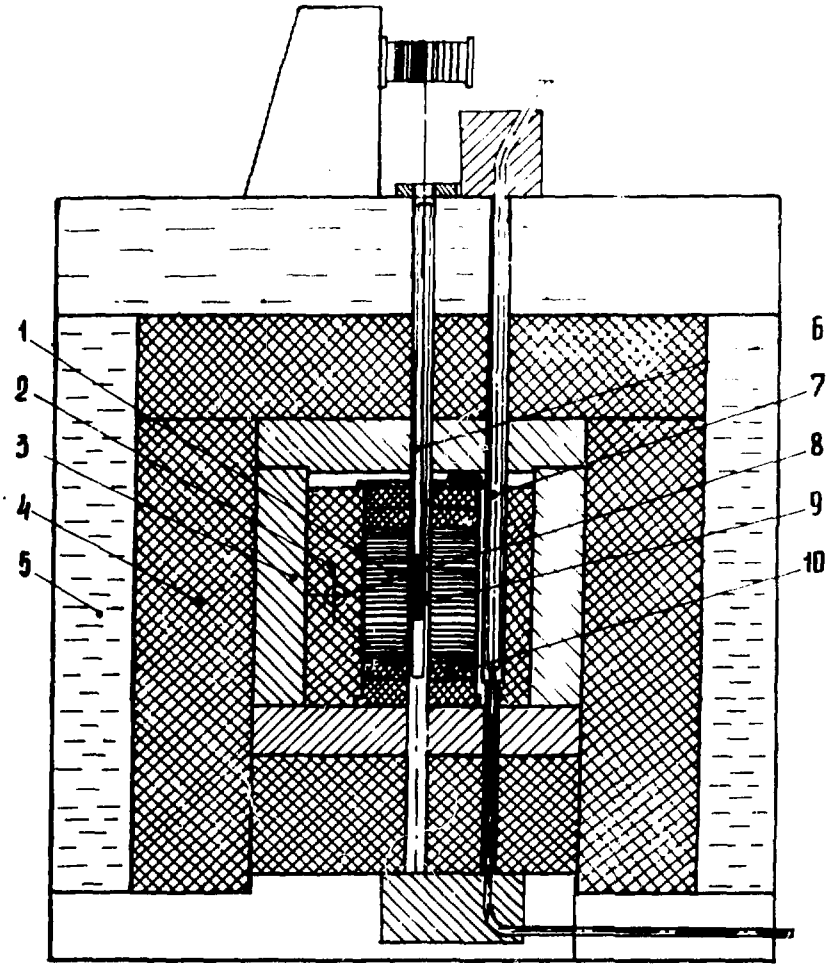

Fig. 3. Neutron multiplier:
1 - core
2 - graphite reflector
3 - lead, boron-containing
4 - *paraffin and water*
5 - shieldings correspondingly
6 - central channel
7 - vertical and horizontal experimental
8 - channels correspondingly
9 - ^{252}Cf neutron source
10 - rod-regulator

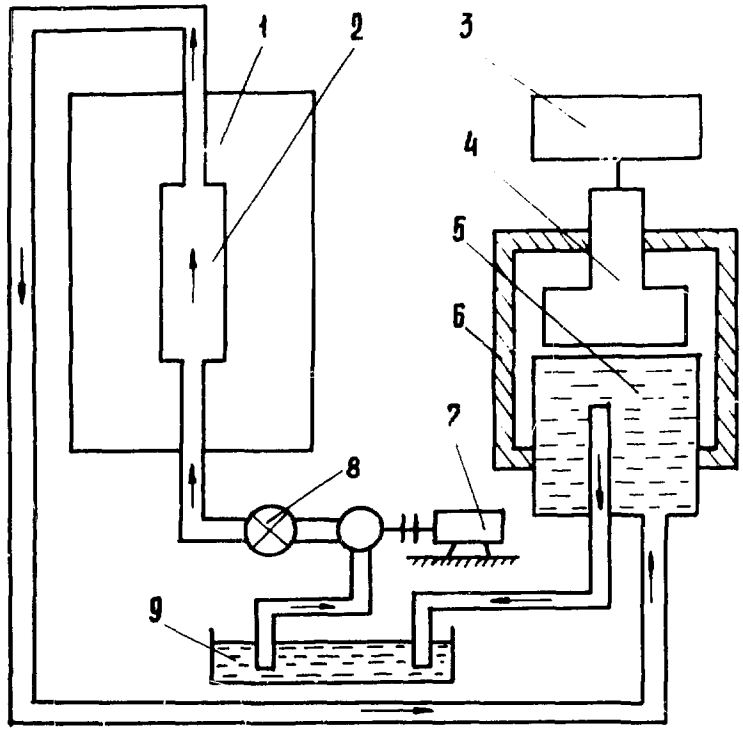

Fig. 4. Block-diagram of the analysis of solutions in flux when using a neutron multiplier:
1 - multiplier
2 - activation chamber
3 - assemblies of electronic registering apparatuses
4 - detector
5 - measurement chamber
6 - shielding
7 - pump
8 - valve
9 - tank with a solution to be analyzed

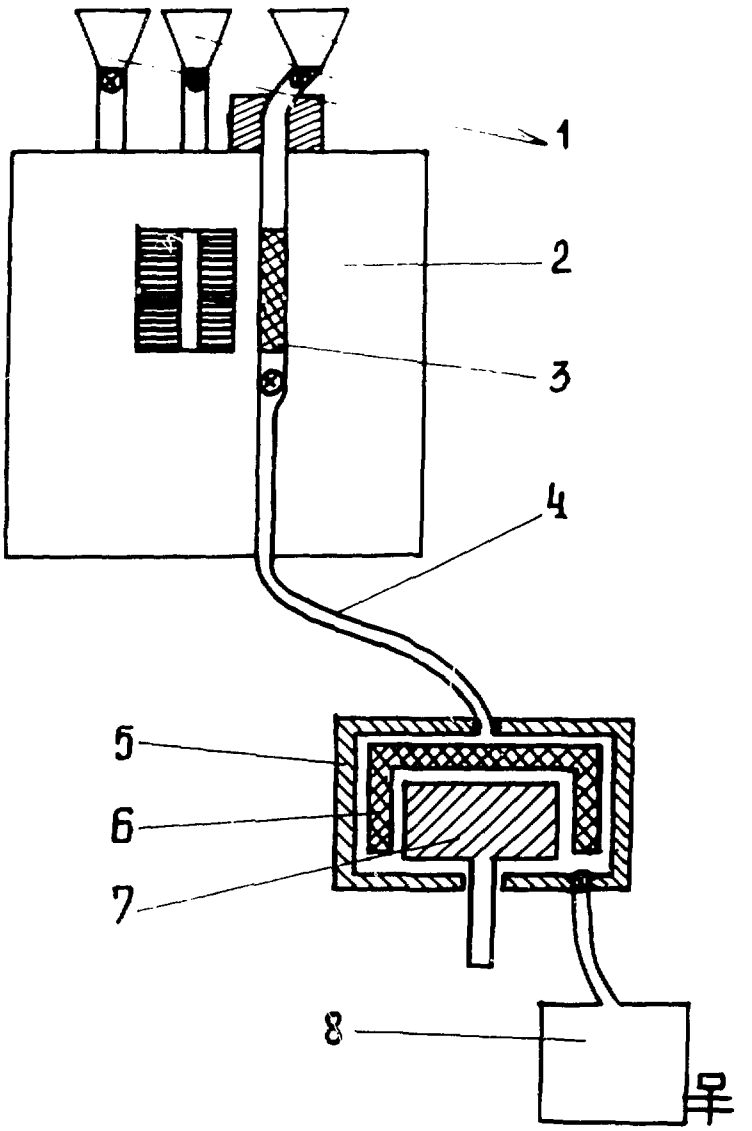

Fig. 5. Scheme of carrying out the analysis of liquid samples when using a neutron multiplier:
1 - funnels
2 - multiplier
3 - sample to be analyzed
4 - discharge lead
5 - shielding
6 - measurement chamber
7 - detector
8 - tank

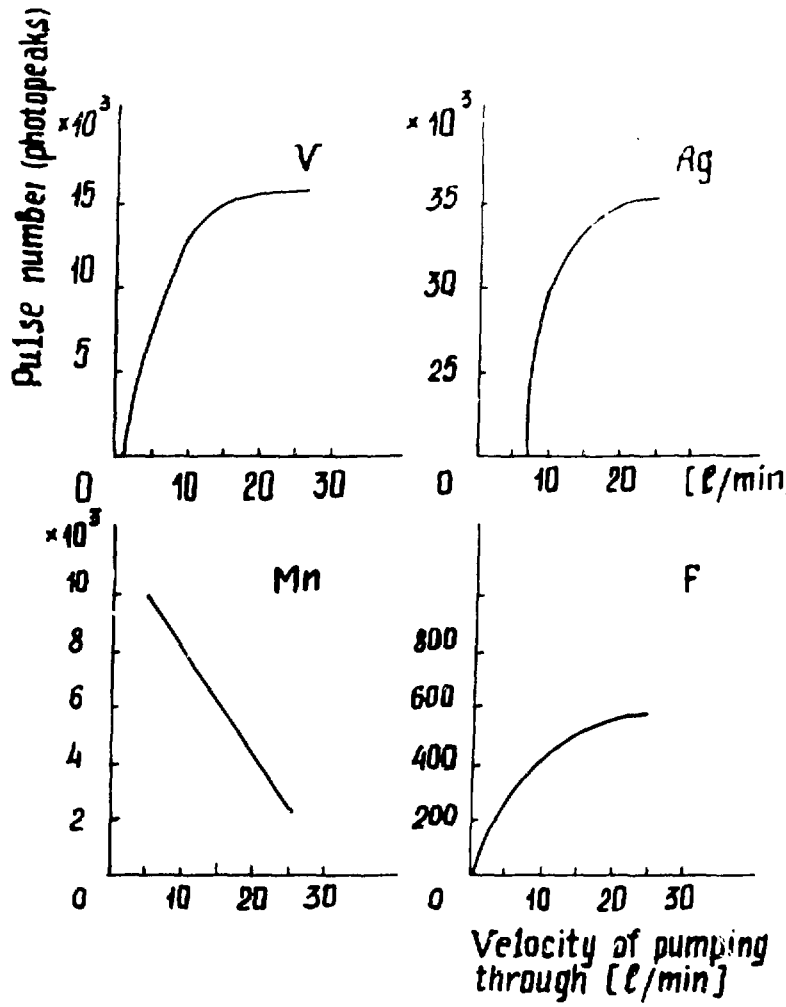

Fig. 6. The dependence of the registered pulse number on the velocity of pumping through solutions to be analyzed.

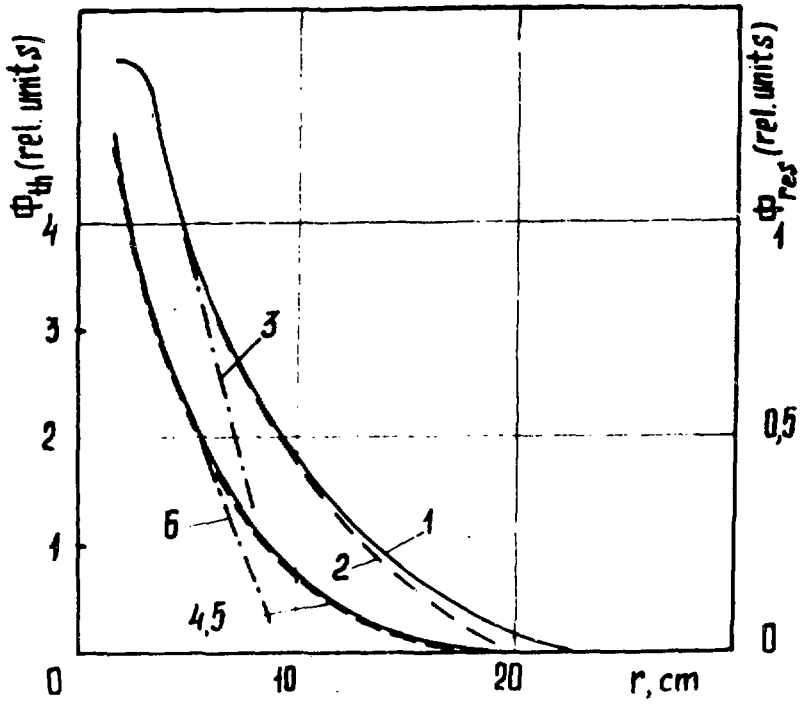

Fig. 7. The space distribution of thermal (curves 1, 2, 3) and epicadmium (curves 4, 5, 6) neutrons produced with neutrons of ^{252}Cf source in a water moderator having sizes 1000 mm (curves 1, 4), 400 mm (curves 2, 5) and 200 mm (curves 3, 6).

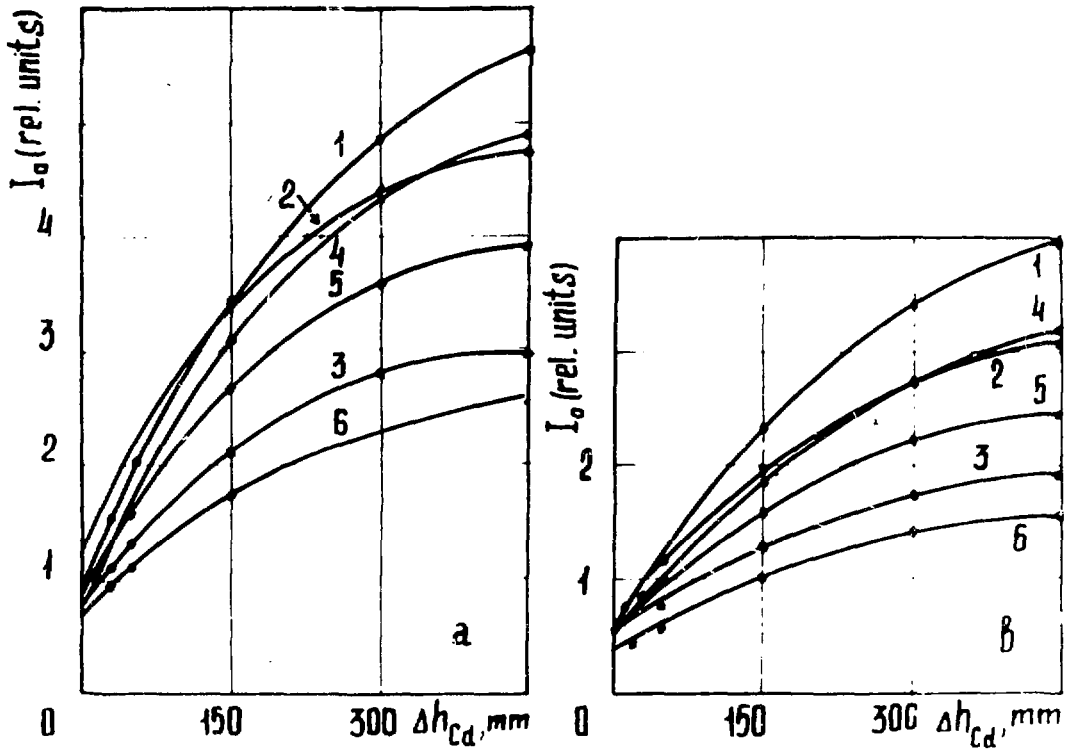

Fig. 8. Effect of the distance between the collimator base having form of a truncated cone and cadmium plating of its walls on slow neutron flux density I_o at the exit of the collimator:
a) collimator base diameter 50 mm; b) 33 mm with the diameter of the exit window 100 mm in both cases:
1, 2, 3 correspond with ^{252}Cf neutron source being on the collimator axis at the distance of 5, 25, and 50 mm from the base; 4, 5, 6 - the same but when the source is shifted from the axis to 30 mm.

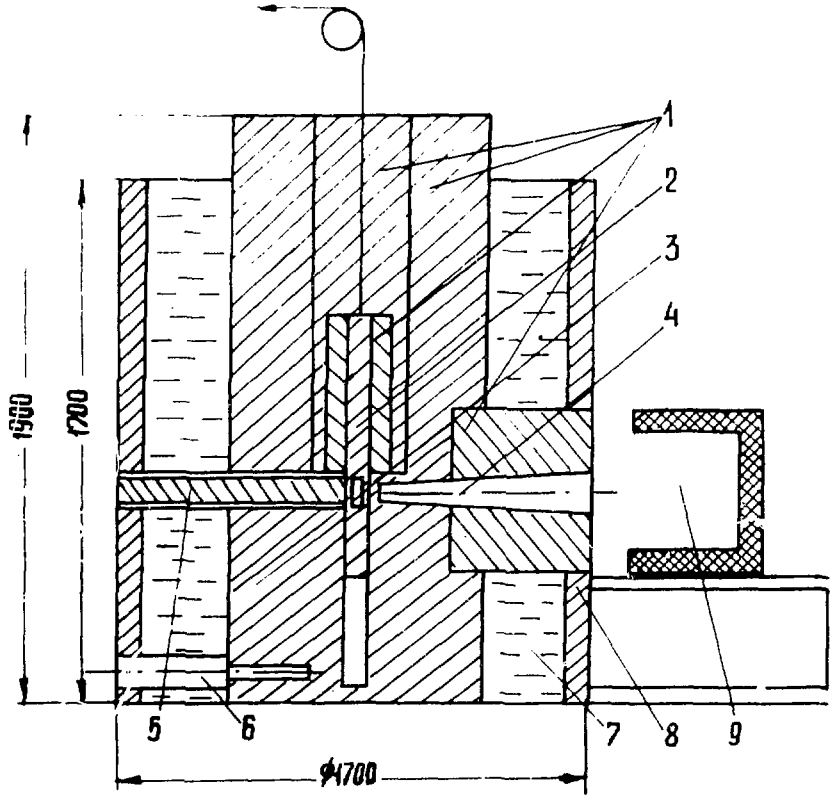

Fig. 9. Neutron radiography facility using radioisotope neutron sources and some charged particle accelerators:
1 - moderator assemblies (paraffin, polyethylene and so on)
2 - holder of the isotope neutron source
3 - isotope neutron source
4 - collimator channel
5 - channel with a plug for arranging ion lead of the charged particle accelerator
6 - monitor arranging channel
7 - shielding (water)
8 - steel body
9 - radiographic chamber (movable)