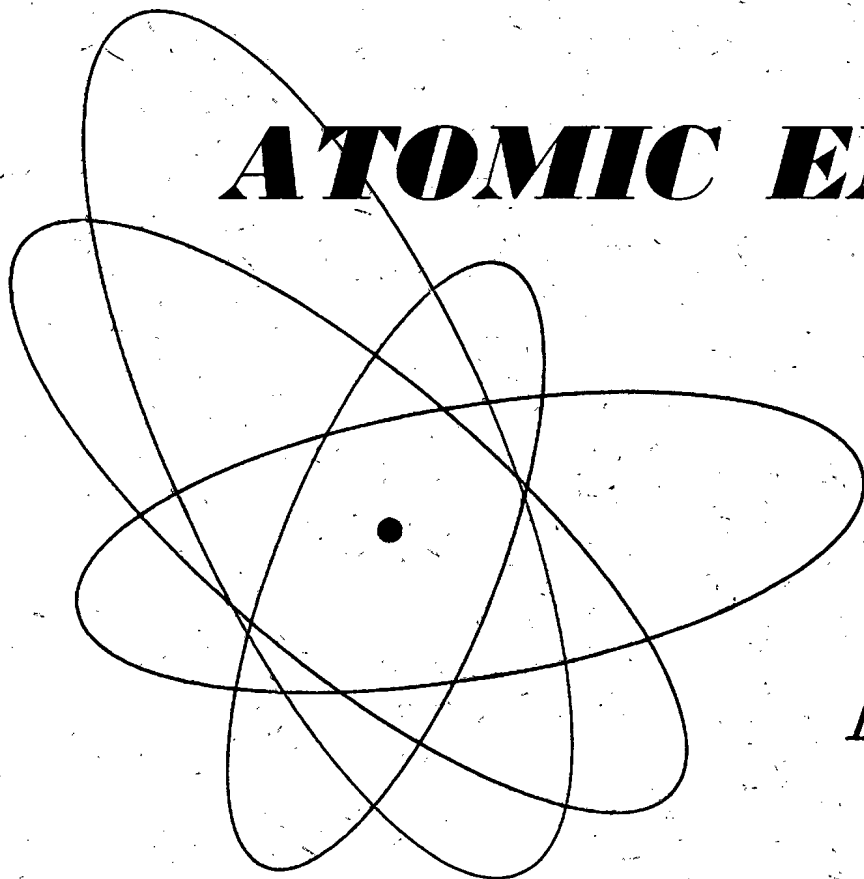


Volume 11, No. 5

May, 1962

THE SOVIET JOURNAL OF

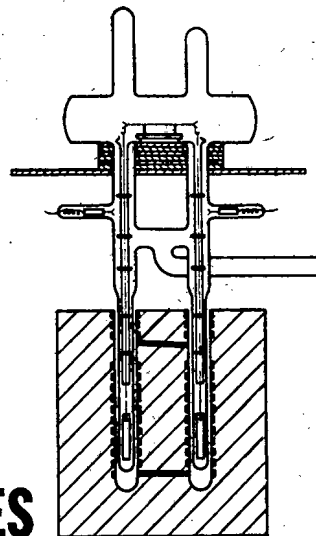
ATOMIC ENERGY



Атомная
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VOLUME I VACUUM MICROBALANCE TECHNIQUES

Proceedings of the 1960 Conference Sponsored by
The Institute for Exploratory Research
U. S. Army Signal Research and Development Laboratory

Edited by
M. J. KATZ

*U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey*

Introduction by
Thor N. Rhodin
Cornell University

The proceedings of this conference provide an authoritative introduction to the rapidly widening scope of microbalance methods which is not available elsewhere in a single publication.

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*A translation of ATOMNAYA ÉNERGIYA,
 a publication of the Academy of Sciences of the USSR*

(Russian original dated November, 1961)

Vol. 11, No. 5

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ON THE DECREASE OF THE ION PULSE DURATION
AND ION PULSE RATE IN A CYCLOTRON

N. I. Venikov

Translated from *Atomnaya Energiya*, Vol. 11, No. 5,
pp. 421-425, November, 1961
Original article submitted March 23, 1961

Results of calculations and experiments dealing with shortening of the duration of ion pulses on the target of a cyclotron are presented. The possibility of changing the ion pulse rate by deflecting with a high frequency potential applied to an electrode inside the dee, which draws off the ions on the first half turn is discussed.

Calculations and experiments were made for the condition of deuteron acceleration up to 10 Mev in the one and one-half meter cyclotron [1].

Shortening the Duration of Ion Pulses

In the case of normal target current intensity (1-10 μ a), minimal duration of the separate accelerated ion pulses is required for resolution improvement in fast neutron time of flight spectrometry [2].

It is possible to decrease the pulse duration both by limiting the interval of the starting phases and by selection of the accelerating condition. A collimator, shown schematically in Fig. 1, which consists of a slotted diaphragm and a narrow channel along the first half turn of the ions, was set up to select a narrow starting phase region of ions in the center of the cyclotron under 10 Mev deuteron accelerating conditions. The collimator was designed to pass ions with starting phases between 0 and $+10^\circ$. This phase region will change in the process of acceleration, during which the character of its charge, for constant potential difference between the dees, will depend on the relative excess of the cyclotron's central magnetic field above the resonance value, i.e., on

$$\delta = \frac{H_0 - H_{res}}{H_{rea}} \%$$

The ion phases and the number of revolutions were calculated for various δ as a function of the radius of acceleration. The extreme starting ion phases which passed through the collimator, i.e., 0 and $+10^\circ$, were used as the extreme starting ion phases. If $\Delta H(R_n)$ denotes the increase of the magnetic field intensity above the resonance value $H_{res}(R_n)$ at the radius R_n then the phase change of an ion on the n th revolution will have the form

$$\Delta\varphi_n = -2\pi \frac{\Delta H(R_n)}{H_{res}(R_n)}, \quad (1)$$

where $H_{res}(R_n)$ depends on the acceleration radius because of the relativistic mass increase.

The ion radius of the n th revolution is determined from the formula

$$R_n = \frac{0.1}{H(R_n)} \sqrt{\frac{E_n}{0.48 \frac{z^2}{A}}}, \quad (2)$$

where E_n is the ion's kinetic energy on the n th revolution equaling

$$E_n = E_{n-1} + 4ZeV_0 \cos \varphi_n, \quad (3)$$

Z and A are the ion charge and mass number respectively; $[E_n]$, $[eV_0]$ are in units of million electron volts; $[H(R_n)]$ is in oersteds; $[R_n]$ is in centimeters.

The calculation showed that, for a dee potential difference of 95 kv and ions with starting phase between 0 and +10°, acceleration to the exit radius was possible only for $\delta = 0.75-1.2\%$ (Fig. 2), during which, according to the calculation, the beam intensity does not vary for a change in δ from 0.8 to 1.1%.

The calculated results were well confirmed by experiments on the cyclotron. The dependence of the beam intensity removed at the exit radius on the cyclotron's magnetic field intensity is given in Fig. 3. A mixture of deuterium and helium ions was fed to the source and the magnetic field was varied, while holding other parameters constant, in order to measure the dependency of I_{D^+} and $I_{He_4^{+2}}$ on H.

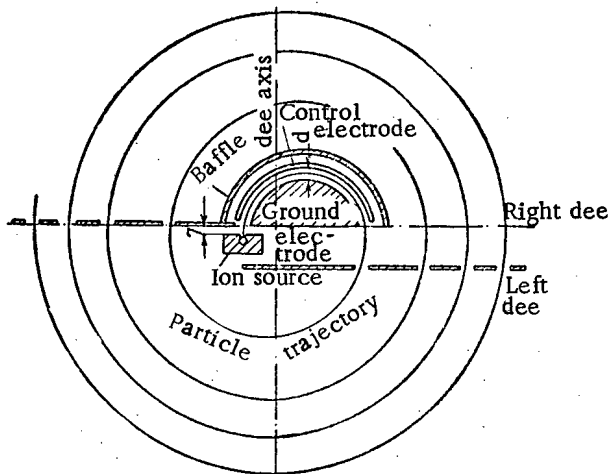


Fig. 1. Schematic of the cyclotron's central region.

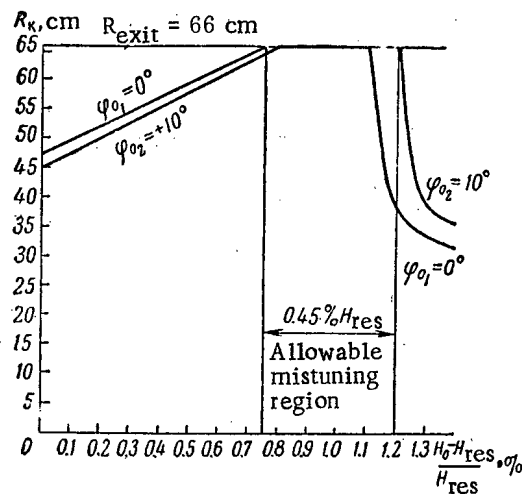


Fig. 2. Dependence of the final acceleration radius on the mistuning of the magnetic field for two ion starting phases (0 and +10°).

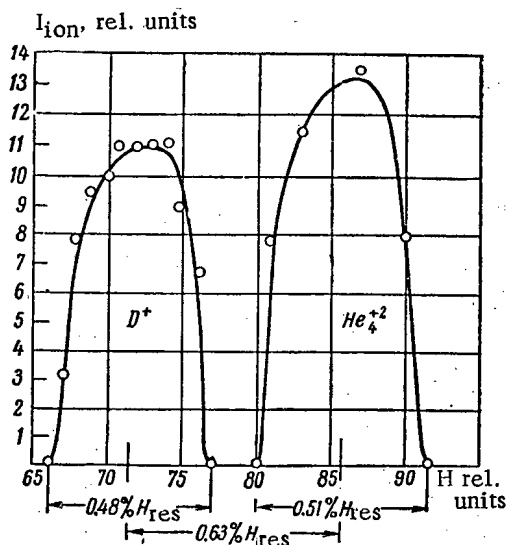


Fig. 3. Dependence of the ion current stripped at the exit radius on the magnetic field. (A mixture of D_2 and He fed to the ion source.)

The distance between the centers of the I_{D^+} and $I_{He_4^{+2}}$ on the abscissa is determined by the corresponding value of A/Z and is 0.63% of H; the full width of the I_{D^+} or $I_{He_4^{+2}}$ peak is about 0.5% (0.45% according to the calculation).

Figure 4 shows the calculated dependence of the ion phases at the exit radius on δ ; the values of the ion phases which were measured with the neutron spectrometer described in reference [4] are plotted by the intersecting straight segments. The abscissa calibration is described above. The height of the segment corresponds to the peak width at a height 0.1 from the maximum intensity. The slope of the calculated curve and the experimental dependence are practically identical. The permitted phase region on an external target is apparently somewhat smaller than calculated since ions with phase close to $\pi/2$ are not able to pass through the deflector because of small spiral pitch ($\Delta R = R_{exit} \frac{2ZeV_0}{E_k} \cos \varphi_k$).

The permissible cyclotron magnetic field instability can be calculated as a function of the allowed ion pulse width from the resulting dependences. An instability in the magnetic field intensity of $2 \cdot 10^{-4}$, which is possible in the cyclotron used, results in a broadening at the target of the ion pulse equal to 1.5% of the high frequency period.

Figure 5 shows the calculated dependence of the ion phase difference at the exit radius on δ . The experimental values fall above the calculated curve apparently because of the inherent spectrometer resolution; however, the nature of the calculated and experimental dependence is practically identical.

For a given magnitude of δ there is a minimum final ion phase difference which corresponds to the case when the final phase of an ion from the center of the phase region under consideration is equal to zero. It is necessary to utilize this circumstance to effect a significant decrease in ion pulse duration at the target without a substantial lessening of the ion current intensity.

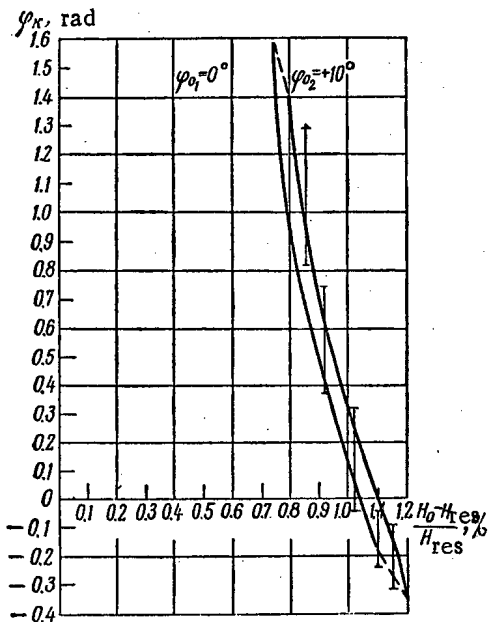


Fig. 4. Dependence of the ion phase at the exit radius on δ . The experimental results (on an external target) are shown by straight line segments.

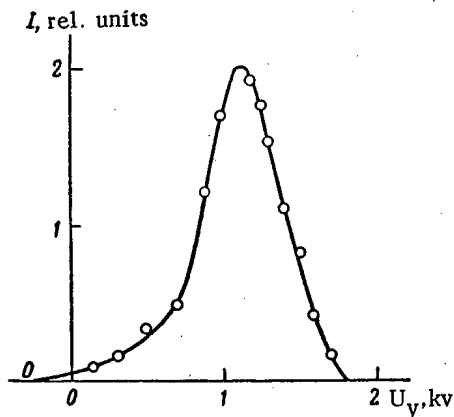


Fig. 6. Target current dependence on the control electrode potential.

In order to reduce this broadening to a minimum without an intensity loss, it is necessary to employ either a two magnet system with a compensating path difference or to decrease the beam dispersion, for example, by using quadrupole magnets.

* The distance of the target from the deflector was 12 cm; the maximum dimension of the beam halfway from the deflector to the target was 10 cm; the average deflection angle was 26° .

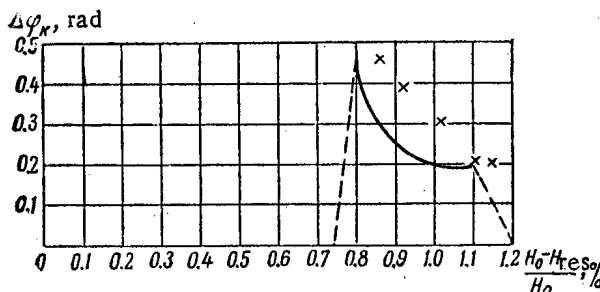


Fig. 5. Dependence of the ion phase difference at the exit radius on δ . Experimental values for an external target are shown by the crosses.

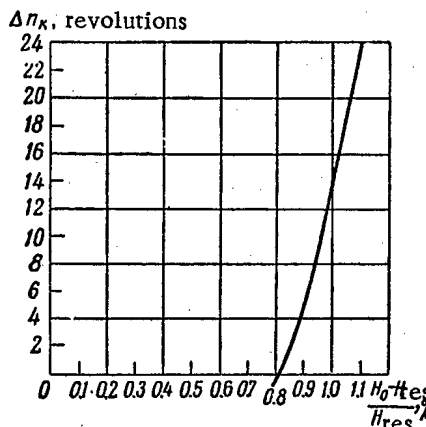


Fig. 7. Dependence of the difference in the number of revolution made by ions with $\varphi_{01} = 0^\circ$ and $\varphi_{02} = +10^\circ$ during their acceleration out to the exit radius on the excess magnetic field at the center above the resonance field.

An additional increase of ion pulse duration on the external target may be produced by the geometrical path difference of the various beam trajectories from the deflector to the target. The "broadening" of the ion pulses at the target* due to the increase of the geometrical path difference was measured for the operating conditions under consideration using a neutron spectrometer and shown to be approximately 4% of the high frequency period. It is possible to reduce the pulse broadening (with a loss of intensity) to a sufficiently small value by stopping down the beam with a simple dia-

In most of the work which was carried out on the cyclotron with the system described, the ion pulse duration at the target was 2-3% of the high frequency period (width at half maximum) for normal (1-10 μ amp) ion current intensity.

Change of the Ion Pulse Rate

It is desirable to decrease the ion pulse rate in order to extend the time of flight spectrometer's range to lower neutron energies. To do this an electrical ion deflector can be employed either after or during acceleration. It would be extremely desirable to effect a beam modulation at the beginning of the acceleration process with an electrostatic system.* A lower voltage is necessary to supply such a system; the system also removes the background from the deflected particles.

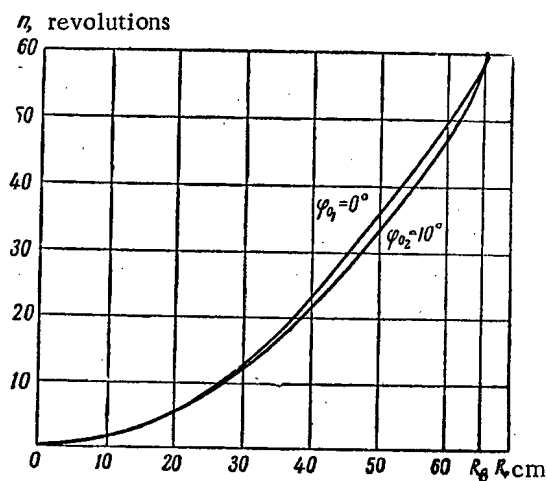


Fig. 8. Variation in the number of ion revolutions as a function of the acceleration radius with

$$\frac{H_0 - H_{res}}{H_{res}} = 0.08\%$$

There was studied and tested in practice a modification for changing the ion pulse rate, which deflected the ions in the first half turn by means of an alternating voltage at one-half the cyclotron's frequency and of about 1 kv amplitude applied to the control electrode (see Fig. 1). The collimator in the cyclotron's center was so designed that it allowed ions in the phase region between 0 and $+10^\circ$ to pass when a negative potential of about 1 kv was applied to the control electrode. With the same positive potential, the collimator did not allow any ions to pass. Figure 6 shows the target current dependence on the fixed potential on control electrode. The potential at which the maximum quantity of ions are allowed to pass corresponds to the calculated value. When a high frequency potential in proper phase with the high frequency dee voltage is applied to the control electrode, the collimator passes every second ion pulse. Thus the ion pulse rate in the central region of the cyclotron was decreased by a factor of two.

Unfortunately, this still does not mean a decrease in the ion pulse rate in the beam issuing from the cyclotron. Ions, which leave the source in different phases of the dee accelerating voltage, in general, make a different number of revolutions during acceleration out to the exit radius. For the system described, with $2V_0 = 95$ kv, the difference in the number of revolutions made by ions with starting phases between 0 and $+10^\circ$ during acceleration out to the exit radius was calculated to be between 0-24 depending on the magnetic field adjustment (Fig. 7). Because of the variation in the number of revolutions, the ion pulse rate striking on the target is the same as the cyclotron frequency. Ions with starting phases between 0 and $+10^\circ$ make an identical number of turns out to the exit radius when the central magnetic field is a certain amount higher (in this system at $\delta = 0.8\%$) than the resonance value (Fig. 8). In this case a decrease by one half in ion pulse rate should be observed. The experiments which were carried out showed that such a decrease in the ion pulse rate (actually very unsteady) is observed, but careful tuning and a high degree of stability are required of the cyclotron parameters.

The allowable instability in the magnetic field intensity for the system described was calculated to be equal to $0.7 \cdot 10^{-4}$, and the allowed high frequency dee voltage amplitude instability was $4 \cdot 10^{-3}$. The maintenance of these limits should guarantee a steady "skipping" for a given tuning of the magnetic field. Both tolerances are less than the accuracy of the stability secured from the stabilizing apparatus on the cyclotron used.

It is quite obvious, that the stability requirements are simplified by decreasing the ion starting phase region and in the limiting case of an infinitely narrow phase region there will be no "mixing." All this indicates that at the present time one should change the ion pulse rate on the target by deflecting ions which are accelerated up to full energy, for example, as is suggested in reference [6].

The authors deeply thank N. A. Vlasov, S. P. Kalinin, B. V. Rybakov, and V. A. Sidorov for sustained interest in the work and their joint discussion of it; N. I. Chumakov, V. P. Konyaev, and G. N. Golovanov for making a series of calculations; Yu. V. Korshunov, A. V. Antonov, and E. A. Meleshko for the design and adjustment of the electronic apparatus for the control electrode supply.

* Reference [5] suggests the production of a modulated beam by sufficiently short pulses on the deflection system near the ion source.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

THE CALCULATION OF HEAT TRANSFER IN TUBES
FOR THE TURBULENT FLOW OF LIQUIDS WITH SMALL
PRANDTL NUMBERS ($Pr \ll 1$)

V. M. Borishanskii, N. I. Ivashchenko, and T. V. Zablotskaya

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,
pp. 426-430, November, 1961

Original article submitted December 29, 1960

A method is described for calculating the heat transfer in turbulent flow for a three-layer thermal model with $Pr \ll 1$. A comparison is made of the results of the three-layer calculation of the temperature field with results obtained from experiment.

Heat transfer in the turbulent flow of a liquid in a tube for $Pr \ll 1$ is most often treated by using the two-layer (Prandtl-Taylor) or three-layer (Von Karman-Shvab) dynamic-flow model. It is assumed in this theory that the transfer of heat and momentum in the laminar sublayer is determined by molecular processes, in the turbulent core it is determined by molar transfer, and in the transitional layer (in the three-layer model) by both processes. In liquid metals, when $Pr \ll 1$, it is also necessary to take into account the molecular transfer in the dynamic-turbulent-core region. This was done analytically in the work of Martinelli [1]. Lyon, in [2], simplified the methods of calculating heat transfer by introducing integral relations for the calculation of the temperature field. At the same time, the works of Pohlhausen [3], Schlichting [4], Kruzhilin [5], Shvab [6], and others, in combination with the idea of a dynamic layer, led to the conception of the thermal layer. In calculations, in this case, the question arises of the difficulty of taking into account the fact that the boundaries of the dynamic and thermal layers are not the same.

The general theory for liquid metals was developed by Levich in [7]. For the calculations the latter proposed the two-layer thermal model and its superposition on the two-layer dynamic model. Calculations using this method yield only a qualitative agreement with experimental results on heat transfer in liquid metals. In the present work an attempt is made to develop this theory by introducing the idea of the three-layer thermal model that was proposed by Borishanskii in [8].

The Three-Layer Model for Heat and Momentum Transfer

In the calculation of heat transfer in a cross section of the flow, we will use the following three-layer model:

- 1) a thermal sublayer with molecular heat transfer;
- 2) an intermediate thermal layer with molecular and turbulent transfer;
- 3) a turbulent thermal core, where the heat transfer occurs only as the result of turbulent transfer.

Momentum transfer is assumed to occur as in the usual three-layer model, where the boundaries of the dynamic regions are taken to be equal to [4]

$$\eta_{d1} = \frac{y_{d1} v^*}{\nu} = 5; \eta_{d2} = \frac{y_{d2} v^*}{\nu} = 30, \quad (1)$$

where $v^* = \sqrt{\frac{\tau_w}{\rho}}$ is the dynamic velocity (here τ_w is the tangential stress at the tube wall and ρ is the density of the heat-transfer medium); y is the distance from the tube wall; ν the kinematic viscosity; $\eta_d = (y v^* / \nu)$ the non-dimensional distance from the tube wall used in describing the velocity field; the subscripts d1 and d2 denote respectively the boundary of the dynamic sublayer and the boundary of the dynamic turbulent core. The boundaries of the thermal sublayer and the thermal turbulent core can be determined from the following considerations:

1. We can assume that in the flow zone, relative to both the dynamic and thermal development of the turbulent core, there is similarity of the non-dimensional differences of the temperature and velocity. Analytically, this can be expressed by the relation

$$\varphi = \frac{1}{\kappa} \ln \frac{\eta}{\eta_2} \tag{2}$$

In the consideration of the temperature field we have

$$\varphi = \varphi_T = \frac{t - t_{T2}}{t^*}, \quad \eta = \eta_T = \frac{yv^*}{a},$$

while for the velocity field

$$\varphi = \varphi_d = \frac{w - w_{d2}}{v^*}, \quad \eta = \eta_d = \frac{yv^*}{\nu}.$$

Here t is the temperature, $t^* = \frac{q}{C\gamma v^*}$ the dynamic temperature (where q is the thermal load, C the specific heat, and γ the density of the heat-transfer medium); a the temperature transfer coefficient; η_T the non-dimensional distance from the tube wall, used in obtaining the temperature field; w the velocity at the distance R from the center of the tube; and κ the turbulence constant.

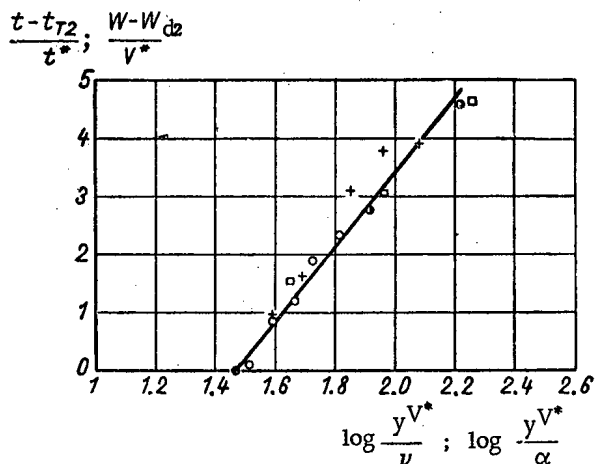


Fig. 1. Comparison of experimental measurements of temperature and velocity in the turbulent core. Temperature field for mercury: \circ) $Re = 119 \cdot 10^3$ [9]; $+$) $Re = 290 \cdot 10^3$ [10]. Velocity field for water [11]; \bullet) $Re = 396 \cdot 10^3$; \square) $Re = 205 \cdot 10^3$; $-$) graph for the relation $\varphi = \frac{1}{\kappa} \ln \frac{\eta}{\eta_2}$ for $\kappa = 0.4$.

From the similarity of the fields of the temperature difference and the velocity difference [the formula (2)], it follows that in the turbulent thermal core we will have the relation

$$\eta_T = \eta_d, \tag{2'}$$

from which it follows that the boundary of the thermal turbulent core is given by the expression

$$y_{T2} = y_{d2} \frac{1}{Pr}, \tag{3}$$

where $Pr = \nu/a$, and the subscript T2 indicates the boundary for the thermal turbulent core. For the confirmation of this assumption, we show in Fig. 1, using non-dimensional coordinates $\varphi = f(\eta)$, a comparison of the results of measurements of temperature fields in a current of mercury [9, 10] and for measurements of velocity fields in a current of water [11]. The continuous line was obtained from the formula (2) with $\kappa = 0.4$. It can be seen that, in the region of developing turbulent flow, temperature-field and velocity-field measurements are in completely satisfactory agreement.

These same values are shown in Fig. 2 in the coordinates $(t_A - t)/t^* = f(y/R_0)$ and $(w_A - w)/v^* = f(y/R_0)$, where the subscript A denotes values at the axis of the tube, and w is the velocity at a distance y from the wall, while R_0 is the internal tube radius.

In the turbulent thermal core ($\frac{y}{R_0} > \frac{y_{T2}}{R_0}$), the non-dimensional temperatures and velocities agree. This shows that in the region of the developed thermal turbulence core the relation (2') actually holds.

The position of the dotted line y_{T2}/R_0 in Fig. 2 was obtained from (3) for $y_{d2} = 30\nu/v^*$.

2. Pohlhausen in [3], for the calculation of the heat transfer under the conditions prevailing in the laminar boundary layer in flow about a plate for $Pr \gg 1$, found that the ratio of the thickness of the dynamic layer to that of the thermal layer was equal to $Pr^{1/3}$ with a reasonable degree of accuracy. The validity of applying this relation in the case of the flow of a liquid metal ($Pr \ll 1$) about a plate was verified by Kutateladze and Fedorovich in [12]. In the present work this consideration, relative to the boundary between the thermal sublayer and the intermediate thermal layer, leads to the formula

$$y_{T1} = y_{d1} \frac{1}{Pr^{1/3}}, \tag{4}$$

where $y_{d1} = \eta_{d1} \frac{\nu}{v^*} = \frac{5\nu}{v^*}$ and the subscript T 1 denotes the boundary of the thermal sublayer. The application of this relation to flow in a tube must, of course, be considered only as one of the possible numerical approximations and subject to further improvement.

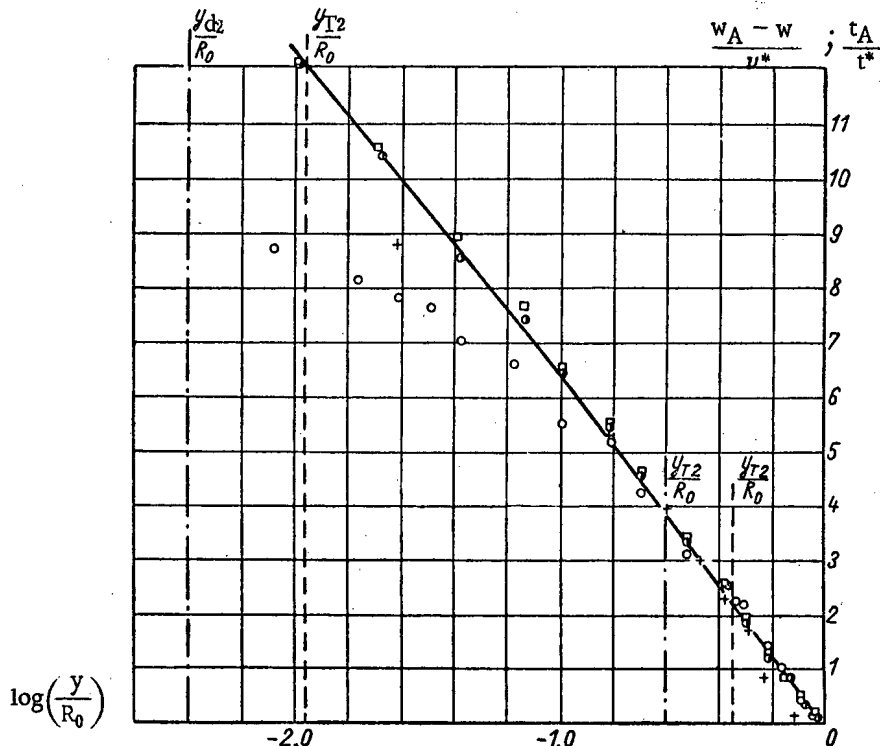


Fig. 2. Temperature and velocity distributions in the flow from experimental results. Temperature field for mercury: ○) $Re = 119 \cdot 10^3$ [9]; +) $Re = 290 \cdot 10^3$ [10]. Velocity field for water [11]: ●) $Re = 396 \cdot 10^3$; □) $Re = 205 \cdot 10^3$; —) mean line; - - - -) boundaries of the layers for $Re = 119 \cdot 10^3$; - · -) boundaries of the layers for $Re = 290 \cdot 10^3$.

Calculation of the Heat Transfer and the Temperature Field

The heat-transfer coefficients and the temperature fields were calculated by using the integral relations proposed in [2], which in the present case are

$$Nu = \frac{1}{2} \left[\int_0^{\xi_{T2}} \frac{\left(\int_0^{\xi} \omega \xi d\xi \right)^2}{\epsilon Pr \frac{\mu_T}{\mu} \xi} d\xi + \int_{\xi_{T2}}^{\xi_{T1}} \frac{\left(\int_0^{\xi} \omega \xi d\xi \right)^2}{\xi \left(1 + \epsilon Pr \frac{\mu_T}{\mu} \right)} d\xi + \int_{\xi_{T1}}^1 \frac{\left(\int_0^{\xi} \omega \xi d\xi \right)^2}{\xi} d\xi \right]^{-1}; \tag{5}$$

$$\frac{t_w - t}{t_w - t} = Nu \left[\int_{\xi}^{\xi_{T2}} \frac{\int_0^{\xi} \omega \xi d\xi}{\epsilon Pr \frac{\mu_T}{\mu} \xi} d\xi + \int_{\xi_{T2}}^{\xi_{T1}} \frac{\int_0^{\xi} \omega \xi d\xi}{\xi \left(1 + \epsilon Pr \frac{\mu_T}{\mu} \right)} d\xi + \int_{\xi_{T1}}^1 \frac{\int_0^{\xi} \omega \xi d\xi}{\xi} d\xi \right]. \tag{6}$$

Here $\epsilon = \frac{1}{Pr_T}$; $\xi = \frac{R}{R_0}$ is the non-dimensional radius (R is the variable, dimensional distance from the axis); μ the dynamic viscosity coefficient; $\omega = \frac{w}{\bar{w}}$, where \bar{w} is the mean velocity over the section. Here the non-dimensional boundaries between the layers are given by the relations

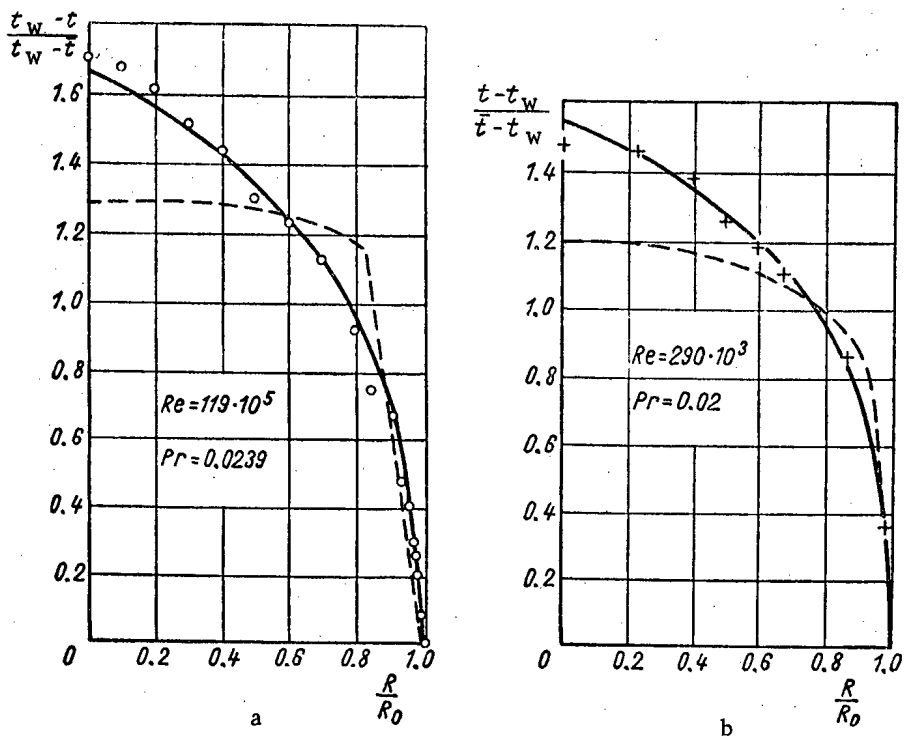


Fig. 3. Comparison of the calculated temperature field with experimental results. [a) $Re = 119 \cdot 10^3$; $Pr = 0.0239$; b) $Re = 290 \cdot 10^3$; $Pr = 0.02$]: ———) calculated from the three-layer thermal model; - - - -) calculated from the two-layer thermal model; O) experiments in heating mercury [9]; +) experiments in the cooling of mercury [10].

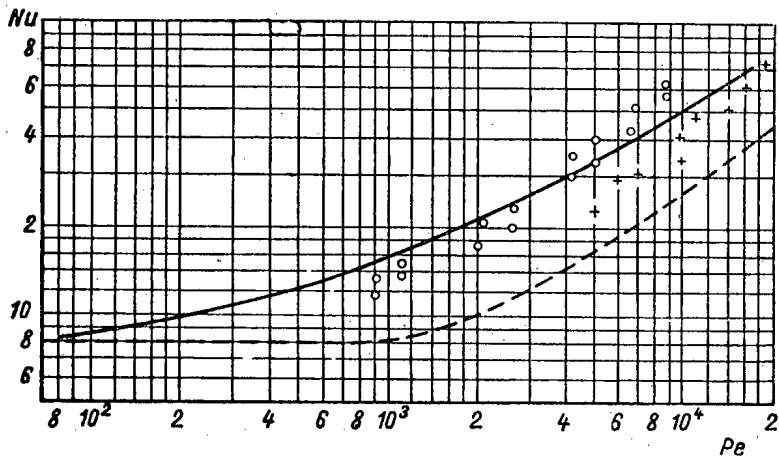


Fig. 4. Comparison of calculated and experimental results for heat transfer; ———) calculated from the three-layer thermal model [Formula (5)]; - - - -) calculated from the two-layer thermal model [7]; O, +) results taken from [9] and [10] respectively (experiments with mercury).

$$\xi_{r1} = 1 - \frac{10}{Re Pr^{1/3} \sqrt{\xi/8}}; \tag{7}$$

$$\xi_{r2} = 1 - \frac{60}{Re Pr \sqrt{\xi/8}}; \tag{8}$$

Calculations were made for the conditions

$$\tau = \tau_w \frac{R}{R_0} \text{ and } \frac{\omega}{v^*} = A \ln \frac{yv^*}{\nu} + B. \quad (9)$$

For the dynamic turbulent core the values $A = 2.5$ and $B = 5.5$ were used, and for the dynamic transitional region $A = 5$ and $B = -3.05$.

The integrals were calculated with the difference between the boundaries of the thermal and dynamic layers taken into account, and with a corresponding choice of the equations for the velocity distribution in the determination of μ_T / μ . The physical properties of the flow were determined for its mean temperature.

The Comparison of Calculated with Experimental Results

The results of temperature-field calculations using (6), in terms of coordinates in the formula

$$\frac{t_w - t}{t_w - t} = f\left(\frac{R}{R_0}\right)$$

are shown in Fig. 3. Experimental results from [9] and [10] are also shown. It can be seen from the figure that the calculated curves obtained from the three-layer model of heat transfer, are quite well confirmed by the experimental results.

A comparison is shown in Fig. 4, in the coordinates $Nu = f(Re)$, of the calculated and experimental results for mercury [9, 10]. The upper curve was obtained by calculation from the formula (5), while the lower was obtained by calculation from the double thermal model [7], assumed in the present case to be a first approximation. It is evident from the diagram that the experimental results are in good agreement with the calculated results. Here we must point out the fact that the heat-transfer coefficient was calculated from the formula (5), in which the velocity profile is given in semilogarithmic form. In the range where $Re < 100 \cdot 10^3$, in calculations using directly the measured velocity fields [11], there was observed a lowering of the calculated line by 10-15% and an improved agreement with experiment. A similar improvement in accuracy for this range of the Reynolds number is at the present, however, hardly likely to be useful, because of the effect on the absolute value of the heat-transfer coefficient of the so-called thermal resistance, essentially related to the physical-chemical conditions of the process (the content in the metal of oxygen, impurities, contamination from the wall, etc). Such effects are less strongly felt in mercury, and so the experimental results in [9, 10] have been used for comparison.

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THE USE OF ION-EXCHANGE MATERIALS FOR THE PRE-
PARATION OF LOW ACTIVITY RADIATION SOURCES

B. A. Zaitsev, A. I. Grivkova, and M. P. Glazunov

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,
pp. 431-434, November, 1961

Original article submitted January 30, 1961

This article describes the preparation of low-activity radiation sources by the sorption of isotopes on ion-exchange resins and membranes of any shape. Due to the limited radiation stability of organic ion-exchange materials, shown by the noticeable gas evolution, they should be heated before the ampoule is sealed and in the preparation of sources with a specific activity greater than 1.2 C/g a small amount of metallic palladium should be placed in the ampoule to absorb the liberated hydrogen. The universality of ion-exchange processes makes it possible to obtain sources of various radioactive isotopes by this method.

Methods for preparing low-activity radiation sources have been discussed in a number of papers [1-13]. The most reliable are methods based on the preparation of radioactive glasses and enamels [3, 7-9]. However, high-temperature processes are not suitable for all elements and the automation of the preparation of sources then involves a number of difficulties.

The use of sorption processes is very promising for the preparation of sources [10]. The use of sheet plastic for the preparation of flat radiation sources is of interest [11-13].

The present paper considers the use of organic ion-exchange materials for this purpose. For the preparation of volume sources the radioisotope is sorbed by a cation-exchange, the granules of which are in the form of spheres. Flat radiation sources can be prepared on the basis of ion-exchange films and membranes.

Experimental Part

Sulfophenol-formaldehyde cation-exchange material KU-1G (granulated) (Fig. 1) was obtained from the Plastics Institute (Scientific Research Institute for Plastics). Spheres with diameters from 0.25 to 1.50 mm were used, density 1.33 g/cm³. The static exchange capacity for a 0.1 N solution of calcium chloride is 2.3 mg · eq/g and for 0.1 N solution of caustic soda 4.8 mg · eq/g.

The specimens of the DPU ion-exchange membrane and the MK-2 film were also provided by the Plastics Institute. Their densities were 67.8 and 3.8 mg/cm² and the exchange capacities for a solution of cesium chloride were 0.123 and 0.0063 mg · eq/cm² respectively. DPU is a finely divided cation-exchange material KU-2 with polyethylene as the binding material [14]. A film of MK-2 was also prepared on the basis of a cation-exchange material containing sulfo groups.

The γ -radiator was Cs¹³⁷, separated from a mixture of fission products. This choice was due to the long half-life of Cs¹³⁷ (29.5 years), which makes it possible to obtain sources of radiation with a high service life. However, it should be mentioned that the universality of exchange properties of ion-exchange materials means that radiation sources can be prepared from many other radioactive elements by a similar method. In particular, the use of radioactive elements with a short half-life makes it possible to obtain sources with a correspondingly high dose rate, although the service life of these sources will be less with an equal integral dose of absorbed radiation.

The cesium chloride preparation contained about 50% of impurities of rubidium, potassium, and sodium chlorides and had a specific activity of about 13 C/g. The content of radioactive impurities did not exceed 0.1% and was determined by radiochemical and γ -spectrometric methods.

Before the sorption of the radioisotope the ion-exchange material was first prepared. Using special sieves spheres of KU-1G of the same size were selected; discs and strips were cut from the sheet ion-exchange material. The ion-

TABLE 1. Maximum Values of Specific Activity of Ion-Exchange Materials as a Result of Sorption of Cs¹³⁷

Ion exchange material	Exchange capacity for 0,15 N solution of CsCl	Specific activity	
KU-1 G*	2.4 mg · eq/g	4.1 g · eq Ra/g	9.8 C/g
KU-1 G**	3.6 mg · eq/g	6.3 g · eq Ra/g	15.1 C/g
DPU	0.123 mg · eq/cm ²	0.215 g · eq Ra/cm ²	0.516 C/cm ²
MK-2	0.006 mg · eq/cm ²	0.011 g · eq Ra/cm ²	0.026 C/cm ²

* H-form, neutral medium.

** Na-form, 0.032 N solution of NaOH

exchange material was then converted to the H- or Na-form and washed with water. The sorption was carried out under static conditions from a solution of cesium chloride. In experiments with a 0.15 N solution of cesium chloride labeled with Cs¹³⁷, possible values of the specific activity of ion-exchange materials were determined (Table 1). With a maximum specific activity equal to 6.3 g · eq Ra/g on a separate sphere of KU-1G cation-exchange material of diameter 1.5 mm it is possible to apply 35.5 mC of Cs¹³⁷ (Table 2).

After sorption of the radioisotope the ion-exchange material was dried and placed in sealed ampoules.

An advantage of the method is the possibility of applying the radioisotope to particles of sorbent having a definite shape. The same size of particles and their regular shape makes it possible to measure out the active material by the number of particles. The amount of dust is kept to a minimum. Separate spheres of diameter 1-3 mm can be a base for the preparation of "point" sources of radiation. By this method we obtained experimental sources of γ -radiation of low activity from Cs¹³⁷ (Fig. 2).

The insufficient stability of organic ion-exchange materials to the action of radiation can lead to the formation of gases and an increase in pressure in the ampoule. The dose rate for KU-1G with a specific activity with respect to Cs¹³⁷, equal to 1 g · eq Ra/g can be $1.96 \cdot 10^{16}$ ev/g · sec, if it is assumed that the β -radiation is completely absorbed by the cation-exchange material and the absorption of γ -quanta can be neglected in view of the small dimensions of the spheres and their low density.

In this connection experiments were conducted to determine the amount of gas evolved by the KU-1G cation-exchange material as a function of the absorbed dose. The radiation was carried out by two methods. The first of them consisted of preparing the KU-1G spheres, sorbing Cs¹³⁷ up to a specific activity of 3.3 g · eq Ra/cm³. The total activity was 0.0043 g eq Ra, dose rate $2.81 \cdot 10^{16}$ ev/g · sec. With the second method the sample of cation-exchange material (1.0 g) was irradiated with accelerated electrons with an energy of

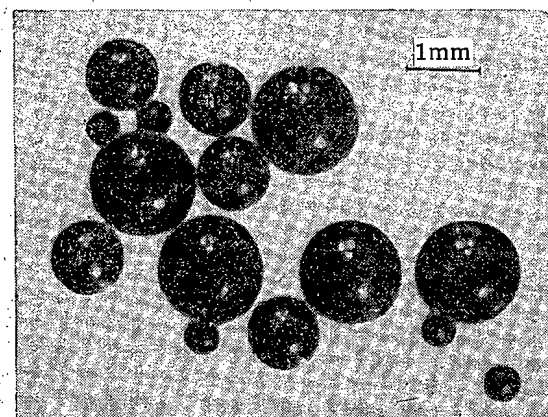
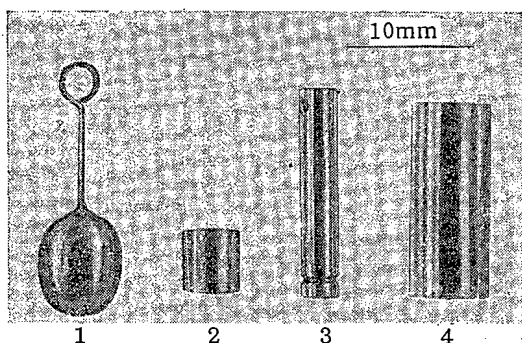


Fig. 1. Cation-exchange material KU-1G in the form of spheres.

Fig. 2. Specimens of sources of γ -radiation from Cs¹³⁷: 1) Standard point source; 2, 4) sources for instruments; 3) applicator for use in medicine.

0.8 Mev in the accelerator of the Institute of Physical Chemistry, Academy of Sciences, USSR. With the selected operating conditions the integral dose in 1 1/2 hr was $0.92 \cdot 10^{23}$ ev/g.

TABLE 2. Dependence of Activity of KU-1G Spheres on Their Size

Diameter, mm	Activity	
	mg · eq Ra	mC
0.25	0.068	0.163
0.50	0.545	1.310
1.00	4.400	10.550
1.50	14.850	35.640

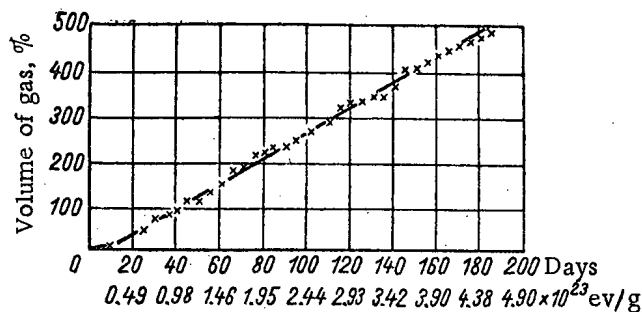


Fig. 3. Dependence of the volume of gas evolved from KU-1G on the absorbed dose.

TABLE 3. Effect of Preliminary Heating of KU-1G on the Volume of Gas Liberated During Irradiation

No. of experiment	Temperature of heating, °C	Time of heating, hr	Character of irradiation	Absorbed dose, ev/g	Volume of liberated gas, % of volume of KU-1G
1	170	3	Internal	$0.44 \cdot 10^{23}$	55
2	170	6	External	$0.92 \cdot 10^{23}$	48
3	400*	6	External	$0.92 \cdot 10^{23}$	13

* Cesium does not evaporate under these conditions.

The cell with the cation-exchange material was filled with nitrogen. During the experiment the temperature was kept at 55-65°C. In both cases the amount of liberated gas was measured by the movement of a drop of mercury in a calibrated horizontal capillary, one end of which was connected to the irradiated cell and the second to a buffer volume, considerably exceeding the volume of the cell. In this way the whole system was isolated from the atmosphere. The accuracy of the volume measurements of the evolved gas by both methods was about 4% of the volume of the cation-exchange material, and the absolute value in the first experiment was 0.05 mm³ and in the second 50.0 mm³.

In the experiment by the method of "internal" radiation the cation-exchange material after sorption of Cs¹³⁷ was dried for 3 hr at a temperature of 170°C. The experiment continued for 180 days. The integral dose was $4.38 \cdot 10^{23}$ ev/g. The evolution of gas occurred at a practically constant rate equal to 0.04 mm³/day, which corresponds to 2.9% of the volume of the cation-exchange material (Fig. 3). This method does not require complicated apparatus for accelerating the electrons; however the dose rate is insufficiently high, which considerably prolongs the time of the experiment.

The method of "external" irradiation was used to check the effect of preliminary heating the cation-exchange material on the amount of gas formed during irradiation (Table 3). The reduction in gas evolution after heating of the cation-exchange material is due to the more complete removal of water and presumably to the known similarity in the action of heating and radiation on ion-exchange materials, expressed in the formation of additional transverse bonds. Although preliminary heating considerably reduces the rate of gas evolution, the danger of an increase in pressure inside the ampoule is not completely eliminated.

According to literature data the increase in gas volume during irradiation of polymers in the absence of air is due mainly to the formation of hydrogen [15]. Using the properties of palladium to dissolve large quantities of hydrogen could prevent the increase in pressure in the ampoule of the source. This possibility was checked in an experiment similar to experiment No. 3 of Table 3, but in the presence of 15 mg of Pd-black. In this case there was no increase in volume of the gas in the cell.

It follows from the obtained results that ion-exchange materials which have sorbed a radioisotope must be heated before the ampoule is sealed. When using a material with a specific activity higher than 0.5 g · eq Ra/g (1.2 C/g) a few milligrams of metallic palladium should be placed in the ampoule.

Other cation-exchange materials having particles with a regular shape, for example KU-6f (spheres) can also be used for the preparation of sources. The results for the test of KU-2 (spheres), due to splitting of particles during swelling, were less successful. It is possible that inorganic ion-exchange materials can be used, for example, zirconium and titanium phosphates, etc. However, allowance must be made for the possibility of dust formation due to the insufficient mechanical strength of the granules of these ion-exchange materials.

An MK-2 film can serve as a base for β -radiation sources, since the self-absorption in it and consequently the radiation action on the film are small. The uniformity of distribution of the radioisotope over the area of the ion-exchange disc, according to the data of Sokolov and Kondrat'eva [13], is fairly good.

SUMMARY

1. A method has been described for preparing sources of β -, γ -radiation with low activity using ion-exchange materials.

2. Conditions have been developed for preparing sources of γ -radiation from Cs^{137} .

On the basis of KU-1G cation-exchange material and the DPU and MK-2 ion-exchange membranes, materials can be obtained with specific activities with respect to Cs^{137} equal to $5 \text{ g} \cdot \text{eq Ra/g}$, $0.215 \text{ g} \cdot \text{eq Ra/cm}^2$, and $0.011 \text{ g} \cdot \text{eq Ra/cm}^2$ respectively.

3. A study has been made of the effect of radiation on the gas evolution from KU-1G cation-exchange material, and a method has been suggested for reducing the amount of gas in the ampoule of the source to a safe level.

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ON THE SEPARATION OF LITHIUM ISOTOPES BY THE METHOD
OF MOLECULAR DISTILLATION OF LIQUID LITHIUM

V. A. Malyusov, V. Yu. Orlov, N. A. Malafeev,

N. N. Umnik, and N. M. Zhavoronkov

Translated from *Atomnaya Energiya*, Vol. 11, No. 5,

pp. 435-439, November, 1961

Original article submitted July 14, 1960

This study determines the value of the separation factor of lithium isotopes in the evaporation of liquid metallic lithium in a single-stage still. At a temperature of 500°C the value of the separation factor is 1.08 ± 0.02 . We carried out studies of the separation of lithium isotopes by the method of molecular distillation in an 8-stage cascade-type metal still. It was shown that when the cells of the still are filled with metallic packing and the condensation temperature of the lithium is raised to 350°C, the efficiency of one stage of the still is 0.4-0.5.

An important task of present-day nuclear technology [1] is the separation of the isotopes of certain elements, and among these elements lithium is distinguished by the absence of thermostable gaseous and highly volatile liquid compounds, as a result of which the separation of lithium isotopes cannot be carried out by such methods as rectification, gas-liquid chemical exchange, gaseous diffusion, and thermal diffusion. The isotopes of lithium have been separated by ionic migration in salt melts [2], by chemical exchange in two-stage liquid-liquid systems [3, 4], and by an electromagnetic method [5]. One of the few processes which give a sufficiently high separation factor of lithium isotopes is the molecular distillation of the liquid metal. In the present study* the value of the separation factor was determined experimentally, and the possibility of using multi-stage cascade-type stills for obtaining enriched lithium isotopes was also investigated. A similar study, published in 1957, was carried out by Trauger et al. [6].

In ideal liquid binary mixtures (and a mixture of lithium isotopes may be considered to be such) the theoretical value of the separation factor for molecular distillation is

$$\alpha_M = \frac{p_1^0}{p_2^0} \sqrt{\frac{M_2}{M_1}}, \quad (1)$$

where p_1^0 and p_2^0 are the vapor pressures; M_1 and M_2 are the masses of the Li^6 and Li^7 atoms respectively. The ratio of the square roots of the masses for the isotopes of lithium is equal to 1.080; the ratio of the vapor pressures may be calculated for the triple point by a statistical method using the Debye characteristic temperature Θ [7]. The value p_1^0/p_2^0 is determined by means of the expression

$$\ln \frac{p_1^0}{p_2^0} = \frac{3}{40} \frac{\Delta M}{M} \left(\frac{\Theta}{T} \right), \quad (2)$$

where T is the absolute temperature of the triple point.

Taking $\Delta M/M = 1/6$ and $T = 453.7^\circ\text{K}$ [8], for $\Theta = 360^\circ\text{K}$ [9], we find $p_1^0/p_2^0 = 1.008$, and for $\Theta = 393^\circ\text{K}$ [8] $p_1^0/p_2^0 = 1.009$. Thus, the separation factor of the lithium isotopes in molecular distillation must be of the order of 1.09. It should be remarked that in the experiments of Trauger et al. [6] no difference was found in the vapor pressures of Li^6 and Li^7 .

Experiments to determine the separation factor were carried out in a cylindrical apparatus (molecular still) with a diameter of 200 mm, made of EYa-1-T stainless steel (Fig. 1). The still was evacuated through the nozzle 1

* The work was carried out in 1955-1956. I. V. Aristova and N. P. Abramova participated in the experiments.

TABLE 1. Data of the Experiments on the Enrichment in the Isotope Li^6

Temperature, °C	Degree of enrichment		
	cone		sm. comp. la. comp.
	la. comp.	sm. comp.	
500	1.02	0.96	1.06
550	1.10	1.02	1.08
500-550	1.16	—	—
500-520	1.08	1.08	1.00
510-520	1.06	1.10	0.96
500	1.09	1.00	1.09
500	1.14	1.21	0.94
500	1.14	1.09	1.04
500-510	1.07	1.14	0.93
520	1.11	1.13	0.98
490-500	1.11	1.03	—
500	—	1.09	—
Mean value	1.10 ± 0.01	1.08 ± 0.02	1.01 ± 0.01

ment in the isotope Li^6 on the cone was compared with the enrichment in the larger and smaller compartments. The results of the experiments, as well as the lithium evaporation temperatures, are listed in Table 1.

It was assumed that the lithium condensing on the cone, which had been enriched in the isotope Li^6 , would flow from it down to the small compartment, and, having filled the latter, would flow over the partition into the large compartment. However, as can be seen from Table 1, there was a mixing of the lithium between the two compartments, which may have been caused by failure to make the partition sufficiently high or to seal it hermetically. Nevertheless, it can be seen from the data listed that the enrichment of the vapor phase (cone) as compared with the enrichment of the liquid phase agrees within the limits of experimental error with the calculated value of the separation factor, equal to 1.09.

For comparison, we point out that Trauger et al. [6] obtained values of α from 1.06 to 1.08 in the temperature interval 462-550°C.

Since the experiment confirmed the fact that the separation factor was high, it was expedient to carry out a multi-stage process. For this purpose we selected cascade-type stills, the principle of which was suggested by Brewer and Madorsky [10].

The molecular distillation of the liquid lithium was carried out in an eight-stage cascade-type metal still, having a rectangular cross section, with the dimensions of each stage (cell) equal to 60 · 10 mm (Fig. 2). The construction of the still has been described earlier [11].

Dowtherm (a eutectic mixture of diphenyl and diphenyl oxide) with a boiling point of 260°C at atmospheric pressure, was poured into the condenser of the still. While the still was operating the Dowtherm evaporated and its vapors condensed on the upper surface of the condenser, which was cooled by running water. The still was heated by a special gas burner.

When the still was heated along its whole length, a countercurrent of liquid and vapor was established as a result of which the isotope Li^6 became concentrated in the highest (eighth) cell and the isotope Li^7 in the lowest (first) cell.

For the removal of samples of lithium from the first and eighth cells and for the measurement of temperatures in them, special sample removers were used, each consisting of a well for a thermocouple with a cup at the end, two hermetically sealed bellows, and a hoisting mechanism. Before the conclusion of the experiment the cup was

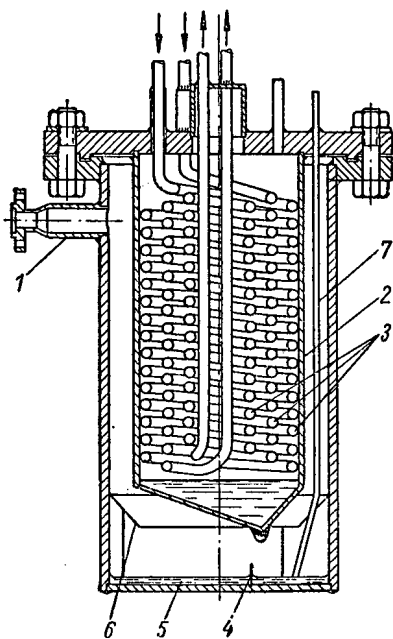


Fig. 1. Diagram of boiler for molecular distillation.

raised and it brought up a quantity of metal. After cooling the still and disconnecting the vacuum system, the still was filled with argon, the sample removers were extracted, and the lithium samples were transferred from the cups into a solution and were analyzed.

The still was tested in advance with a mixture of di-2-ethylhexylphthalate and di-2-ethylhexylsebacinate (EHP-EHS) at a temperature of 148°C, an angle of inclination of 1.7° to the horizontal, and a pressure of $6 \cdot 10^{-3}$ mm of mercury, and a value of 0.70 was obtained for the efficiency of an individual stage [12].

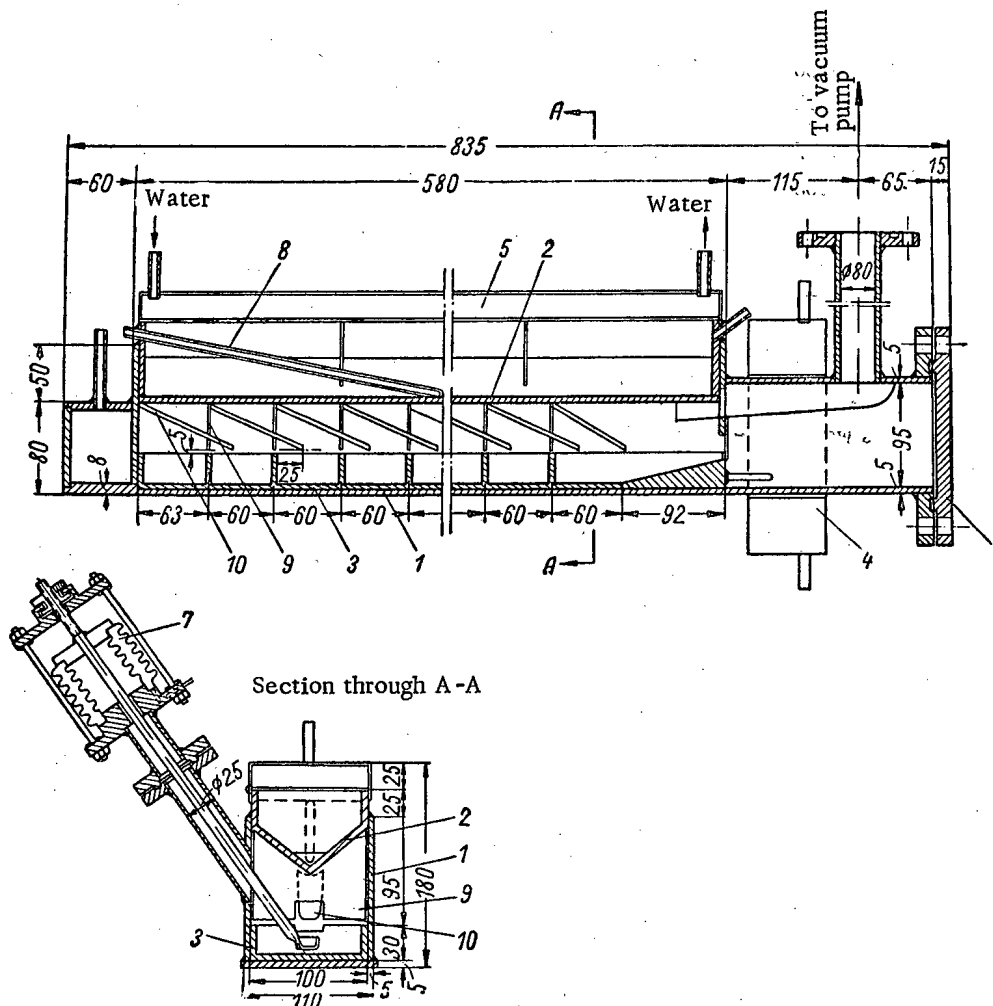


Fig. 2. Diagram of a multi-stage still for molecular distillation: 1) Shell of still; 2) condenser; 3) removable trays; 4) water cooler; 5) condenser for Dowtherm; 6) closure of still; 7) sampling and temperature-measuring device; 8) well for thermocouple; 9) baffle; 10) trough.

Table 2 shows some results of experiments in the molecular distillation of metallic lithium in an eight-stage still with angles of inclination of the apparatus equal to 1, 1.7, and 3.5° to the horizontal and a residual gas pressure of 4-5 microns of mercury. The last graph shows the values of the degree of enrichment of the lithium in the isotope Li^6 , calculated by the formula

$$K = \frac{x_2(1-x_1)}{x_1(1-x_2)}, \quad (3)$$

where x_1 and x_2 are the concentrations of Li^6 in the samples from the first and eighth cells of the evaporator respectively (mole percentages).

It can be seen from Table 2 that the apparatus did not give a sufficiently satisfactory separation of the lithium isotopes. In every case the operation of the still was unstable, considerable fluctuation of the metal level in the

TABLE 2. Data of Experiments on the Distillation of Lithium in an Eight-Stage Still

Angle of inclination of the apparatus, degree	Duration of experiment, hours	Mean temperature in the still, °C		Level of lithium in the trays, mm		Degree of enrichment
		lower	upper	first cell	eighth cell	
1.7	9.5	485	490	12	13	1.095
1.7	14	530	470	>20	0	1.036
1.7	5	500	355	20	15	—
1.7	6	525	300	16	15	1.106
1.7	9	510	410	16	10	1.124
1.7	37	520	470	13	16	1.035
3.5	5	530	490	15	21	0.94
3.5	11	520	490	13	17	0.90

first and eighth cells was observed, and there was poor reproducibility of the results of the experiments with respect to enrichment in the isotope Li^6 . For angles of inclination of 3.5° we even observed a depletion in the isotope Li^6 in the upper part of the still.

The severe fluctuations in metal level in the first and eighth cells, as well as the non-uniform distribution of the metal in the remaining cells, found after removal of the trays from the still, are apparently to be explained by the fact that during the operating process after a particular cell had overflowed, as a result of the good wetting properties of the steel and the high surface tension of the lithium, the metal quickly flowed through the apertures in the partitions until a uniform metal level was attained in the entire still or in its individual parts. We called this phenomenon "siphoning" of the metal.

TABLE 3. Data of Experiments on the Enrichment of Lithium Isotopes Carried out in a Modified Still

Duration of experiment, hours	Mean temperature in still, °C		Mean temperature in condenser, °C	Lithium level in trays, mm			Degree of enrichment
	lower	upper		first cell	fifth cell	eighth cell	
16	460	515	270	0	0	20	1.06
15	490	500	270	26	0	20-25	1.04
23	490	500	270	20	25	20-25	1.07
6	500	495	265	17	25	>20	1.08
16	505	515	265	17	25	>20	—
13	540	530	265	28	>20	>20	—
14	545	520	265	17	>20	>20	1.044
14	500	490	340	16	>20	>20	1.11
10 (24)*	540	500	350	17	>20	>20	1.13

* Continuation of previous experiment.

Thus, while the still was operating, the metal flowed through periodically (intermittently), so that between individual experiments considerable changes in the degree of enrichment in the isotope Li^6 were observed. To ensure a more constant metal level in the cells of the still and to reduce the detrimental effect of siphoning, all the cells (except the first and the fourth) were filled with packing-rings of metal netting (30 mesh) with diameter and height equal to 5-6 mm. Two series of experiments were conducted at an apparatus inclination angle of 1.5° and a residual gas pressure of 9 microns of mercury.

In the first series of experiments the condenser temperature was $265-270^\circ C$, and in the second it was $340-350^\circ C$ (paraffin was poured into the condenser instead of Dowtherm). The metal level was measured in the first, fifth, and eighth cells of the still.

It was found (Table 3) that the use of packing ensures a more uniform operation of the still; in most cases the first, fifth, and eighth cells contained a level of metal which was always considerable although not constant. Better results were obtained at increased condenser temperatures ($340-350^\circ C$), which apparently is explainable by the more uniform distribution of the metal in the condenser and the incline troughs related to the reduced viscosity of the metal at higher temperatures. An isotopic analysis of the lithium samples was carried out in a type MSL-3 mass spectrometer.

Unfortunately, no steady state was obtained in the last experiment, and therefore the efficiency of one stage of the still can be estimated only approximately on the basis of an analysis of the data with respect to the kinetics of the enrichment process.

The time required to achieve a given concentration of an isotope in one half of the still may be calculated by the formula [12]

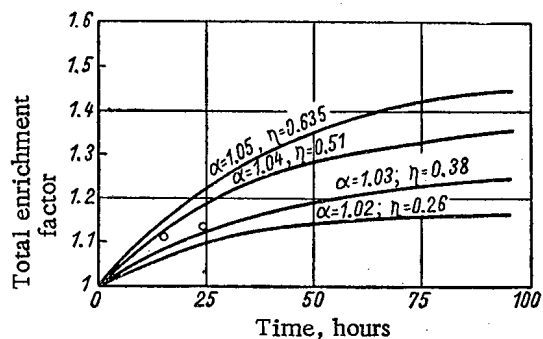


Fig. 3. Variation of the enrichment in the isotope Li^6 with time.

$$t = \frac{2.303\alpha H}{(\alpha-1)L} \left[\frac{\alpha}{\alpha-1} (\alpha^n - 1) - n \right] \times \log_{10} \frac{\alpha^n - 1}{\alpha^n - K} \quad (4)$$

where α is the degree of separation attained in one cell (stage); n is the number of cells (in the present case $n = 4$ for half the still); K is the degree of enrichment achieved in the experiment (the maximum value of K is equal to α^n); H is the capacity of one cell, in grams (in our case the capacity of a cell is 50 g); L is the evaporation rate in each cell in grams of lithium per hour at the mean temperature of the experiment.

A calculation of the evaporation rate by the Langmuir-Knudsen formula for a mean experimental temperature of 520°C and an evaporation surface in each cell of 6 · 9 cm gives a value of $L = 16.2$ grams/hour.

The efficiency η of one stage is defined from the relation

$$\eta = \frac{\log_{10} \alpha}{\log_{10} \alpha_M} \quad (5)$$

where α is the degree of separation achieved in one stage of the still; α_M is the separation factor in the evaporation of the lithium isotopes, equal to 1.08.

In order to determine the efficiency of one stage of the still, curves were calculated on the basis of Eq. (4) for the variation of enrichment as a function of time for various degrees of separation achieved in a cell of the still (α equal to 1.02, 1.03, 1.04, and 1.05), and correspondingly for various efficiencies of one stage. The calculated and experimental (two points) data are shown in Fig. 3, from which we can conclude that the efficiency of one stage of the still lies between the limits of 0.4 and 0.5.

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LETTERS TO THE EDITOR

INVESTIGATION OF THE REACTION $\text{Be}^9(d, t)\text{Be}^8$

V. I. Serov, V. A. Pereshivkii, M. F. Andreev,
and I. K. Aver'yanov

Translated from *Atomnaya Ėnergiya*, Vol. 11, No. 5,
pp. 440-442, November, 1961
Original article submitted May 8, 1961

The reaction $\text{Be}^9(d, t)\text{Be}^8$ has been studied by a number of workers [1-4]. Nevertheless, detailed studies have not been performed for deuteron energies in the range 1.4 to 4.0 Mev. In this work measurements have been made

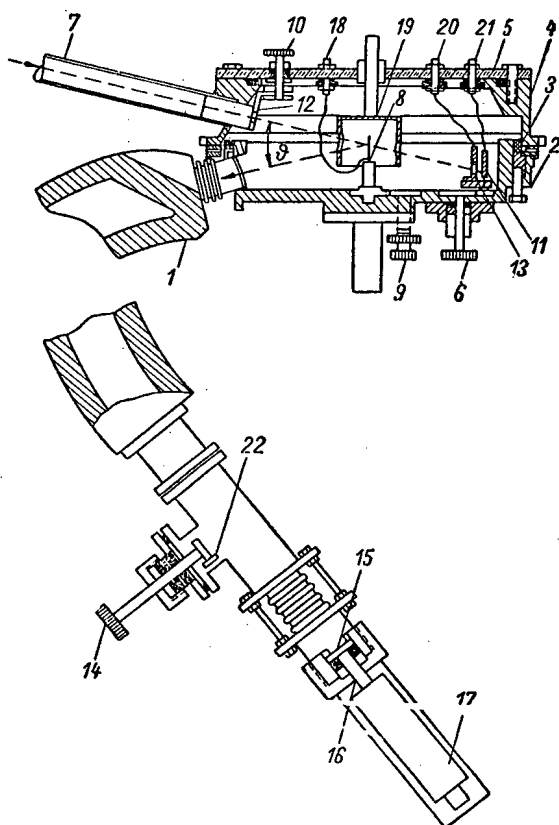


Fig. 1. General scheme for the arrangement of the target, spectrometer, and detectors. 1) Magnet chamber; 2) rotating section of the spectrometer chamber; 3) vacuum seal; 4) stationary section of the spectrometer chamber; 5) cover made of plexiglass; 6, 9, 10, 14) arrangement for the regulation of the position of target, diaphragm, etc.; 7) generator discharge pipe; 8) target; 11) beam current measuring electrode; 12) traveling diaphragm; 13, 19) electrodes for suppressing secondary emission; 15) CsI crystal; 16) light transmitting tube; 17) photomultiplier; 18, 21) leads for the set adjustment of the integrators; 20) leads for secondary emission suppressing electrodes; 2) source for calibrating the apparatus.

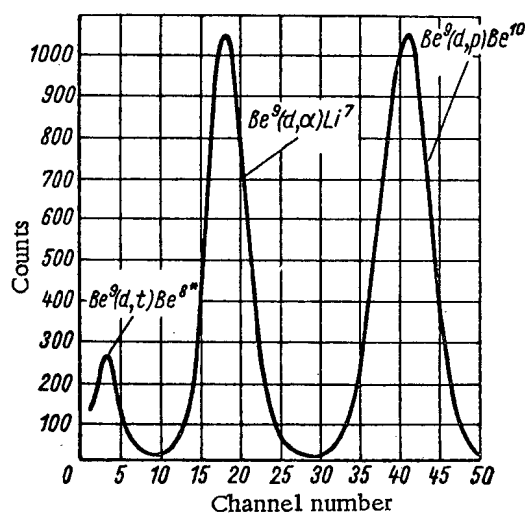


Fig. 2. Momentum spectrum amplitude of particles passing through the magnetic spectrograph.

on the differential cross section for triton production. We have considered the dependence of the differential cross-section for primaries scattered through 17° on deuteron energy over a range of 1.125 to 3.8 Mev, and in this energy range we have examined the angular distribution from 0 to 150° .

The experiment was carried out using an electrostatic generator. Deuterons are directed through a diaphragm 4 mm in diameter and then into the magnetic spectrometer chamber. In the center of this a foil with a layer of beryllium (density 100 to $150 \mu\text{g}/\text{cm}^2$) was situated. The deuteron current was measured by an integrator when the deuterons are all stopped in the foil, or by an insulated electrode adjusted in the path of the beam and lying behind the target. The secondary particles emitted from the target were analyzed in a magnetic spectrograph using nonhomogeneous magnetic fields. Using this spectrometer it was possible to analyze tritons with energies up to 5.4 Mev. For those cases in which tritons were produced

with large energy a foil was adjusted behind the target to retard them. A general arrangement of the apparatus is shown in Fig. 1.

To obtain measurements of the angular distribution, the spectrometer was rotated relative to an axis which passed through the center of the target. The particle detector was a thin crystal of CsI used in conjunction with a

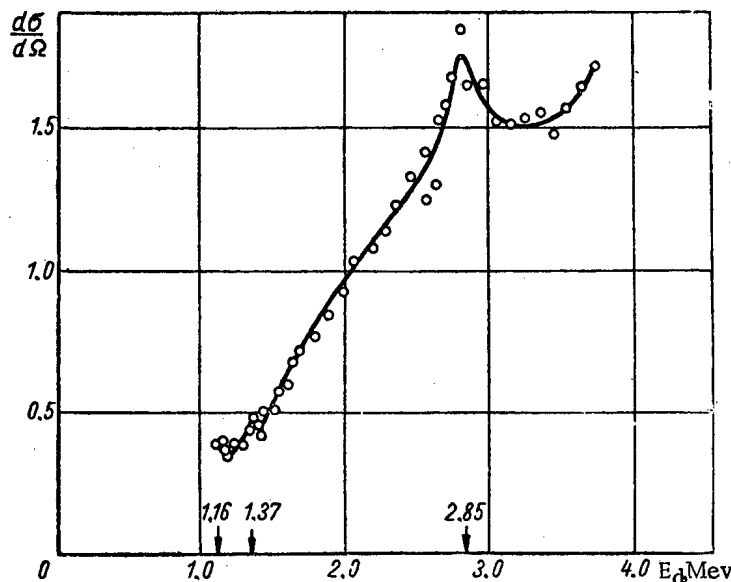


Fig. 3. The differential cross section for tritons produced from the reaction $\text{Be}^9(d, t)\text{Be}^8$ as a function of deuteron energy plotted in relative units.

photomultiplier. In order to determine the type of particle the momentum spectrum was recorded in a 50 channel pulse height analyzer. The spectral amplitude as a function of momentum for particles emitted from the target in a fixed magnetic field is shown in Fig. 2. The particle path for a given deuteron energy was determined by summing over the channels and then graphically integrating the curve as a function of the number of points read in the magnetic field.

In Fig. 3, the differential cross section for triton production is displayed as a function of deuteron energy. Superimposed on the smooth development of the curve we note resonances at deuteron energies of 1.37 and 2.85 Mev. In

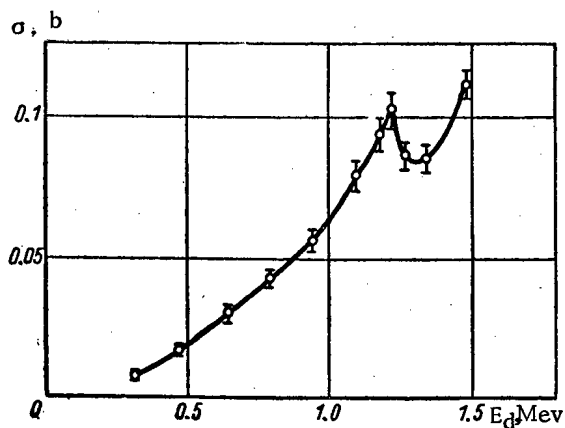


Fig. 4. The total cross section for triton yield as a function of deuteron energy for the reaction $\text{Be}^9(d, t)$.

addition, we obtained a total cross section for the tritium reaction for deuteron energies of 305 to 1480 kev by measuring the absorption of tritium in the target substrate.* The curve illustrating these results is given in Fig. 4. Comparison of Figs. 3 and 4 seems to indicate that there is another resonance for deuteron energy of 1.16 Mev. Both measurements and calculations for the angular distribution for deuteron energies of 1.4, 2.5, and 3.5 Mev are shown in Fig. 5. The calculations were made using Butler's theory of knock-on (d, t) reaction without accounting for coulomb interactions. The magnitude of the orbital angular momentum, l_n , of captured neutrons in the absorption calculations was taken equal to one. Good

* The work in measuring the path and the absorption of the tritium was performed jointly with B. Ya. Guzhovskii.

Reaction	E_{res}	Energy level	Reaction	E_{res}	Energy level
$Be^9(n, \alpha)He^6$	2.6	2.43	$Be^9(p, \gamma)B^{10}$	3.14	3.04
$Be^9(p, n)B^9$	2.3		$Be^9(d, t)Be^8$	≥ 3.10	
$Be^9(d, t)Be^8$	2.33		$Be^9(\alpha, n)C^{12}$	3.08	
$Be^9(\alpha, n)C^{12}$	2.75				

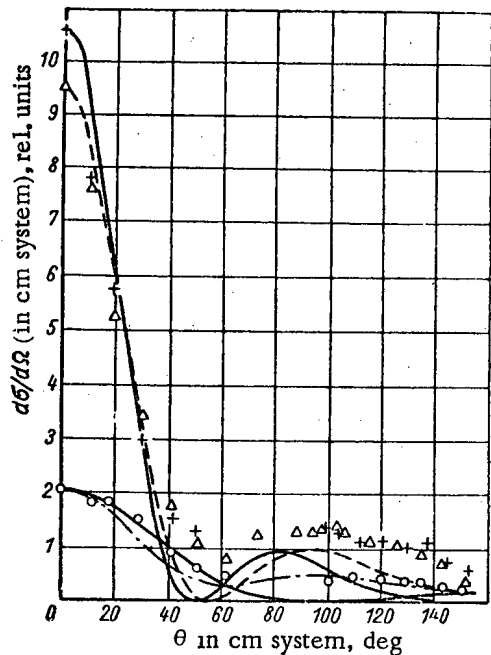


Fig. 5. The angular distribution of primary tritons from the reaction $Be^9(d, t)Be^8$. The experimental points are plotted using the following key for deuteron energy.) \circ) 1.4; Δ) 2.5; $+$) 3.5; $-\cdot-\cdot-$) 1.403 [2]; $---$) calculated using Butler's theory.

The authors wish to convey thanks to V. A. Ivanov and his group for providing clarity to the workings of the electrostatic generator and also to V. Kuzyanov for assistance in taking measurements.

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CROSS SECTIONS OF INELASTIC INTERACTION
OF FISSION SPECTRUM NEUTRONS

G. N. Lovchikova and O. A. Sal'nikov

Translated from Atomnaya Énergiya, Vol. 11, No. 5,
pp. 442-443, November, 1961

Original article submitted May 27, 1961

The source of fission neutrons was a converter, which was placed in a stream of thermal neutrons leaving the reactor and which consisted of an aluminum box containing the mixed oxide of U^{235} with 75% enrichment. The converter was placed at an angle of 45° to the direction of the thermal neutron beam. The detector was placed at a distance of 30 cm from the center of the converter.

The neutrons were recorded by a multielectrode ionization fission chamber with U^{238} , having a spherical housing of diameter 22 mm with a cylindrical space inside. The amount of material applied to the electrodes was 40 mg; the U^{238} was depleted 100 fold, i.e., there was 100 times less U^{235} than in the natural mixture of isotopes. The chamber was surrounded by a 0.5 mm thick cadmium cover for protection against thermal neutrons. The effective threshold of the detector for the neutrons of the fission spectrum was 1.4 Mev.

Cross Sections of Inelastic Reaction of Fission Spectrum Neutrons Leading to a Loss in Energy by Neutrons to a Value Less Than the Fission Threshold of U^{238}

Element	$N \cdot 10^{20}$, number of atoms in cm^3	σ_{tr} , b	T	$\sigma_{in} > b$
Sodium	254.3	2.0	0.037	0.47 ± 0.08
Potassium	133.1	2.3	0.981	0.47 ± 0.11
Strontium	180.0	3.1	0.950	0.93 ± 0.08
Barium	163.7	3.8	0.933	1.36 ± 0.10
Molybdenum	639.9	3.0	0.727	1.54 ± 0.03
Niobium	176.7	3.2	0.883	1.44 ± 0.08
Iron	845.8	2.2	0.807	0.73 ± 0.04

The diffusers were materials consisting of a natural mixture of isotopes. All specimens except niobium were cast. The niobium was used in the form of a powder. The diffusers were split hollow spheres consisting of equal halves. The dimensions of the internal space corresponded to the dimensions of the detector. The external diameter of all diffusers was 90 mm.

The transmission T_1 was measured, i.e., the ratio of the count rates of the fission spectrum neutrons in the presence of a diffuser and without it. Therefore,

$$T = \frac{N_2}{N_1},$$

where N_1 is the number of counts of the detector corresponding to neutrons with the initial energy (without a diffuser); N_2 is the number of counts of the detector (with a diffuser).

The difference between the values N_2 and N_1 is caused by all the processes leading to discarding the energy of the neutrons below the fission threshold of the detector. The value of transmission therefore depends in the first place on the cross sections of inelastic scatter, capture and cross sections of other reactions which can cause disappearance of neutrons or a high loss in energy. The main role is played by inelastic scatter since an analysis of experimental data on the capture cross section in the region of energies 1-14 Mev for the elements in which we were interested [1] showed that all cross sections were within the limits 1-10 mb. The threshold of reaction (n, p) is about 5 Mev, the cross section for most elements near a threshold of the order of 10 mb, in some cases reaching 100 mb with a neutron energy of 14 Mev. The cross section of other reactions, for example (n, α) ; $(n, 2n)$ with a neutron energy of 14 Mev, is of the same order, only the threshold of these reactions is much higher [1]. The cross section of inelastic scattering therefore makes the main contribution to the total cross section which we found.

The cross sections for transmission were calculated by a method developed in [2]. Geometrical corrections and corrections for the absorption of neutrons in the detector showed much lower experimental errors and were therefore not introduced into the final calculation of the cross sections. The correction for energy losses in elastic collisions was not considered since the final result included cross sections of all processes leading to loss in energy by neutrons

to a value less than the fission threshold of U^{238} . It is clear that corrections such as those for fission in the detector under the action of γ -quanta and the generation of photoneutrons in the diffuser are small and can be neglected.

The neutron background was determined experimentally. Owing to the high fission threshold of U^{238} it was insignificant.

The results of the measurements are given in the table. All cross sections, except those of iron, have not yet been published in the literature and are given here for the first time. Iron was chosen to compare our data with those of other authors. The cross section obtained for iron was 0.73 ± 0.04 b, and within the limits of statistical errors it agrees well with the cross section of inelastic scattering of fission spectrum neutrons equal to 0.686 ± 0.043 b, obtained for iron in [2].

A consideration of the experimental results shows that the cross sections increase with the atomic number.

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ANGULAR DISTRIBUTION OF IRON-SCATTERED γ -RADIATION FROM A PLANE, MONODIRECTIONAL Co^{60} SOURCE

A. V. Larichev

Translated from *Atomnaya Energiya*, Vol. 11, No. 5,
pp. 443-445, November, 1961
Original article submitted March 13, 1961

There have been papers [1, 2] devoted to the experimental study of the angular distribution of γ -radiation from an isotropic Co^{60} point source in a semi-infinite medium. Similar results from experiments with parallel beams of 8-10 Mev bremsstrahlung radiation and 1.25 Mev Co^{60} radiation have been reported [3, 4].

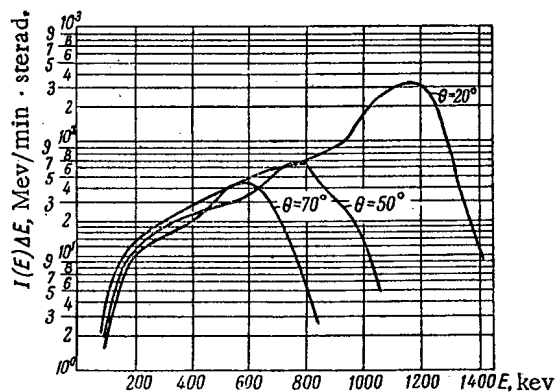


Fig. 1. Energy spectra for γ -radiation scattered at angles of 20, 50, and 70°.

The results for the spectral distribution of γ -radiation in an infinite medium as calculated by the moments method have been presented [5].

The angular distribution of γ -radiation from a plane, monodirectional Co^{60} source which is scattered in a plane iron slab is given in this paper.

The experimental method has been described previously [4]. The spectra were taken with a total absorption spectrometer having a NaI(Tl) crystal 80 mm in height and diameter.

The pulse height distribution was worked out by means of data for the spectrometer sensitivity function [6]. The spectral distribution of γ -radiation scattered in an iron slab six mean free paths thick (15.6 cm) at angles of 20, 50, and 70° is shown in Fig. 1.

The relative angular intensity distribution (relative to the intensity of unscattered radiation) of scattered radiation per unit solid angle is shown in Fig. 2 for three slab thicknesses. These curves are similar to curves shown in [1].

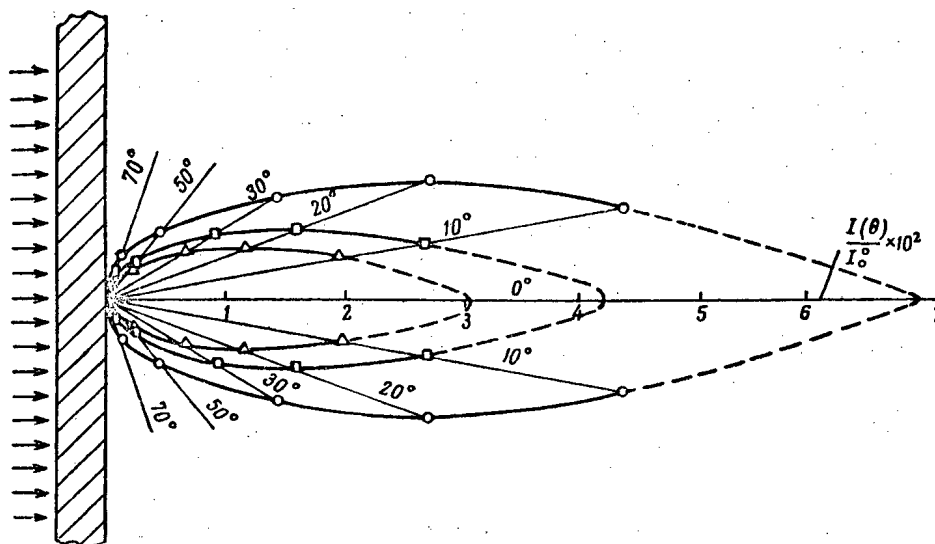


Fig. 2. Relative angular intensity distribution of scattered radiation for various slab thicknesses: \circ) $6\mu_0x$; \square) $4\mu_0x$; \triangle) $2\mu_0x$.

The outermost points of the curves (those for small angles) were obtained on the assumption that the dependence of scattered radiation intensity per unit solid angle on angle is exponential, i.e.,

$$I(\theta) = I(0) \exp(-\theta/\theta_0).$$

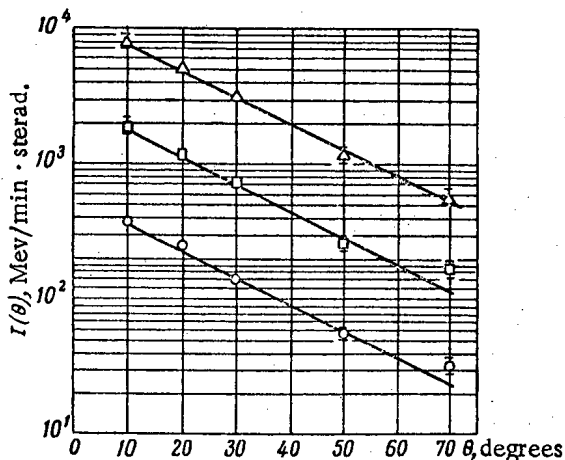


Fig. 3. Dependence of $I(\theta)$ on θ in the range $10-70^\circ$ for various slab thicknesses. (For meaning of symbols, see Fig. 2.)

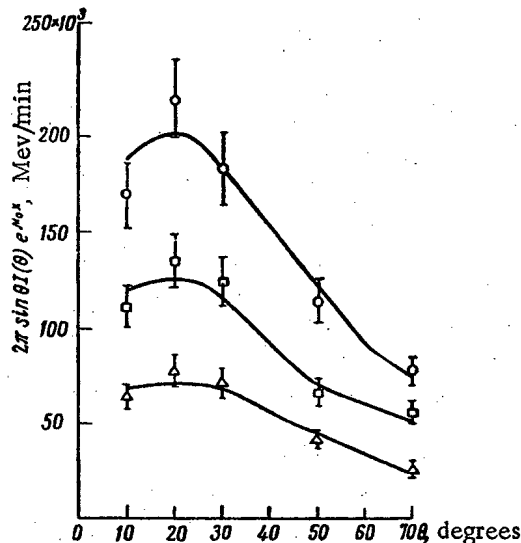


Fig. 4. Angular dependence of the intensity of radiation scattered in the solid angle element $2\pi \sin \theta \Delta \theta$ for three slab thicknesses. (for meaning of symbols, see Fig. 2.)

The values of $I(0)$ were obtained from the experimentally known quantities $I(\theta)$, θ , and θ_0 . The dependence of $I(\theta)$ on θ is shown in Fig. 3 on a semilogarithmic scale. The dependence of scattered radiation intensity in the

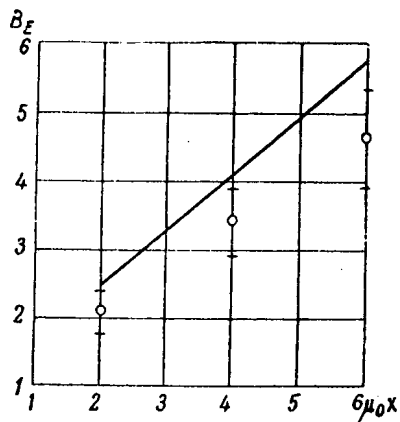


Fig. 5. Comparison of experimental and theoretical [7] values for energy build-up factor.

solid angle element $2\pi \sin \theta \Delta \theta$ on angle is shown in Fig. 4 for three barrier thicknesses. A maximum in the interval from 20 to 30° is characteristic for all three thicknesses. The total scattered radiation intensity was determined by graphical integration of the curves in Fig. 4. The dependence of the scattered radiation build-up factor B_E on slab thickness $\mu_0 x$ is shown in Fig. 5. The solid line was drawn through build-up factor values taken from [7] (a Monte Carlo calculation). These values lie outside the limits of experimental error. However, the data in [7] has an error of $\sim 8\%$ itself; therefore the agreement between experimental results and the results in the paper mentioned can be considered to be satisfactory.

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THE EFFECT OF THE RESONANCE STRUCTURE OF CROSS SECTIONS ON THE PROPAGATION OF FAST NEUTRONS IN IRON

M. N. Nikolaev, V. V. Filippov, and I. I. Bondarenko

Translated from *Atomnaya Energiya*, Vol. 11, No. 5, pp. 445-447, November, 1961

Original article submitted March 23, 1961

Until recently, in the calculation of fast reactors systems of multigroup constants were used, compiled on the basis of data on the mean cross sections [1, 2]. This method of calculating group parameters is reliable if the cross sections within the limits of the energy group are sufficiently smooth energy functions. If a resonance structure appears in the cross sections, then when compiling multigroup constants it is essential to consider the resonance blocking of the cross sections. Until now this has usually only been performed in the region of isolated resonances when calculating group cross sections of radiation capture and fission for heavy nuclei [3, 4]. When calculating group parameters such as the coefficient of fusion (or the transport cross section corresponding to it) and the moderation cross section, the influence of resonance effects was neglected.* However, the effects connected with the blocking of resonances can have an important effect on these values also, which was mentioned in [6] where an allowance was made for the resonance blocking in the compiling of a multigroup system of constants for U^{238} (see also [7]). As can be seen from the results of these papers, even for such a heavy nucleus as uranium and comparatively high energies (several tens of kiloelectron volts) the resonance blocking has a noticeable effect not only on the capture cross section but also on the transport cross section.

* The effect of resonance blocking on the neutron moderation cross section for heavy nuclei in the region of isolated resonances was described in [5].

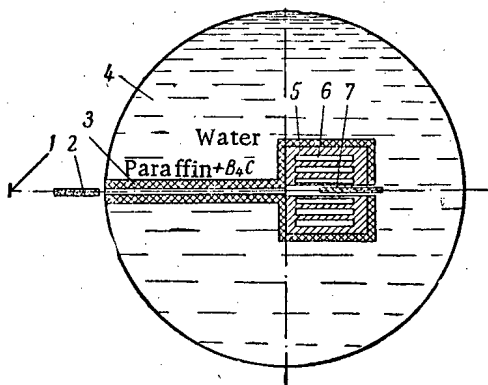
For medium weight nuclei the resonance structure of the cross sections appears up to energies of the order of several megaelectron volts. It might therefore be supposed that for such nuclei the effect of blocking of resonances will be important over the whole energy region, which is of interest for reactor physics. This conclusion is confirmed by experimental data [6].

As follows from [7], the diffusion coefficient and the neutron moderation cross section for a certain energy group are determined (with low capture) in the following way:

$$\langle D \rangle = \frac{1}{3(1-\bar{\mu})} \frac{\langle \frac{1}{\Sigma^2} \rangle}{\langle \frac{1}{\Sigma} \rangle}; \quad \langle \Sigma_m \rangle = \frac{\xi}{\ln \frac{E_u}{E_l}} \frac{1}{\langle \frac{1}{\Sigma} \rangle}, \quad (1)$$

where $\bar{\mu}$ is the mean cosine of the angle of scattering; ξ is the mean logarithmic energy loss; E_u and E_l are the upper and lower boundaries of the group; Σ is the total macroscopic cross section, equal to the scattering cross section with the assumption made. The brackets indicate averaging for the energy group considered.

The information which is available at the present time on resonance parameters in the region of fast neutrons is insufficient for calculating the values of $\langle 1/\Sigma \rangle$ and $\langle 1/\Sigma^2 \rangle$ with the required accuracy. We also notice that these values are strongly affected by interference effects which have not been studied at all in this energy region. In this connection it is of interest to directly measure the values $\langle 1/\Sigma \rangle$, $\langle 1/\Sigma^2 \rangle$ and other similar characteristics.



Experimental layout

We will consider the transmission $T(t)$ of neutrons uniformly distributed in the range of averaging of ΔE :

$$T(t) = \frac{1}{\Delta E} \int_{\Delta E} e^{-\Sigma(E)t} dE. \quad (2)$$

The area under the transmission curve is equal to the mean length of free path ($\langle \lambda \rangle = \langle \frac{1}{\Sigma} \rangle$):

$$\int_0^{\infty} T(t) dt = \frac{1}{\Delta E} \int_{\Delta E} \frac{dE}{\Sigma(E)} = \langle \frac{1}{\Sigma} \rangle. \quad (3)$$

Double integration of the transmission curve gives the mean square of the path length:

$$\int_0^{\infty} dt \int_t^{\infty} T(t') dt' = \frac{1}{\Delta E} \int_{\Delta E} \frac{dE}{\Sigma^2(E)} = \langle \frac{1}{\Sigma^2} \rangle. \quad (4)$$

The mean values can also be determined in a similar way from the higher powers of $1/\Sigma$.

If in expression (2) we remove $\exp[-\langle \Sigma \rangle t]$ from the integral sign and expand the remaining expression into a Taylor series and integrate termwise, we then obtain

$$T(t) = e^{-\langle \Sigma \rangle t} \left[1 + \frac{\langle \Sigma^2 \rangle - \langle \Sigma \rangle^2}{2!} t^2 + \dots \right]. \quad (5)$$

Using this expression, from the shape of the transmission curve at low thicknesses we can determine the mean cross section $\langle \Sigma \rangle$ and evaluate the dispersion of cross section $\langle \Sigma^2 \rangle - \langle \Sigma \rangle^2$.

The apparatus with which the transmission curves were measured is shown in the figure. The source of neutrons was the reaction $T(p, n)He^3$. Protons accelerated by an electrostatic generator impinged on tritium-titanium target 1; its thickness was about 100 kev. The measurements were made at an angle of 0° to the proton beam. The neutrons, emitted from the target and passing through the diffuser 2 without collision, through the collimator 3 in the

Results of Treatment of Experimental Data

E_n, keV	$\langle \sigma \rangle, b$	$\frac{1}{\langle 1/\sigma \rangle}, b$	$\sqrt{\frac{1}{\langle 1/\sigma^2 \rangle}}, b$	$\frac{\langle 1/\sigma \rangle}{\langle 1/\sigma^2 \rangle}, b$	D_{true}/D	$\frac{\langle \sigma^2 \rangle}{\langle \sigma \rangle^2}$	$\frac{\langle 1/\sigma^2 \rangle}{\langle 1/\sigma \rangle^2}$
350	3.8 ± 0.1	2.49 ± 0.03	1.95 ± 0.04	1.52 ± 0.06	2.5 ± 0.1	1.26 ± 0.08	1.64 ± 0.07
650	3.4 ± 0.1	2.00 ± 0.04	1.54 ± 0.03	1.21 ± 0.08	2.8 ± 0.2	1.48 ± 0.15	1.68 ± 0.13
950	2.8 ± 0.1	2.00 ± 0.03	1.78 ± 0.04	1.57 ± 0.09	1.8 ± 0.1	1.31 ± 0.10	1.27 ± 0.04
1350	3.56 ± 0.06	2.66 ± 0.01	2.49 ± 0.02	2.34 ± 0.05	1.5 ± 0.1	1.28 ± 0.10	1.14 ± 0.01
1750	3.28 ± 0.12	2.86 ± 0.02	2.55 ± 0.03	2.31 ± 0.09	1.4 ± 0.1	1.04 ± 0.01	1.24 ± 0.02

protective water tank 4, entered the detector 5. The cylindrical 50 mm diameter diffuser was of Armco iron. It consisted of separate sections of different thickness, suspended on steel filaments. Using different sets of sections we were able to change the thickness of the diffuser.

The neutrons were recorded by 48 proportional counters 6 with enriched boron (type SNMO-5). The counters were placed inside a cylindrical paraffin block. Along the axis of the block there was a 50 mm diameter channel half filled with a polyethylene stopper 7. The neutrons passing through the collimator were scattered in this stopper and, moderating in the paraffin block, were recorded by counters. The detector was placed inside protective tank 4 of diameter and height 2 m. Only those neutrons which had passed through the diffuser reached the collimation hole of the 45 mm diameter tank. To measure the background the inlet hole of the collimator was closed from the target by a copper cone of height 800 mm. The background was less than 0.1% of the count with the open target. The angular resolution of the apparatus was about 1° . The maximum thickness of the diffuser was 25 cm, which corresponded to approximately 100-fold attenuation of the neutron beam.

Transmission curves were measured for several values of the mean neutron energy in the range 0.3-1.8 Mev. The forms of the curves differed considerably from the exponential form, pointing to the strong fluctuation of the cross section in the observed energy region.

The results obtained by the above treatment of the transmission curves are shown in the table. In the first five columns there are the energy, mean cross sections and cross sections which should be used to calculate $\langle 1/\Sigma \rangle$, $\langle 1/\Sigma^2 \rangle$ and $\langle D \rangle$.

The mean cross sections which we obtained are 10-20% higher than the figures given in the atlas of D. Hughes [8]. This difference can be explained if the experiments, the results of which are given in the atlas, used a diffuser with a thickness of about one path length. From the data of the table it can be seen that for the calculation of the mean path $\langle \lambda \rangle$ and the mean square of this length $\langle \lambda^2 \rangle$ cross sections should be used which are much smaller than the mean cross section $\langle \Sigma \rangle$. The resonance blocking has a particularly important effect on the coefficient of diffusion. The sixth column gives the ratios of the diffusion coefficient calculated from formula (1) to the value $1/3(1-\mu)\langle \Sigma \rangle$; even at energies of about 1.5 Mev these values differ by 50%. In the seventh and eighth columns there are the relative dispersions of the cross section and the path lengths. Of interest is the fact that at an energy of about 1800 keV the dispersion of the cross section is very small whereas the dispersion of the path length is large. This points to the fact that in the energy range considered the cross section has one or several fairly deep and narrow dips, between which it does not undergo strong fluctuations. Since the dips are narrow they do not have a noticeable effect on the value of the mean cross section. However, the presence of dips in the cross section has a strong effect on the mean path length. It might be expected that the observed fact is characteristic for the region of almost overlapping resonances where, due to the geometrical limitations and the phenomenon of "repulsion" of the level, the cross section cannot have sharp peaks. The dips in the cross section caused by random fluctuations in the density of the levels can also occur in this energy region.

The results given are preliminary. At the present time more detailed measurements are being made of the mean cross sections and path lengths of neutrons for a number of medium weight nuclei.

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AN EXPERIMENTAL STUDY OF A LINEAR ACCELERATOR WITH AN ELECTRON PRE-BUNCHER

G. I. Zhileiko and D. A. Yakovlev

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,

pp. 447-449, November, 1961

Original article submitted May 27, 1961

A simplified diagram of the device is shown in Fig. 1. The high-frequency power is fed to a double resonator pre-buncher (more accurately, an electron cluster-former) through a cable to which phase changers are connected. By means of the phase changers the phase of arrival of the electron cluster to the accelerator is changed, which ensures that the instant of injection of the cluster into the accelerator coincides with the equilibrium phase. In the feed circuit of the gridless resonators of the pre-buncher there are (not shown on the diagram) attenuators and devices permitting remote switching on and off of the supply to the resonators, with the accelerator operating.

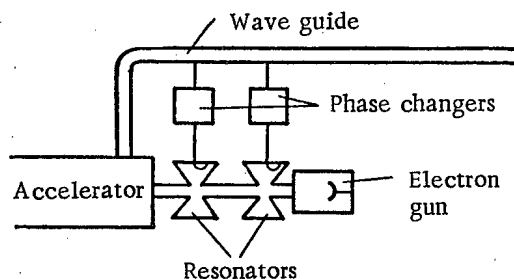


Fig. 1. Block diagram of accelerator with electron pre-buncher.

high-frequency oscillations, led only into one resonator, close to the accelerator (single resonator pre-buncher). Figures 3 and 4 illustrate the dependences of the width of the spectrum and the beam current on the injection voltage U_1 on the electron gun and the high-frequency power P_{res} fed into the resonator.

For a double resonator pre-buncher Figs. 5 and 6 give curves showing the dependence of the width of the spectrum and the beam current on the phase of oscillations φ_2 , fed into a resonator which is at a distance from the accelerator, and the injection voltage. The systems of both resonators are chosen from the point of view of their best mutual operation.

On the basis of the experimental data the following conclusions can be drawn:

1. The pre-buncher effectively acts on the operating system of the accelerator; the experimental dependences being well-explained theoretically. In fact, it can be seen from the curves of Fig. 2 that for $\varphi = 20-40^\circ$, the electron cluster from the pre-buncher enters the accelerator with the equilibrium phase: here the spectrum width is a mini-

mum and current is a maximum; the phase of the phase changer $\varphi = -(80-120^\circ)$ corresponds to the cluster entering the region of phases of the traveling electromagnetic wave, where the conditions of bunching are the worst observed.

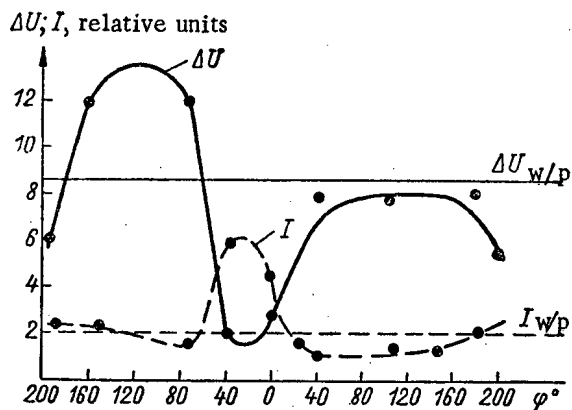


Fig. 2. Dependences of width of spectrum of accelerated electrons and the beam current on the value of the phase at which the electron cluster is fed into the accelerator: $\Delta U = \Delta U(\varphi)$; $I = I(\varphi)$ with a single resonator pre-buncher; $\Delta U_{w/p} = \Delta U_{w/p}(\varphi)$; $I_{w/p} = I_{w/p}(\varphi)$ without a pre-buncher.

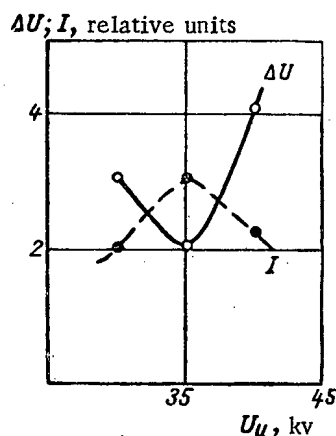


Fig. 3. Dependence of width of spectrum and beam current on voltage at which electrons are injected into single resonator pre-buncher.

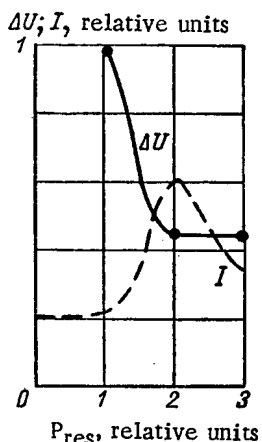


Fig. 4. Dependence of width of spectrum and beam current on the high-frequency power fed into the single resonator pre-buncher.

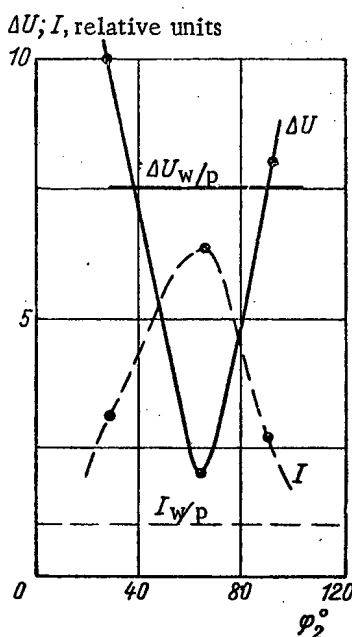


Fig. 5. Dependences of width of spectrum and beam current on the phase of oscillations fed into the second resonator of the double resonator pre-buncher from the accelerator. Straight lines: the same, without pre-buncher.

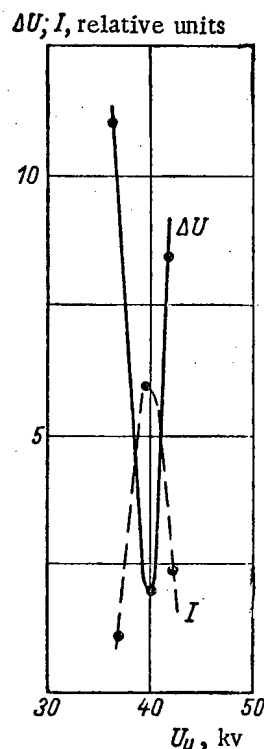


Fig. 6. Dependences of width of spectrum and beam current on the voltage at which electrons are injected into the double resonator pre-buncher.

2. The use of a pre-buncher, even a single resonator type, triples the beam current and reduces the spectrum width to a third or a quarter.

3. A double resonator pre-buncher considerably increases the beam current but there is a sharp increase in the criticality of the operating conditions of the accelerator (injection voltage, etc.) and the choice of the conditions of the resonators for mutual operation is complicated.

ONE ACCURATE SOLUTION OF A NONSTATIONARY
ALBEDO PROBLEM

T. Kh. Sedel'nikov

Translated from Atomnaya Energiya, Vol. 11, No. 5,

pp. 449-450, November, 1961

Original article submitted May 27, 1961

We will consider a homogeneous isotropic elastically-diffusing half-space. To solve the problem of finding the outgoing flux intensity of neutrons as a function of the time we will write the corresponding albedo equation.

The latter can be obtained by formal transfer from a nonstationary kinetic equation with zero initial conditions to a stationary equation, using the Laplace transform. The neutron capture cross section then changes formally:

$$\Sigma_c \rightarrow \Sigma_c + p/v, \quad (1)$$

where p is the Laplace transform parameter; v is the speed of the neutron.

From the stationary kinetic equation we can transfer to the corresponding albedo equation [1, 2] for the intensity of the outgoing flux $I(\mu, \mu_0)$:

$$\left(\frac{1}{\mu} + \frac{1}{\mu_0} \right) I(\mu, \mu_0) = \frac{\Lambda}{4\pi\mu} \left[1 + 2\pi\mu \int_0^1 \frac{I(\mu, \mu')}{\mu'} d\mu' \right] \times \left[1 + 2\pi \int_0^1 I(\mu'', \mu_0) d\mu'' \right], \quad (2)$$

where μ_0 is the cosine of the angle of incidence of the neutron; μ is the cosine of the angle of exit of the neutron;

$$\Lambda = \frac{\Sigma_s}{\Sigma_s + \Sigma_c + p/v}; \quad (3)$$

Σ_s is the neutron scatter cross section.

A nonstationary albedo equation can also be obtained on the basis of the invariance principle [1-3]

$$\begin{aligned} & \left(\frac{1}{\mu} + \frac{1}{\mu_0} \right) \frac{\partial I}{\partial t} + \left(\frac{1}{\mu} + \frac{1}{\mu_0} \right) (\Sigma_c + \Sigma_s) I \\ & = \frac{\Sigma_s}{4\pi\mu} \int_0^t dt' \left[\delta(t-t') + 2\pi \int_0^1 I(t-t', \mu', \mu_0) d\mu' \right] \times \left[\delta(t') + 2\pi\mu \int_0^1 \frac{I(t', \mu, \mu'')}{\mu''} d\mu'' \right]. \end{aligned} \quad (4)$$

Transforming it with respect to t according to Laplace, we again obtain equation (2). Equation (2) can be used to find an accurate expression for the total intensity of the outgoing flux for an isotropic incident flux $A_0(p)$ [1]

$$A_0(p) = (1 - \sqrt{1 - \Lambda}) / (1 + \sqrt{1 - \Lambda}). \quad (5)$$

Substituting expression (3) for Λ , we find the original of the Laplace transform

$$A_0(t) = \frac{I_1 \left(\frac{v\Sigma_s}{2} t \right) e^{-\left(\Sigma_c + \frac{\Sigma_s}{2} \right) vt}}{t} \quad (6)$$

To allow for the moderating neutrons (multiplying half-space) we should proceed from a kinetic equation with moderating neutrons

$$\frac{1}{v} \frac{\partial \Phi}{\partial t} + \mu \frac{\partial \Phi}{\partial z} + (\Sigma_s + \Sigma_c + \Sigma_f) \Phi = \frac{1}{2} \left[(\Sigma_s + v(1 - \beta) \Sigma_f) \Phi_0 + \sum_i C_i \lambda_i \right], \quad (7)$$

$$\frac{\partial C_i}{\partial t} = -\lambda_i C_i + \nu \Sigma_f \beta_i \Phi_0; \Phi_0(t, z) = \int_{-1}^{+1} \Phi(t, z, \mu) d\mu. \quad (8)$$

Here ν is the number of secondary neutrons per fission; Σ_f is the fission cross section; β_i is the fraction of the i -th group of moderating neutrons; λ_i is the constant of decay of the i -th group; C_i is the density of the nucleus-precursor of the i -th group;

Transforming the equation with respect to t according to Laplace for zero initial conditions and excluding C_i , we find:

$$\mu \frac{\partial \Phi}{\partial z} + (\Sigma_c + \Sigma_s + \Sigma_f + p/\nu) \Phi = \frac{1}{2} \left[\Sigma_s + \nu \Sigma_f \left(1 - p \sum_i \frac{\beta_i}{p + \lambda_i} \right) \right] \Phi_0. \quad (9)$$

This equation leads to an albedo equation (2) where Λ will have the form:

$$\Lambda_{\text{mod}} = \frac{\Sigma_s + \nu \Sigma_f \left(1 - p \sum_i \frac{\beta_i}{p + \lambda_i} \right)}{\Sigma_s + \Sigma_c + \Sigma_f + p/\nu}. \quad (10)$$

The isotropic albedo is expressed as previously by formula (5) but with a new value $\Lambda = \Lambda_{\text{mod}}$.

If we only consider one group of moderating neutrons, we can find analytically the original $A_0(p)$:

$$A_{\text{mod}}(t) = \frac{1}{t} I_1 \left(\frac{x}{2} vt \right) \exp \left\{ vt \left[\Sigma - \frac{x}{2} - \frac{\lambda}{v} \frac{y}{x} \right] \right\}$$

where

$$+ B \int_0^t \frac{I_1(2B \sqrt{s(t-s)})}{\sqrt{s(t-s)}} I_1 \left(\frac{x}{2} vs \right) \times \exp \left\{ vs \left[\Sigma - \frac{x}{2} - \frac{\lambda}{v} \frac{x+2y}{x} \right] + \lambda t \frac{x+y}{x} \right\} ds, \quad (11)$$

$$\left. \begin{aligned} B &= \sqrt{\lambda \frac{y}{x} \left(\Sigma v - \lambda \frac{x+y}{x} \right)}; \\ \Sigma &= \Sigma_c + \Sigma_s + \Sigma_f; \\ x &= \Sigma_s + \nu \Sigma_f (1 - \beta); \\ y &= \beta \nu \Sigma_f. \end{aligned} \right\} \quad (12)$$

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. Some or all of this periodical literature may well be available in English translation. A complete list of the cover-to-cover English translations appears at the back of this issue.

SOME PHYSICAL PROPERTIES OF A LAYER OF ARTIFICIAL
GRAPHITE PARTICLES

Z. R. Gorbis and V. A. Kalender'yan

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,
pp. 450-454, November, 1961

Original article submitted March 28, 1960

The use of a moving layer of graphite particles as a coolant is of interest for nuclear power. However, for this purpose it is essential to know the basic physicomachanical and thermophysical properties of the layer of graphite particles. The material which we investigated was graphite scrap from the Zaporozh (batch 1) and Novocherkassk (batch 2) electrode plants. The ash content in the particles did not exceed 0.5%. The dimensions of the particles are given in Tables 1 and 2.

Density and Weight of One Cubic Meter of Dry Granular Graphite Particles

The mechanical and thermophysical properties of free-flowing materials are determined by the porosity of the layer (β) or the density of packing (ϵ). These characteristics are determined by the weight of one cubic meter of dry granular particles (γ_g) and the density (γ), where

$$\beta = 1 - \epsilon = 1 - \frac{\gamma_g}{\gamma} \quad (1)$$

The density of the material of the particles, determined with an accuracy of 1%, was 2050 kg/m³. The density of graphite in a component is 1650 kg/m³. These data agree well with those of [1]. The densities of the individual particles were also determined (see Table 1), which lie within the limits of the above values of densities of the material and component.

TABLE 1. Density and Weight of One Cubic Meter of Dry Graphite Particles

Particle size, mm	Density, kg/m ³	Weight of one cubic meter of stationary layer, kg/m ³		
		batch 1		batch 2
		before operation in apparatus	after operation in apparatus	after operation in apparatus
> 2.88	1799	862	—	940
2.08	1930	874	920	978
1.44	1980	914	—	948
0.77	2019	943	1050	993
0.4	2046	—	1013	1044
Mixture	—	974	1100	1112

The mean (with an accuracy of $\pm 2\%$) results of repeated determinations of the weight of one cubic meter of dry granular material of a stationary layer, given in Table 1, show that this weight of the layer increases with decrease in the particle size. This is due to the better filling of the volume by the small particles. Characteristic is the closeness of γ_g of a mixture of particles to γ_g of dust-like particles of size 0.4 mm.

TABLE 2. Angles of External Friction and Natural Slope of a Layer of Graphite Particles (Screening on laboratory sieves)

Particle size, mm	Angle of external friction of rest, degrees	Coefficient of external friction of rest	Angle of external friction of motion, degrees	Coefficient of external friction of motion	Angle of natural slope, degrees
> 3.5	18°50'	0.33	9°30'	0.167	39
2.96	19°30'	0.35	6°26'	0.113	35
2.24	27°30'	0.52	10°00'	0.176	36
1.70	23°30'	0.43	8°40'	0.152	37
1.32	23°30'	0.43	7°30'	1.132	36
1.10	24°	0.45	13°20'	0.237	36
0.975	26°	0.49	12°50'	0.228	37
0.925	27°	0.51	12°50'	0.228	36
0.85	27°30'	0.52	16°45'	0.301	36
0.73	29°30'	0.57	19°40'	0.357	36°30'
< 0.3	32	0.62	27°30'	0.52	48
Mixture	32	0.62	24°40'	0.459	44—46°30'

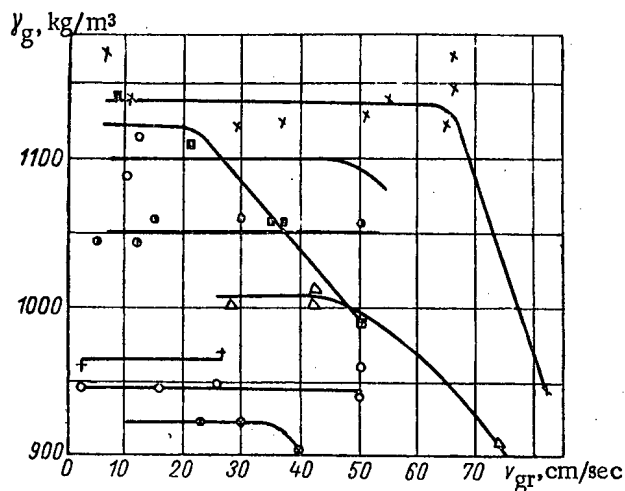


Fig. 1. Dependence of the weight of one cubic meter of moving layer of graphite particles on their size (d_r) and speed v_{gr} in different channels. Annular channels of diameter $100 \cdot 33$ mm (smooth rod): x) Mixture; +) $d_r = 2.88$ mm; O) $d_r = 2.08$ mm; ⊕) $d_r = 0.77$ mm; line for the value $\gamma_g = 1100$ kg/m³ - mixture (rod with inclined ribs); ■ mixture (rod with straight ribs). Annular channel of diameter $63 \cdot 33$ mm (smooth rod): Δ) mixture; ⊗) $d_r = 0.77$ mm).

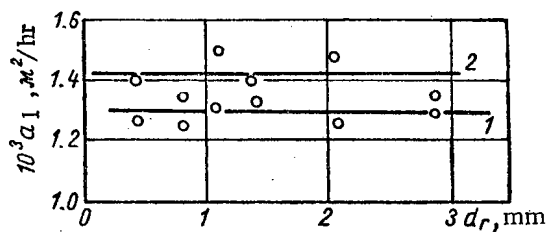


Fig. 3. Dependence of the temperature conductivity of a layer of particles on their size: 1) Before using particles in a moving layer; 2) after using particles for about 600 hr in a moving layer.

The weight of one cubic meter of the moving layer was determined during movement of the layer along smooth and ribbed tubes in various vertical channels of annular cross section. For this purpose there was simultaneous closing of a measured section of height 3 m at the inlet and outlet followed by weighing of the separated part of the layer. Experiments were carried out with graphite particles of different sizes and a mixture of particles, with change in the speed of the layer from 3 to 80 cm/sec. The results of the measurements, given in Fig. 1 for various channels, point to the practical constancy of the weight of one cubic meter of the layer with increase in the rate to a certain value depending on the cross section of the channel. If this speed is exceeded there is a sharp decrease in the weight of one cubic meter due to tearing of the layer.

With repeated use of the moving layer in the metal channels there is a reduction in size of the graphite particles due to which the fractional composition of the layer changes, there is a decrease in the mean particle size, and an increase in the weight of one cubic meter. For example, the composition of batch 1 in 500-700 hr of use in an experimental apparatus changed in the following way, the number of particles measuring 2.88 mm was reduced from 20.3 to 14.1%; those measuring 0.77 mm increased from 15.2 to 24% and those measuring less than 0.5 mm increased from 37.1 to 40.7%. The mean particle size of the mixture was then reduced from 1.34 to 1.22 mm, the volumetric weight of the moving layer of mixture increased by 22%, and that of the stationary layer by 21%. On the whole this phenomenon requires further study to establish the rate of particle-size reduction of the graphite particles.

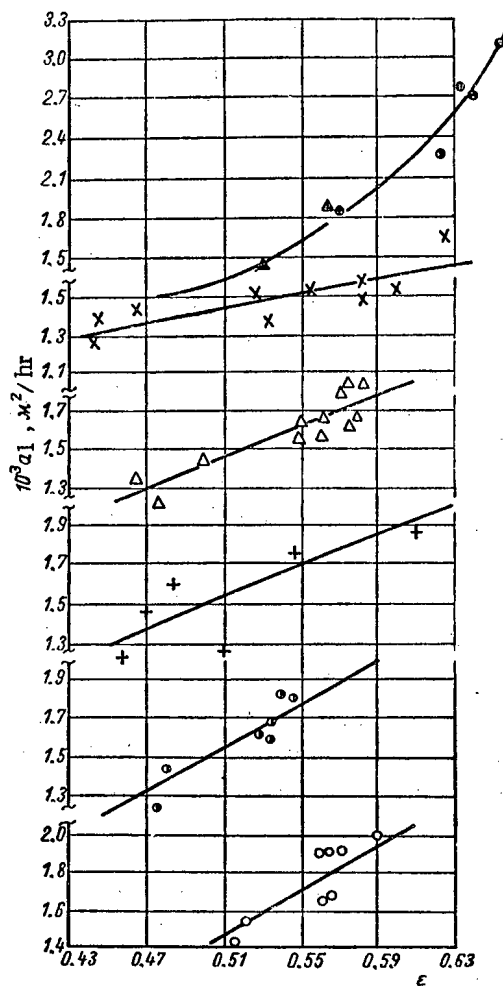


Fig. 2. Dependence of the temperature conductivity of a layer of graphite particles on the density of its packing: Δ, ●) Mixture; x) $d_r = 0.4$ mm; Δ) $d_r = 0.77$ mm; +) $d_r = 1.44$ mm; ⊕) $d_r = 2.08$ mm; O) $d_r = 2.88$ mm.

The weight of one cubic meter of the moving layer was determined during movement of the layer along smooth and ribbed tubes in various vertical channels of annular cross section.

Angles of External Friction and the Natural Slope of a Layer of Graphite Particles

The angles of external friction were determined for 11 fractions of graphite particles and their mixture of batch 1 both in the state of rest and in motion. The angle of external friction of rest was determined as the angle of in-

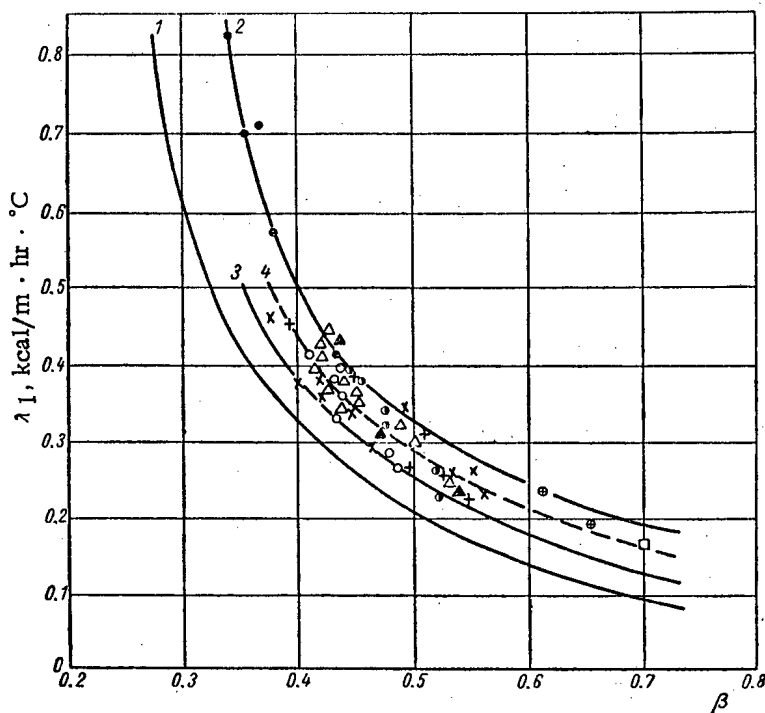


Fig. 4. Dependence of the coefficient of thermal conductivity on the porosity of the layer: 1) According to the Bogomolov formula; 2 and 3) boundary of scatter of the experimental points; 4) averaged curve; ○) $d_r = 2.88$ mm; ●) $d_r = 2.08$ mm; +) $d_r = 1.44$ mm; Δ) $d_r = 0.77$ mm; ×) $d_r = 0.4$ mm; ●) mixture of batch 1; ▲) mixture of batch 2; ⊙) data of Kozak [4]; □) data of Fokin [5].

clination of the plane for which a mound of particles begins to move with this plane. The angles of external friction of motion was determined on a special instrument. The data were used in the formula

$$f_m = \tan \sigma_m = \tan \alpha - \frac{x^2}{4l(y - x \tan \alpha) \cos^3 \alpha} \quad (2)$$

where f_m , ρ_m are the coefficient and angle of external friction of motion respectively; α is the angle of inclination of the plane of motion (acceleration), equal to 30° ; x , y are the coordinates of the trajectory of free motion of the particles, marked on the coordinate grid of the instrument; l is the length of the plane of motion, equal to 28 cm.

The results of the measurements are given in Table 2. The effect of particle-size reduction on the angle of external friction is due to the increase in their specific surface and the forces of adherence to the plane.

In the experiments with graphite particles measuring 0.4 mm a lack of dependence was detected between the angle of external friction and the material of the plane (for steel 27.4° , for rubber 27.3° , for plastic 26.6°). Also characteristic are the somewhat better pouring properties of dust of artificial graphite ($\rho_m = 27^\circ 30'$) compared with dust of natural graphite (30°).

The angle of natural slope, characterizing the coefficient of internal friction, was found for graphite particles distributed on ten sieves. More reliable results were given by two methods for determining this angle; the method of a vessel with a moving wall and the method of a rotating rectangular vessel. Table 2 gives results for repeat determinations, with an accuracy of $\pm 5\%$, of the angle of slope during free pouring of the layer.

The effect of layer packing on the angle of slope was found for a mixture of particles and graphite dust. With a change in the weight of one cubic meter of dry material from 925-950 to 1040-1100 kg/m³ the angle increased from 46-48 to 57-60°. Experiments also showed that heating the layer to ~ 400°C somewhat reduces the angle of natural slope (by ~10%).

It should be mentioned that according to the obtained data the angle of natural slope is always higher than the angle of external friction both in motion and at rest.

Temperature Conductivity of a Layer of Graphite Particles

The coefficient of temperature conductivity was determined by the first method of a regular system [2] as a function of the size and density of packing of the graphite particles according to the formula

$$a_1 = km_\infty, \quad (3)$$

where $k = \left(\frac{R}{\pi}\right)^2$ is the coefficient of the form a of the calorimeter, equal to $0.914 \cdot 10^{-4} \text{ m}^2$; $m_\infty = \frac{\Delta \ln \theta}{\Delta \tau}$ is the rate of heating of the layer with the condition $\alpha \rightarrow \infty$; $\Delta \ln \theta$ is the change in the logarithm of the relative temperature during the interval of time $\Delta \tau$.

Figure 2 shows the results of experiments. The greater effect of density of packing for mixtures of particles is due to the greater heterogeneity of the layer in this case.

The effect of the particle size on the temperature conductivity of the layer was evaluated at the same density of packing and is given in Fig. 3. The increase in temperature conductivity of the layer after prolonged use as a moving layer is due to the previously-mentioned effect of reduction in particle size leading to a certain increase in density of packing of the layer.

Thermal Conductivity of a Layer of Graphite Particles

In the region of low temperatures ($t_m = 60^\circ\text{C}$) the coefficient of effective thermal conductivity of the layer was determined from the above data on the temperature conductivity of the layer of graphite particle by the formula

$$\lambda_1 = a_1 c \gamma_g$$

where c is the mean gravimetric specific heat of the graphite, determined by a formula given in [3],

$$c = 0.342 + 0.85 \cdot 10^{-4} T - \frac{0.175}{T^2} \cdot 10^6 \text{ kcal/kg } ^\circ\text{C}.$$

The dependence of λ_1 on the size of the graphite particles and on the porosity of the layer is shown in Fig. 4. The curve 1 was plotted from the theoretical formula of Bogomolov [6]

$$\lambda_1 = 21.7 \lambda_a \log \frac{0.74 - 0.31e}{0.74 - e}.$$

The equidistant placing of the curves points to the qualitative satisfying of the Bogomolov regularity for the material under investigation. The quantitative difference from this regularity can be explained by the heterogeneity of the layer, the high thermal conductivity of graphite, the deviation of the particles from spheres with octahedral packing, assumed by Bogomolov, which should be particularly noticeable for mixtures of particles [6].

The position of the points (see Fig. 4) obtained in the region of low porosity of the layer ($\beta < 0.45$) for an industrial mixture of graphite particles on the upper curve 2, points to the higher coefficient of thermal conductivity of the mixture of particles compared with the coefficient of thermal conductivity of the fractionated layers.

Figure 4 also gives the data of Kozak on the thermal conductivity in the region of low temperatures for "Acheson" and "Korea" graphite powders with weights of one cubic meter of dry material 690 and 780 kg/m³ [4] and the data of Fokin for graphite particles screened through a sieve with 3, 6 and 16 holes per 1 cm² [5].

The data of Fokin, which are often referred to in the literature as an illustration of the increase in thermal conductivity of a layer due to increase in the particle size [6], give rise to doubts since in the first place he did not study fractionated particles but a mixture of unknown composition, in the second place there is no regular dependence of

the weight of one cubic meter of dry material on the particle size, in the third place the data on the thermal conductivity are given with a simultaneous change in two factors – the particle size and the weight of one cubic meter of dry material, when the particle size is doubled the thermal conductivity becomes six times as large, in the fourth place the method and conditions for determining the thermal conductivity are not given.

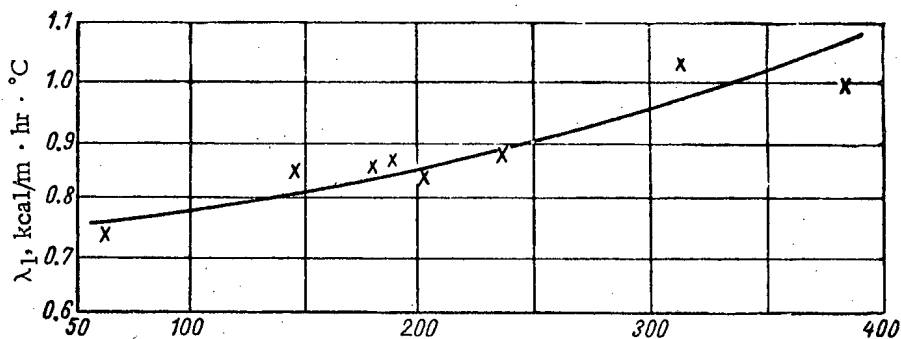


Fig. 5. Temperature dependence of thermal conductivity of the layer, obtained by methods of regular and stationary conditions (mixture of batch 1; $\gamma_g = 1280 \text{ kg/m}^3$; $\epsilon = 0.664$).

To determine the coefficient of thermal conductivity of a layer of graphite particles in the region of low temperatures the following calculation formulas can be recommended.

For particles measuring 0.4-3 mm [along the middle line (see Fig. 4) with an error of $\pm 6-8\%$]

$$\lambda_1 = 29.7 \lambda_a \times \log \frac{0.74 - 0.31 \epsilon}{0.74 - \epsilon} \quad (4)$$

For an industrial mixture of particles, i.e., for graphite scrap in the region $0.55 < \epsilon < 0.65$ [along the upper line (see Fig. 4)].

$$\lambda_1 = 4.8 \pi \lambda_a \ln \frac{0.43 + 0.31 \beta}{\beta - 0.26} = 34.8 \lambda_a \log \frac{0.74 - 0.31 \epsilon}{0.74 - \epsilon} \quad (5)$$

where λ_a is the thermal conductivity of air.

To study the effect of temperature on the thermal conductivity of a layer of artificial graphite particles (Fig. 5) we used the method of a stationary system of "a sphere in a sphere." The coefficient of effective thermal conductivity of the layer was then determined by the formula

$$\lambda_1 = \frac{0.86 \delta I U}{\pi D_1 D_2 \Delta t} = A \frac{I U}{\Delta t},$$

where A is a constant for the instrument, for our apparatus equal to 0.413; I and U are the current intensity and voltage of the heater placed in the inside sphere; Δt is the temperature difference established with stationary conditions on the surfaces of the spheres.

Increase in the thermal conductivity of the layer with increase in temperature is due to the increase in molecular thermal conductivity of the gas layers and at high temperatures it is also due to the increase in the radiation component of the total heat exchange. Assuming in certain temperature boundaries a linear relationship $\lambda_1 = f(t)$, we obtain for a mixture of particles and $t \leq 400^\circ$

$$\lambda_t = \lambda_0 [1 + \beta_1 (t_1 - 60) + \beta_2 (t_2 - 225)], \quad (6)$$

where λ_t is the coefficient of effective thermal conductivity of the graphite particle layer at a mean temperature t (kcal/m · hr · °C); λ_0 is the coefficient of effective thermal conductivity of the layer at $t = 60^\circ\text{C}$, determined from formulas (4), (5) (see Fig. 4), (kcal/m · hr · °C); β_1 , β_2 are the temperature coefficients, for $60 < t_1 < 225^\circ$ equal to $0.807 \cdot 10^{-3}$ and for $225 < t_2 < 400^\circ$ equal to $1.75 \cdot 10^{-3} \text{ }^\circ\text{C}^{-1}$.

The experimental data also show that the density of packing of the layer has an important effect not only at low temperatures but also at high temperatures. Thus, with change in density of the layer of the mixture of particles from 0.578 to 0.644 the coefficient of effective thermal conductivity at 400°C increases from 0.81 to 1.08 kcal/m · hr · °C.

Mention should be made of the agreement between data obtained for low temperatures by methods of stationary and regular conditions. Further studies should show the effect of temperature on the properties of the layer as a function of its fractional composition. As well as this it is important to study the dependence of the effective thermal conductivity of the moving layer on its speed, which involves considerable difficulties in procedure.

As yet there are no direct data on the change in physical properties of a layer of graphite particles under the action of irradiation in a reactor. However, it can be assumed that these changes are not serious. However, the thermal conductivity of graphite components under irradiation according to the data of [1] decreases considerably, the effective thermal conductivity of a layer of graphite particles can remain practically unchanged, since the determining factor is not the thermal conductivity of the particles but the thermal conductivity of the gas layers between the grains. It would therefore be of considerable interest to study the effect on thermal conductivity of possible ionization of these gas layers in the active zone of a reactor.

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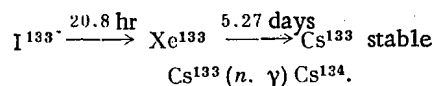
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DETERMINING BURN-UP IN SPENT FUEL ELEMENTS

A. P. Smirnov-Averin, V. I. Galkov, I. G. Sheinker,
V. P. Meshcheryakov, L. A. Stabenova, and B. S. Kir'yanov

Translated from *Atomnaya Énergiya*, No. 11, No. 5,
pp. 454-456, November, 1961
Original article submitted September 13, 1960

When studying spent fuel elements the determination of burn-up of the nuclear fuel is very important. The most accurate is the mass spectrometric method for determining burn-up directly, from the decrease in U^{235} . However, this method requires very complex and expensive apparatus, a special building and a special staff of workers. Burn-up is most simply determined from the accumulation of some long-lived fragment. Cs^{137} is usually used for this purpose. The method of investigation for fuel elements with a low burn-up was described previously [1, 2]. For fuel elements with a higher burn-up (more than 20%) the determination of the total number of fissions is complicated by the accumulation during reactor operation of the radioactive isotope Cs^{134} , which occurs according to the following scheme:



The relative activities of individual components in the mixture of radioactive isotopes $Cs^{137} + Cs^{134}$ were determined by means of a single crystal scintillation γ -spectrometer, a scintillation β -spectrometer and schemes of β - γ coincidences.

The apparatus γ -spectrum of a mixture of Cs^{134} and Cs^{137} has two photo peaks (Fig. 1), one of which is caused by γ -radiation of only Cs^{134} ($E_{\gamma m} = 0.80$ Mev), and another is a superimposition of the photo peaks Cs^{137} ($E_{\gamma} = 0.66$ Mev) and Cs^{134} ($E_{\gamma m} = 0.59$ Mev).

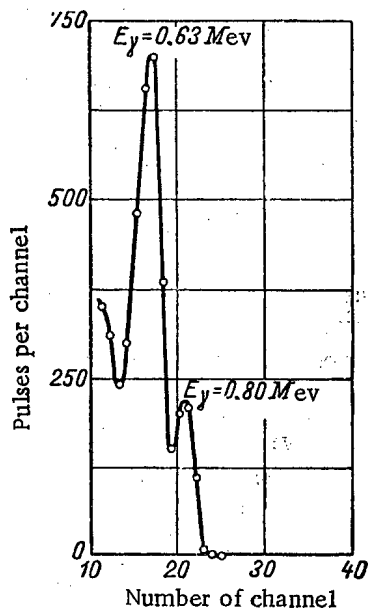


Fig. 1. Apparatus γ -spectrum of $Cs^{137} + Cs^{134}$.

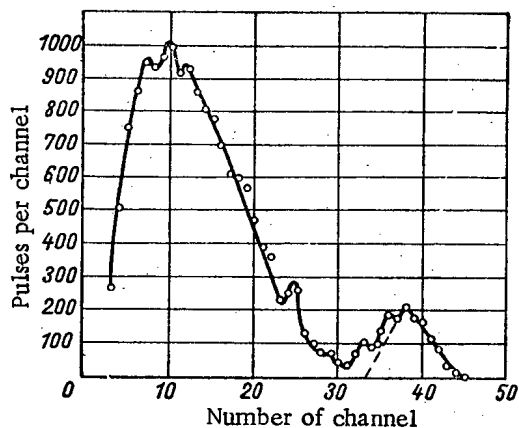


Fig. 2. Apparatus β -spectrum of $Cs^{137} + Cs^{134}$.

content of Cs^{134} and Cs^{137} ; in the investigated specimens of radioactive cesium separated from a mixture of fragments this calibration could be used to determine (with an accuracy of $\pm 5\%$) the relative content of Cs^{137} , in which we were interested.

On the scintillation β -spectrometer the apparatus spectrum of a mixture of Cs^{134} and Cs^{137} has the form shown in Fig. 2. The coefficient of internal conversion was determined from the measured spectrum of Cs^{137} and was found to agree well with the tabular value of 0.119.

Multiplying the area of the Cs^{137} conversion peak separated from the spectrum of the Cs^{134} and Cs^{137} isotope mixture by the coefficient of conversion gave the area of the Cs^{137} continuous spectrum of β -radiation. Subtracting the area corresponding to Cs^{137} from the area of the continuous β -spectrum of the mixture gave the area of the continuous spectrum of the β -radiation of Cs^{134} and, consequently, the relative content of Cs^{137} and Cs^{134} .

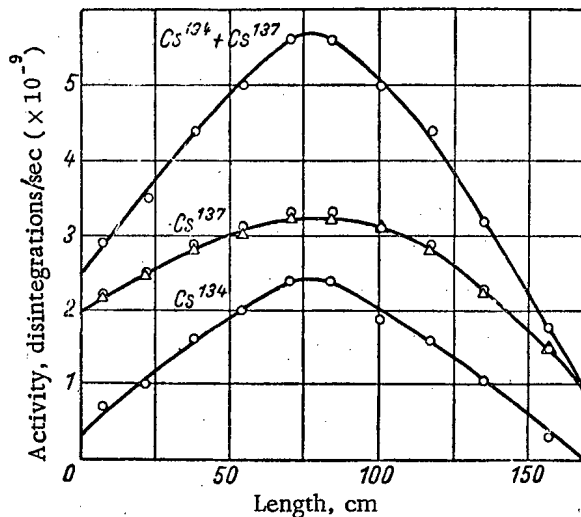


Fig. 3. Distribution of the isotopes Cs^{137} and Cs^{134} along the length of the fuel element: \circ) Measurement; Δ) calculation.

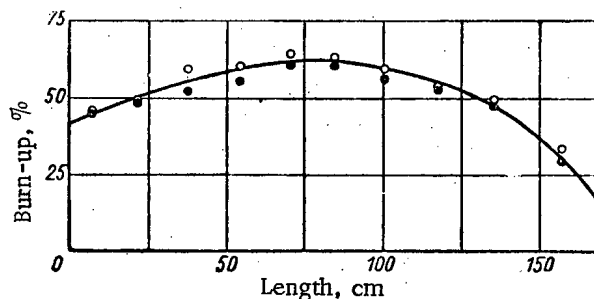


Fig. 4. Burn-up along the length of a fuel element, determined from cesium (\bullet) and mass spectrometrically (\circ).

Artificially prepared mixtures of isotopes Cs^{134} and Cs^{137} were used to calibrate the dependence of the ratio of areas of the above photo peaks on the relative

The β - γ coincidences in the mixture of Cs^{137} and Cs^{134} were only due to radiation of Cs^{134} . Consequently, by measuring the intensity of radiation of a mixture of cesium radioisotopes and then the rate of count of the β - γ coincidences from this mixture it is possible to calculate the relative content of Cs^{137} in the mixture.

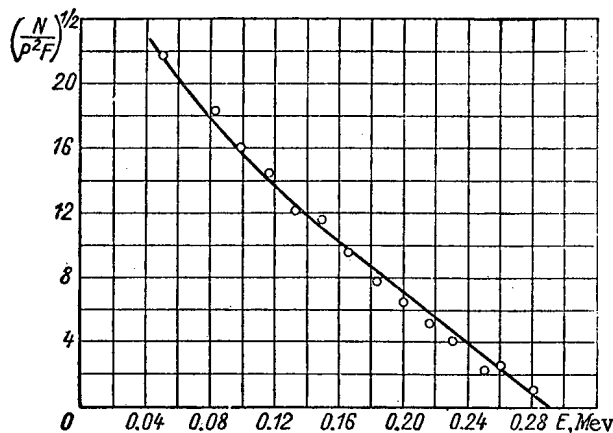


Fig. 5. Curie graph for Tc^{99} .

10^5 years), which makes it possible to determine burn-up in specimens with an unknown system of irradiation; has a high yield per fission (6.02%); in the disintegration products there is only one long-lived isotope of Tc^{99} .

The following method was used to separate the technetium. Hydrogen peroxide was added to the initial solution of irradiated uranium to oxidize the technetium to the septivalent state, then iron nitrate and NaOH were added. The precipitate, containing uranium and a number of fragments as well as iron, was separated by centrifuging. The technetium was extracted three times from the centrifugate by equal volumes of methylethylketone. The methylethylketone was then distilled off on a water bath. The solution was then made 2 N with respect to NaOH and hydrogen peroxide was added. After heating the solution and then cooling, another extraction was performed with methylethylketone. The total coefficient of purification of technetium from the other fragments was $2 \cdot 10^5$. Final purification of the technetium was performed with a column of the cation-exchange material KU-2. The specific activity of the separated technetium was determined on a 4π -counter, the purity was checked by a scintillation β -spectrometer (Fig. 5).

The technetium separated by this method was radiometrically pure, which was also confirmed by the coincidence of the percentage of burn-up determined by different methods.

The burn-up determined from technetium was 67%, that determined from cesium for the same sample was 68%; for this specimen the mass spectrometric method gives 66.2%. As can be seen from these figures, the results obtained by various methods are in good agreement.

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THE EFFECT OF THE NATURE OF THE OXIDANT
ON THE TRANSFER OF URANIUM INTO SOLUTION

G. M. Nesmeyanova

Translated from *Atomnaya Énergiya*, No. 11, No. 5,
pp. 456-458, November, 1961

Original article submitted March 13, 1961

A previous paper [1] showed the deciding effect of oxidation processes on the transfer of uranium into solution from pure mixed oxides of uranium. It seemed of interest to study the effect of the nature of the oxidant, the composition of the solvent, the temperature, and duration of the process on the transfer of uranium into solution from natural pitch.

As yet there have been no sufficiently definite data on the comparison of the behavior of individual uranium minerals in solutions of acids with oxidants. Most of the studies used pure uranium compounds such as the dioxide and the mixed oxide and not natural uraninite and pitchblende, having varying ratios of the tetra- and hexavalent uranium [2]. In the present work a sample of pitchblende was used in which of 67% uranium, 22% was contained in the tetravalent state.

In order to obtain comparative data on the effectiveness of various oxidants in the solution of uranium in an acid medium under identical conditions several oxidants were studied. The experiments were carried out at atmospheric pressure, the concentration of the solvent, temperature and duration of the process being varied.

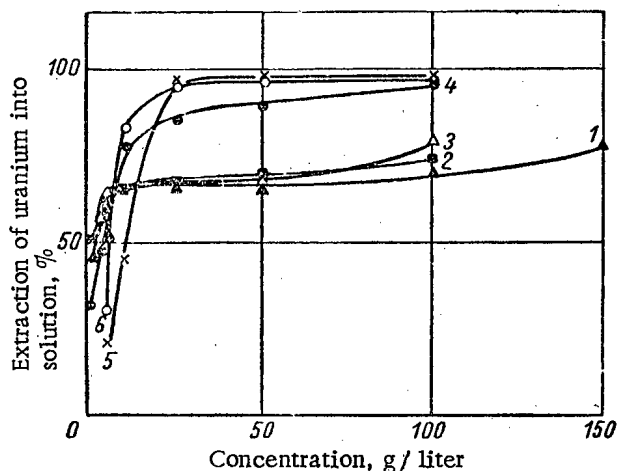


Fig. 1. The effect of the initial concentration of acid on the transfer of uranium into solution during the solution of pitch in nitric acid (6) and in sulfuric acid with the oxidants MnO₂ (1), Fe₂(SO₄)₃ (2), KMnO₄ (3), KClO₃ (4), HNO₃ (5) ($t = 90^{\circ}\text{C}$, $\tau = 30$ min).

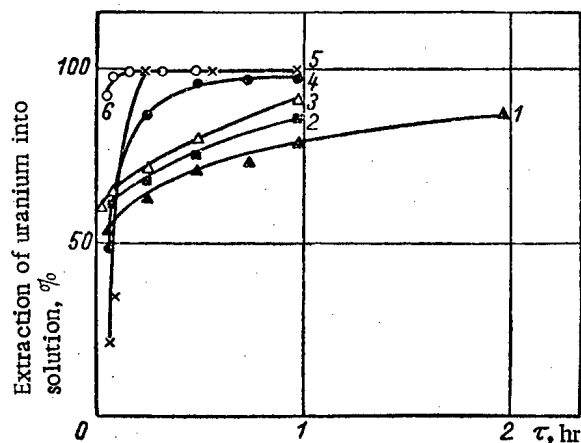


Fig. 2. Effect of duration of the process on the transfer of uranium into solution in the solution of pitch in nitric acid (6) and in sulfuric acid with the oxidants MnO₂ (1), Fe₂(SO₄)₃ (2), KMnO₄ (3), KClO₃ (4), HNO₃ (5) ($t = 90^{\circ}\text{C}$, concentration of acids 100 g/liter).

Figure 1 shows curves for the dependence of the solution of uranium on the initial concentration of the acid. With an acid concentration of 10-25 g/liter the best results are given by nitric acid in the absence of sulfuric acid and also KClO₃ and HNO₃ in a sulfuric acid medium. Even with a sulfuric acid concentration of 100 g/liter, and duration of the process 30 min and a temperature of 90° potassium permanganate, manganese dioxide and ferric salts are not able to produce total solution of the uranium.

Nitric acid is a vigorous solvent, readily reacting not only with uranium but also with impurities contained in the pitch. With a solvent concentration of 100 g/liter the effect of the duration of the process is especially high for

Comparative Characteristics of Various Oxidants with Respect to Uranium, Contained in Pitch

	HNO ₃	Mixture HNO ₃ and H ₂ SO ₄	KClO ₃	KMnO ₄	Fe ₂ (SO ₄) ₃	MnO ₂	Temper- ature, °C
Extraction of uranium in solution in 30 min, %	44	19	32	58	52	38	20
	98	96	95	78	76	68	90

nitric acid in a sulfuric acid medium (Fig. 2); in nitric acid alone the solution of uranium at a temperature of 90° occurs almost instantaneously. Although potassium chlorate in its oxidation properties with regard to uranium is inferior to nitric acid, the process of oxidation and solution of uranium in its presence occurs with sufficient speed. The reaction proceeds most slowly with manganese dioxide, which is presumably due to the low content of iron ions in the pitchblende specimen [3] and the long period needed to dissolve the manganese dioxide.

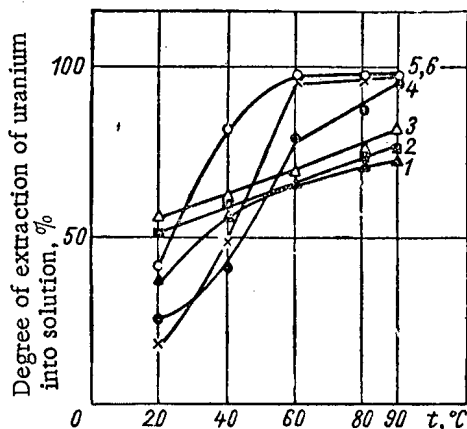


Fig. 3. Effect of temperature of the process on the transfer of uranium into solution during the solution of pitch in nitric acid (6) and in sulfuric acid with oxidants MnO₂ (1), Fe₂(SO₄)₃ (2) KMnO₄ (3), KClO₃ (4), HNO₃ (5) (τ - 30 min, concentration of acids - 100 g/liter).

As can be seen from Fig. 3, only for nitric acid and potassium chlorate does increasing the temperature from 20 to 60° have a deciding effect. For potassium permanganate, manganese dioxide and ferric salts, increasing the temperature from 20 to 30° increases the degree of extraction of uranium into the solution by 15-20%, whereas for nitric acid this increase is 75-80%.

It is interesting to observe that potassium permanganate and ferric salts with widely differing values of the oxidation-reduction potentials approach one another (see table) in their oxidation capacity with respect to uranium. This increased oxidation capacity of ferric ions with respect to uranium makes them a catalyst in the oxidation of uranium by other oxidants [4] in a sulfuric acid medium. The comparatively low efficiency of potassium permanganate compared with other oxidants can be explained by analogy with the solution of molybdenite in solutions of hydrochloric acid [5]. It is supposed that the precipitate of manganese dioxide formed due to reaction between the permanganate and the divalent manganese ions covers the particles of the pitch and slows down its reaction with permanganate.

These data combined with the results for the study of oxidation and solution of pure compounds of uranium in acid media make it possible to compare the effectiveness of various oxidants with respect to uranium.

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THE PROBLEM OF CALIBRATING RADIOMETRIC SEPARATORS

Yu. A. Ėrivanskii

Translated from *Atomnaya Ėnergiya*, No. 11, No. 5,
pp. 458-459, November, 1961

Original article submitted October 17, 1960

The aim of calibrating separators used in the radiometric enrichment of uranium ores is to determine the dependence between the intensity of radiation of the ore specimen and the probability of its separation by the separator into the product of enrichment, for example the concentrate (Fig. 1). However, since the separator can separate the initial raw material into products according to a previously given boundary concentration determined by the adjustment of the radiometer (A), in practice it is more convenient to use the dependence of the probability of separation on the adjustment (Fig. 2). In this case calibration amounts to determining the position of the adjustment regulator of the radiometer, which should correspond to a given probability of separation of a lump of ore with a known content.

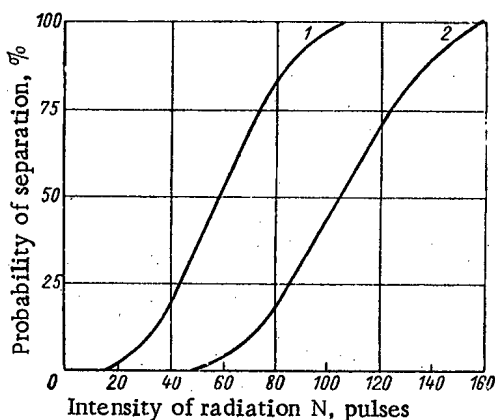


Fig. 1. Dependence of the probability of separation of an ore specimen on the intensity of radiation. Curves 1 and 2 correspond to the position of the adjustment regulator A_1 and A_2 ($A_2 > A_1$).

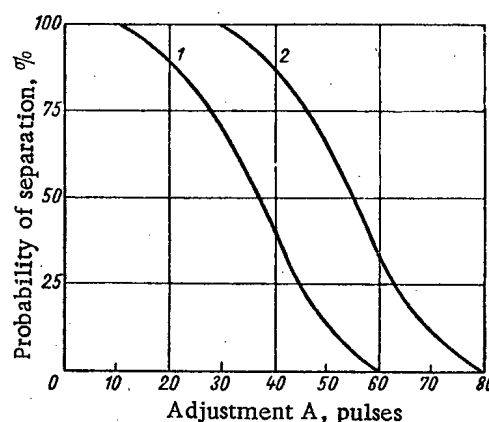


Fig. 2. Dependence of the probability of separation on the adjustment of the radiometer. Curves 1 and 2 correspond to a content of uranium α_1 and α_2 ($\alpha_2 > \alpha_1$).

The method for adjusting the separators described in the literature [1] requires long periods of time or a large number of operators. This operation should therefore be remote controlled from the control panel of the radiometric enrichment plant. The adjustment can be performed quickly by one operator.

It is known [2] that the intensity of radiation of a specimen of known weight recorded by the radiometer during the measurement is equal to

$$N_c = 0.01qaS,$$

and the number of pulses of the adjustment A of the radiometer is determined by the expression

$$A = N_c + N_b + R\sqrt{N_c + N_b}, \quad (1)$$

where N_c is the intensity of radiation of a lump of ore recorded by the radiometer during the time of measurement, pulses/time; q is the weight of the lump, g; α is the uranium content in the lump, %; S is the efficiency of recording of the separator, pulses/g · time; N_b is the intensity of the background radiation recorded by the radiometer during the measurement, pulses/time; R is the argument of the probability function determining the probability of separation.*

* For example, with a probability of separation equal to 5; 50; 95%, R is equal to +1.65; 0.00; -1.65 respectively.

If the radiometer of the separator has an adjustment regulator calibrated in pulses, then it is set in a position corresponding to the found value of A. Otherwise the position of the regulator must be determined which would correspond to the value of A found from formula (1). For this purpose the radiometer must be fed from a distance with a number of pulses equal in value to the adjustment A and, by changing the position of the regulator, a given probability of separation achieved.

In order to obtain the required number of pulses it is possible to use either an additional radiometer placed at the control panel of the radiometric enrichment plant or a standard signal generator. In the first case a given pulse count rate is established by means of a standard specimen at the radiometer, corresponding to the value of $(N_c + N_b)^*$. The pulse detector at the control panel is then connected to the panel of the separator which is being calibrated and the radiation receiver of the separator is disconnected. A number of pulses is then fed to the control panel of the separator equal to the mean value which would be recorded when measuring a large number of standards with the same content, passing through the sensitivity zone of the radiation receiver of the separator. By changing the position of the adjustment regulator we can obtain a given probability of separation.

When using a standard signal generator the dependence of probability of separation on the adjustment changes considerably. The graph characterizing this dependence for a fixed frequency of pulse arrival is a straight line parallel to the ordinate axis.** This type of graph is due to the fact that the control panel of the separator is fed with pulses with a strictly fixed frequency and not statistically distributed in time as in the case when a standard specimen is used (Fig. 2). If the control panel of the separator is fed with pulses from the signal generator with a frequency corresponding to the calculated value of adjustment A, then the separator will operate with a probability of separation equal to 100%. However, a 100% probability of separation will also be obtained for any other position of the adjustment regulator which corresponds to a value exceeding the value of A. Therefore, to determine the accurate position of the adjustment regulator in unit time the control panel of the separator must be fed with a number of pulses equal in value to the calculated adjustment minus one or two pulses.

By changing the position of the adjustment regulator we find a position at which a small deviation on this point in any direction would cause a zero or 100% probability of separation respectively. To check the correctness of adjustment the number of pulses being fed is increased to a value equal to the adjustment plus one or two pulses. The position of the adjustment regulator should then remain unchanged.

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EFFECT OF DUST FROM DISCHARGED SMOKE ON THE AMOUNT OF RADIOACTIVE FALLOUT

P. N. Yagovsi

Translated from *Atomnaya Energiya*, Vol. 11, No. 5,
pp. 459-461, November, 1961
Original article submitted April 17, 1961

The aim of this work is the study of the effect of dust from discharged smoke on the amount of radioactive fallout. Snow samples were used as a material for the study of this problem.

* From one standard specimen, by varying the distance from the standard to the detector or by introducing additional screens between the standard and detector, etc., it is possible to obtain a different pulse count rate.

** The straight line can have a small slope which is due to fluctuation in the threshold of the counting circuit, the instability of the generator and other factors.

TABLE 1. Activity of Snow Samples and Neva River Water (average of three parallel determinations)

Sample number	Sample collection data	Ashed residue content of unfiltered melted snow, g/liter	Activity of melted snow, 10^{-11} C/liter	Activity of prepared sample after 6 months storage, in percent of original activity
	February 11, 1958			
1	Top layer of snow, two hours after deposition	0.2700	5.5	48.2
2	Snow of the same fall as for sample 1, but without the surface layer	0.0152	4.3	44.0
3	Underlying layer of old snow at the collection point for samples 1 and 2	0.1764	12.7	62.8
	March 7, 1958			
4	Top layer of snow 16 hours after deposition in a location heavily contaminated by discharged smoke	24.3500	101.7	63.7
5	Same snow as in sample 4, but without the surface layer	0.0438	4.1	30.0
6	Top layer of snow 16 hours after deposition in a location lightly contaminated by discharged smoke	0.3900	12.4	44.1
	April 7, 1958			
7	Mean sample of city snow	2.0800	22.9	57.0
8	Mean sample of suburban snow	0.0500	13.4	34.5
9	Neva River water	0.0434	0.45	62.4

For determining radioactivity, these samples were collected around Leningrad during the period February-April, 1958, within a definite time after snowfall. Sample collection was carried out in places where snow had been blackened to varying degrees by the dust from smoke discharged by a thermal power station which used coal as fuel. In addition, average snow samples were collected within the city and outside the city (near Pulkovo).

The snow samples were collected in such a manner that about five liters of water were obtained after melting. Three samples were simultaneously collected at each point in order to obtain more reliable average results. All snow samples to be used for intercomparison were collected from the same area (average samples from all snow layers were collected from a 400 cm² area). The melted snow was acidified with nitric acid and evaporated in a weighed porcelain dish. Then the dish, with the residue, was heated in a muffle furnace to a dull red heat and weighed again. An amount of the ashed residue not exceeding one gram was transferred to a weighed aluminum planchet 24 cm² in area. The surface of the ashed residue on the planchet was made smooth and the resulting preparation weighed. The activity of the preparation was determined three days after snow sample collection. A second determination of each preparation was made after six months. The number of background counts and the number of counts from sample plus background was sufficient in every case to assure a relative counting error of not more than 5%. The activity was calculated with the help of uranium standards.

Mean data from three snow sample activity determinations is presented in Table 1. It should be noted that all three samples from the same collection point gave very similar results. For purposes of comparison, the average activity of three samples of Neva River water (six liters each) is presented in the table also.

As is obvious from Table 1, the activity per liter of melted snow is sharply increased for snow contaminated by dust from discharged smoke. This can be seen both by comparison of samples of newly-fallen snow (samples 4 and 5), and by comparison of city and suburban snow samples (samples 7 and 8). Newly-fallen snow without the surface layer (samples 2 and 5) has the least activity. Attention is drawn to the fact that suburban snow and Neva River water contain approximately equal amounts of ash residue, but the snow activity is 30 times higher than the activity of the water.

TABLE 2. Activity of Coal Ash (average of five determinations)

Sample number	Type of sample	Radioactivity of ash, 10^{-11} C/g
1	Fly ash, obtained by burning coal in power station furnaces	1.28
2	Ash in the form of cinders, obtained by burning coal in power station furnaces	1.60
3	Ash, obtained by burning coarse lumps of coal in a muffle furnace	1.88
4	Ash, obtained by burning fine coal in a muffle furnace	1.28

the aforementioned power station. The average result of five activity measurements for each sample of ash is shown in Table 2. As is indicated in the table, samples of fly ash and of cinders, as well as samples of coarse and fine coal were selected for activity determinations.

One can take $1.5 \cdot 10^{-11}$ C/gm as the activity of ash produced by burning coal, according to the data of Table 2. If it is assumed that the activity of snow is increased only because of the activity of the contamination from discharged smoke, then the activity of snow sample 4 should be more than the activity of sample 6 (see Table 1) by $1.5 \cdot 10^{-11}$ C/gm \cdot 24 gm = $36 \cdot 10^{-11}$ C/liter. Actually, it is more by $(101.7-12.4) \cdot 10^{-11} = 89.3 \cdot 10^{-11}$ C/liter. Therefore, each gram of ash in discharged smoke picked up activity equalling $2.2 \cdot 10^{-11}$ C/gm on its path from chimney to point of deposition (a distance of 200-300 m).

If the mean city and suburban snow samples are compared (see Table 1, samples 7 and 8), then one can say that 2.03 gm of ash added $9.5 \cdot 10^{-11}$ C/liter to the city snow, i.e., each gram of ash added not $1.5 \cdot 10^{-11}$ curies, but $4.7 \cdot 10^{-11}$ curies. Therefore, dust from discharged smoke adsorbed on its surfaces radioactive particles from the air to the amount of $3.2 \cdot 10^{-11}$ C/gm of ash. Thus, dust from discharged smoke, settling on the snow, increased its activity "washed out" of the air. Moreover, the inherent activity of dust from discharged smoke is less than that adsorbed from the air.

The results of activity determinations (in percent of initial activity detected three days after sample collection) of the preparations following a six-months storage period are also given in Table 1. These results indicate that snow samples contaminated by discharged smoke (samples 3, 4, and 7) have high activities. Material with shorter half-life is found in snow samples lightly contaminated by discharged smoke (samples 2, 5, and 8). This difference depends on the long-lived isotopes in the ash from discharged smoke as the following calculation shows. If, for sample 4, the $36 \cdot 10^{-11}$ C/liter emitted in the ash from discharged smoke is subtracted from the initial activity and the activity after six-months storage, then the activity of this sample determined after six months amounts to only 43.3% of the initial activity. Therefore, dust from discharged smoke adsorbs from the air the same radioactive particles which independently fall on snow uncontaminated by discharged smoke.

The data obtained make it possible to assume that much more radioactive material falls out on snow, soil, and plant cover in locations which are dusty from discharged smoke than in non-dusty locations. This phenomenon can acquire important significance in the neighborhood of an atomic plant.

The adsorption of radioactive particles from the air by dust from discharged smoke leads not only to an increase of radioactive fallout in places where the dust settles, but also leads to a decrease in the concentration of radioactive dust floating in the air. This should be taken into consideration when determining the radioactivity of the air in regions made dusty by discharged smoke.

The data obtained shows that, at the time of fall, snow has a minimum activity which then increases because of deposition of dust on the top snow layer. If the snow is heavily contaminated by dust from discharged smoke, its activity is considerably increased even after a short time, as can be seen from a comparison of samples 4 and 5. Because of this, it is possible to assume that, with contamination by discharged smoke, snow activity is increased either because of the activity of the dust from discharged smoke (ash) itself, or because of the adsorption of radioactive particles from the air onto the surfaces of the dust particles or because of those and other factors. In order to clear up this problem, we carried out determinations of the activity of ash which was obtained by burning coal in the furnaces of that same power station where the contamination of snow by dust from discharged smoke occurred. In addition, the activity was determined for ash which was obtained by burning in a muffle furnace the same coal as that used for fuel by

NEWS OF SCIENCE AND TECHNOLOGY

INTERNATIONAL CONFERENCE ON REACTOR MATERIALS
AND RADIATION EFFECTS

Translated from *Atomnaya Energiya*, Vol. 11, No. 5,
pp. 462-465, November, 1961

The Berkeley (United Kingdom) international conference on reactor materials and radiation effects was held May 29 to June 2, 1961. The conference was scheduled for the inauguration of a nuclear reactor at the Berkeley reactor construction site (near Bristol). 137 scientists from 19 nations attended the conference.

The conference was planned as a broad discussion on topics of importance for the improvement and further development of reactor design, with particular emphasis laid on gas-cooled reactors. The discussion covered the following range of topics: measurement of neutron flux and neutron spectra responsible for radiation damage within the reactor system; theory of displacements; radiation effects and point imperfections in metals (observation by direct methods and flaw detection by indirect methods); mechanical properties (radiation hardening and fracture); corrosion, dimensional stability.

The way the agenda was set up was quite interesting. An introductory lecture was read on the day prior to the discussion of a particular topic by one of the leading specialists in the field. The purpose of this was to outline the status of the problem and to pose questions for discussion. Kinchin, Lomer, Seitz, Cottrell, and Rotheram were among the authorities selected. The morning session started right off with a discussion. Two topics were discussed each day. A short break was followed by a discussion among the participants or groups on any subtopic which captured the interest of the delegates, following which the evening lecture on the general topic for the following day was read to the gathering.

The main report in the field of radiation-damage theory was delivered by Lomer. Of the two major consequences of bombardment of matter by fast particles, we may consider the primary formation of vacancies and interstices (intermediate or displaced atoms). They may be retained in unequal quantities as a result of partial coalescence and the formation of more complex defects. Effects related to damping of thermal spikes are more obscure. We learn from Vineyard's data that there is little ground for talking about anything except pair displacements. In this case the bulk of the energy associated with the primary impact is spent on substitutions, so that the number of displacements per se must turn out to be less and a certain correspondence will shape up between the theoretically-computed number of defects and the experimentally-determined number, and these, as we know, diverged markedly in earlier investigations.

Seitz and Keller moreover hold the view that this apparent discrepancy must be accounted for in terms of annealing in the region of the thermal peak. They showed that this interpretation requires that the energy of the primary impact exceed 1000 ev. Lomer indicates that this is indeed confirmed by the experiments of Kaufman and Ward. We might infer from a general view of Lomer's report that the earlier simplified statistical models of impact energy transfer to atoms must yield its place to concepts which start off by taking into account the paramount significance of a regular crystalline structure.

In a report on electron irradiation, Kewson et al. report some interesting data on the effect of an electron beam on iron and copper whiskers. Depending on the orientation of the beam with respect to the crystal axes (100 and 110), a difference will be observed in annealing kinetics, as well as the absence of polycrystalline metal. This indicates that different types of Frenkel pairs form in different lattice directions under electron bombardment.

Of the papers related to direct observation of radiation-induced defects, we invite attention to the electron-microscopic observations of Menter, Pashley, and Presland on complex defects, in this case dislocation rings brought about by bombardment by ions evaporated from the cathode filament of the electron microscope and accelerated by the field to energies of 80-100 kev. Such ions must always behave in a manner similar to slowed-down fission fragments. Annealing at 400°C results in the disappearance of most of the dislocation rings, but some of them survive and apparently become converted to a special type of defects of tetrahedral form with faces containing a stacking

fault. Another portion of the dislocation ring imperfections increases, providing evidence therewith that these formations contain complexes of interstices

The report by Williamson dealt with an electron-microscopic study of radiation damage in graphite. Graphite lamellae irradiated with neutrons at 300°C showed disks formed by interstices. Their absence from vacancy disks is noted in a detailed studies of contrast effects in an electron microscope. The large size of the disks ($\sim 10^6$ atoms) leads us to infer that interstices are derived from a small volume (3 microns), i.e. possess high mobility. The plates also show clusters of vacancies obtained by quenching from 3000°C and subsequent annealing at 1600°K. One layer is missing, and the presence of a stacking fault is noted. Separate rings tend to form clusters when a large concentration of vacancies is present, since the new rings form in the vicinity of those already present.

Beavers and Nelson studied the formation of defect clusters in Al, and showed a high rate of cluster formation was needed for the clusters to grow to stable dimensions. In the authors' experiments, this was attained by bombardment with H and He ions accelerated to 85 kev.

On the basis of observations of radiation defects by indirect techniques, Clark and Mitchell studied the polarization of luminescence in diamonds, as a means of extracting information on the electron structure of crystal defects. In the same line, we may single out a paper by Eales and Satcliffe on low-angle scattering of x-rays by pile-irradiated graphite. An exposure of $17 \cdot 10^{20}$ nvt at 150-200°C and at angles $>1.5^\circ$ brought about appreciable scattering, but less scattering was observed at smaller angles in pile-irradiated graphite. The former phenomenon is accounted for by the appearance of disk-like clusters (radii from 5 to 15 Å) of intermediate atoms sandwiched between [0002]-layers. The nature of the lowest-angle scattering is to be explained by the fact that primary voids were filled with crystallites which had experienced radiation growth. The results of an anneal of irradiated graphite are treated in detail. In an intense anneal, growth experiences "recovery," and the initial voids are reopened, with an increase in low-angle scattering ensuing.

Couettier and Rappeneau reported on experiments on storage of Wigner energy in graphite irradiated in the G-1 Marcoule reactor. One fact revealed is highly intriguing: When the initial accumulation is large, the tempo of secondary storage following anneal increases. When the dose originally obtained is small, the slope of the secondary storage is linear. Haskett reported on relaxation behavior in irradiated metals (Fe, Ni, others). The results and the theoretical interpretations are similar to those reported by the delegation of the Soviet Union.

Two of the sessions were devoted to the mechanical properties of irradiated materials. The theoretical report was delivered by Seeger and Diehl. In their view, hardening is due to the existence of embrittlement zones constituting a central vacancy cluster in the neighborhood of a Brinkman displacement spike; these zones tend to push the yield limit upwards by forming hindrances in the path of propagation of dislocations. The question of the quantitative relation between yield limit and amount of flux was discussed, an analysis was made in brief form of relaxation and internal friction phenomena in connection with the assumed dumbbell configuration of interstices, and five stages in the annealing processes of defects were studied.

In their report, Jouquet and Rappeneau touched upon the mechanical properties of irradiated graphite. Specimens were drilled from the inner walls of channels in the G-1 reactor. The irradiation temperature was 40-160°C, the flux $1.2 \cdot 10^{20}$ nvt. Hardness increases linearly with dose. The sharpest increase in hardness (to 100%) is observed at the low end of the temperature range. Tempering at 400°C lowers the acquired hardness by 75%. In the annealing necessary to release the Wigner energy, graphite consequently retains some fraction of the acquired hardness, i.e., the hardness of the graphite in a G-1 type reactor may gradually increase.

Trubeau (Canada) considered radiation hardness, hardening, brittle fracture, and ageing of steel. The behavior of the ductile-to-brittle transition temperature in response to shock tests was studied for steels of different compositions (with Ni, Mn, and other additives). In ferrite steels, the transition temperature was found to be the lowest observed, and changes in response to exposure were less than for steels with a higher carbon content, since the free carbide may contribute to the formation of harmful radiation defects under bombardment. The grain size loses virtually all its significance in irradiated specimens. Irradiation of steel at 130-230°C brings about the greatest shift in transition temperature. The same effect is produced by annealing at 200°C of steel irradiated at 100°C. According to the author's report, experiments are now being carried out to arrive at a choice of iron alloys with Ni, Mn, and Al possessing a low transition temperature with reasonable creep resistance at the same time, conferred by intermetallides.

Gifkins and Hal reviewed deformation, slipping of grain boundaries, the role of twinning in brittle fracture, and other subjects. These topics are invested with importance for reactor material service life.

At sessions devoted to corrosion, Ragon and Zemwalt (USA) showed that complicated and troublesome problems of corrosive attack on graphite by small impurities of active gases such as O_2 , H_2O , N_2 , etc. entrained in the helium coolant occurs as the temperature of gas heat release is brought up to 1500-2000°C in the latest types of graphite reactors. Two hazards must be borne in mind: 1) Softening of the graphite and increase in permeability for fragments and fuels takes place as a result of oxidation; 2) Mass transfer, fouling, and carbonizing of metal parts in the pipe-work and tubing takes place. We may furnish a concrete example of the latter. With the highest degree of purification of helium, assuming that the rate of gas flow is 22.5 kg/sec we may expect a total transfer of 45 tons of graphite in the course of a whole year. The mechanism responsible for the oxidation is broken down into several stages: 1) adsorption on active centers, e.g., impurities or the edges of graphite layers; 2) decay of active centers with the formation of CO; 3) crumbling of the graphite (in the form of whiskers) obeying the reaction $2CO = CO_2 + C$ (in cold parts of the pile); 4) interaction between CO_2 and C in the hot zone. Irradiation speeds up the rate of oxidation, since the number of active centers is increased, the highly active (and corrosive) components of the gas come to the fore, and the rate of dissociation of adsorptive complexes is stepped up. Indications are that a 10% oxidation reduces the strength of reactor-grade graphite to half, and permeability to fragments increases sharply. Impurities in the graphite or in the gas (Fe, Ni, Co atoms) are harmful, since they exert a catalytic effect and at the same time contribute to oxidation even at relatively low temperatures (400-800°C). Cladding protection is not always reliable because of the low strength of cladding.

Entill devoted his report to corrosive attack on uranium. The kinetics of uranium oxidation in CO_2 are linear. Oxidation proceeds by way of diffusion of oxygen ions penetrating along interstices through a thin coherent layer of uranium dioxide adhering to the bulk metal. When the film becomes thicker, it cracks partially owing to the stresses, and only the permanent slender film remains adhering to the metal; this permanent film is responsible for the linear behavior of oxidation. It is assumed that exposure must speed up oxidation of the uranium by activating the gas, radiation damage inflicted on the oxide crystal lattice by fission fragments, penetration of fission fragments into the lattice, and disruption of the protective film layer (when the metal warps). Experiments directed toward a comparative study of oxidation inside and outside the pile are not yet completed. The experiments indicated that a reasonable decrease in uranium corrosion expected when uranium is alloyed with various elements (Mo, Nb, Zr, Si, Ti, V, and Cu) was not observed. However, some improvement was noted with respect to CO at 500°C when 1-3% Mo was added. The harmful effect of free carbides was noted and inferences were drawn as to the need for developing cladding of sufficient plasticity.

A report by L. Leach dealt with the mechanism responsible for the kind in the corrosion curve. Using uranium alloys with 5 and 10% Zr as examples, he showed that even though diffusive oxidation even increases when uranium is alloyed with Zr, the oxide film is capable of growing to appreciable thickness without breaking because of its great plasticity. The second part of the report was devoted to theoretical concepts, according to which the oxide layer is regarded as both electrolyte and semiconductor.

The brunt of the attention was perhaps centered on questions encompassing the scope of the last session (dimensional stability of reactor materials).

Englander and associates reported on work being performed in France where applications of various metallic nuclear fuels in reactors and their stability to exposure are being studied. Details of the design of components were described with thoroughness, as well as the compositions of the alloys used and the methods of fuel fabrication, and methods of hermetic sealing. The stability of some of the components cited in the report is quite high. For example, alloys with 0.1% Cr quenched from the β -region appear to withstand exposures to 800 Mw-days/ton without suffering any perceptible deformation; cast uranium alloys with 0.5% Mo in type C components (28 mm) allow exposure to be brought up to 1000 Mw-days/ton, and in type B components (tubular items 29.5-22 mm) even to 6000 Mw-days/ton, with no perceptible deformation.

Two reports were devoted to fragment-induced swelling of uranium. Greenwood analyzed the problem of whether or not pre-exposures at a higher temperature would contribute to improved behavior of uranium exposed to high operating temperatures, and found no such effect.

Moustellier et al. submitted a report containing a detailed and thorough description of radiation effects at high temperatures (490°C) on uranium-molybdenum alloys. The study was performed using density determination techniques, x-ray diffraction, x-ray micrography, and x-ray analysis. After the exposures (under thermal stresses of 10^6 kcal/m² · hr over a 125 day course at 600°C), the density of the specimens was reduced from 18 to 15.2-12.7, depending

on the percentage content of molybdenum. Pores were observed to concentrate preferentially near the outer surface, and the dimensions of bubbles were $\sim 1 \mu$ at high exposure, with volume swelling reaching 57%. At bubble sizes of 400 A, only negligible swelling was observed, and the internal pressure was offset by surface tension forces. The assumption is entertained that even a fairly tenuous shell must be sufficient to hinder coalescence of bubbles and inhibit swelling.

The swelling phenomenon is characteristic of boron-containing materials exposed to prolonged high-temperature irradiation, as well as of uranium. A report by Holden et al. subjected the behavior of control-rod materials in which boron entered in the form of various chemical compounds to a painstaking analysis. Pure metallic boron and boron carbide suffer drastic cracking when subjected to burn-up, thereby releasing all of the helium formed within the material. The most stable of the borides for the same percentage burn-up are compounds of the MeB_2 type, with MeB_4 and MeB_6 trailing behind. Alloys of B^{10} with stainless steel show superior behavior. At 90% burn-up of B^{10} , a 45% increase in the strength of the steel is observed, with elongation reduced by 70-75%; the B^{10} content in that alloy was 0.19 wt.-%. Alloys with Ti, Zr, zircaloy were tested; in those cases the increase in volume corresponded approximately to the number of atoms burnt up. Cermets and B_4C in aluminum oxide were also tested. The causes for concentration of gas released and for release of bubbles came up in the general discussion.

A second report by Roberts described observations on the formation of gas bubbles in irradiated boron steels. This steel contained 4 wt.-% boron. After exposure at 300°C for 30 months inside a boride constituent, no changes were noted. However, bubbles appear and grow after annealing, with original bubble diameter $\phi = 300$ A. At low burn-up, the size of the post-anneal bubbles in the steel reach 200 A (after an anneal at 900°C). If burn-up is high, then the anneal will be followed by a disappearance of bubbles in the vicinity of the boride, and the bubbles will be observed at a spacing of 4-6 μ from the edge (the range of alpha particles is 4 μ), and they will attain a size of 0.15 μ . The author supposes that the internal pressure of the bubble gas is balanced by surface tension. The phase boundaries are the effective sites of vacancy sinks.

Tottle reported findings on thermal cycling of graphite. Dimensional changes accompanying each cycle were investigated in a specially designed vacuum dilatometer; the temperature ranges were 50-200°C and 50-250°C. The results were that: 1) Specimens contracted by approximately $8 \cdot 10^{-3}\%$ preferentially in the direction parallel to the extrusion direction, after 20 cycles; 2) Specimens contracted along one of the axes perpendicular to the extrusion axis and their thermal-expansion coefficient increased appreciably; 3) Specimens became elongated in the direction perpendicular to the first two axes with a slight increase in thermal-expansion coefficient.

Atchinson and Honickam reported on results of thermal-cycling experiments with zirconium. It was found that the coefficient of thermal expansion increases with the temperature, more so on the c axis than on the a axis. Heating to 600-800°C brought about high thermal stresses in the grains of the polycrystalline metal. Zr with low and high (to 95%) texture were both studied. The first cycles resulted in the appearance of slip lines, with a large share of the changes associated with the cooling phase. On cooling to 720°C, an abrupt migration of grain boundaries is observed. Cooling to 400°C produces twinning, and cooling to 300°C results in slip. Cycling of slightly-textured specimens causes an elongation of about 12% in 850 cycles over a 50-750°C range. However, cycling over the 50-400°C range produces a size reduction. It is somewhat strange that highly-textured specimens grow at a rate only one third that of slightly-textured specimens. The authors invoke the imperfection of its structure, which does not allow any significant intergrain stresses to appear, in an attempt to account for this fact. Photographs clearly showing the migration of grain boundaries during thermal cycling of Zr were shown.

Four reports by members of the Soviet delegation were also made outside of the formal agenda of the conference. S. T. Konobeevskii, B. M. Levitskii et al. reported on "The effect of irradiation on relaxation of stresses in some materials." A. D. Amaev et al. reported on "The effect of neutron exposure on the properties of structural materials," V. M. Golyanov on "Electron-microscopic studies of uranium fission," and Sh. Sh. Ibragimov on "The effect of fast neutrons on some properties of carbon steels."

In conclusion, we may take note of the broad and inclusive scope of the conference agenda. Despite the fact that almost all the reports were related in some way or another to the most important questions in practical engineering of gas-graphite type reactors, they were of no mean interest for reactor design in general. There is also no denying that the data presented in many of the reports contributed to better understanding of the physics of phenomena occurring in materials exposed to irradiation.

S. T. Konobeevskii

EXHIBIT OF CZECHOSLOVAK NUCLEONIC INSTRUMENTS

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,
pp. 465-467, November, 1961

A Czechoslovak exhibit of nucleonic instrumentation was open to the Moscow public during June 1961, at the Polytechnic Museum in the city.

The displays may be broken down into two groups: electronic instruments used in nucleonics, and laboratory devices incorporating radioactive substances.

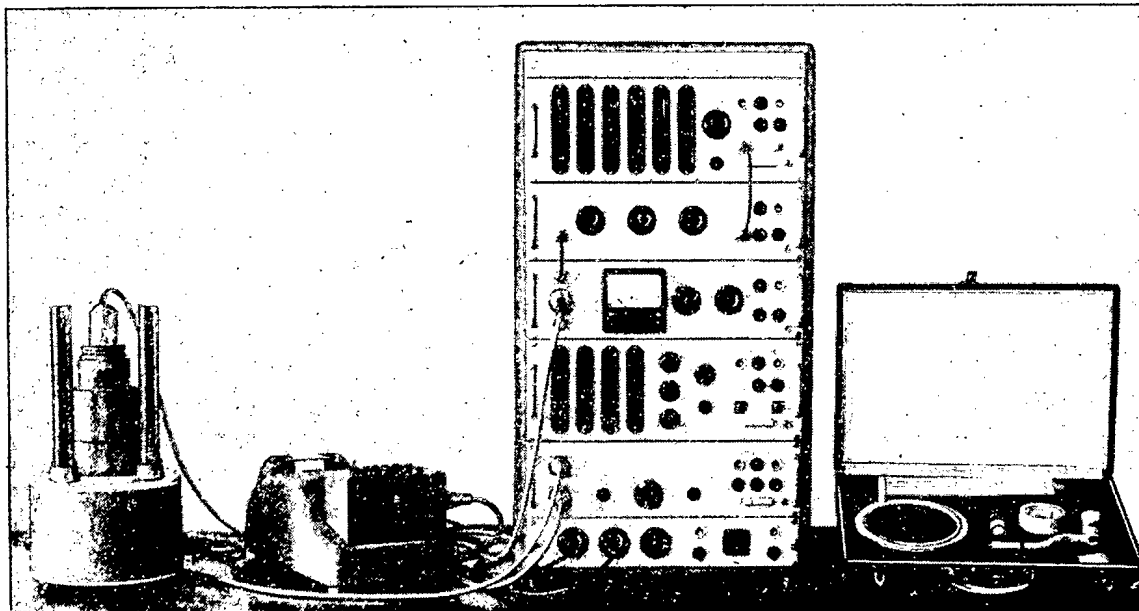


Fig. 1. The NZQ-615 automatic facility for measuring radioactive specimens.

Laboratory equipment is the first point of interest in the electronics line. Visitors showed the most interest in an automatic facility for measuring radioactive samples, model NZQ-615 (Fig. 1). This facility is useful for rapid automatic measurement of a large number of radioactive samples. Use of this facility eliminates subjective errors in the measurements and also minimizes radiation-exposure hazard to service personnel. The input section of the device is adapted to facilitate coupling of transducers containing scintillation counters or Geiger-Müller counters.

Advances in scintillation techniques were represented at the exhibit not only by equipment, but by scintillators as such. At the present time, all of the basic types of scintillators are being produced in the Czechoslovak Socialist Republic: NaI(Tl) and ZnS scintillators, plastic and liquid scintillators, and scintillating gels. The scintillators make it possible to measure and study α -, β -, γ - and neutron radiations. NaI(Tl) scintillators of up to 140 mm diameter are being fabricated in Czechoslovakia, and feature excellent resolution.

The Univel model general-purpose electrometer, designed for measurement of electrical charges, supply voltages, or very small electric currents, also attracted a good deal of attention. The instrument is fabricated in the form of a dynamic electrometer with a vibrating membrane capacitor. It is used in combination with an ionization chamber for laboratory measurements of radioactive isotopes (type L) and for measurements in radioisotope applications in industry (type P).

Pocket dosimeters, including a charger, and the DI-meter, a ratemeter designed for dose measurement and radiation intensity measurement, were among the dosimetry devices on display.

As for industrial nucleonic instrumentation, one item which made a particular impression on visitors was the Sb 725 - Sb 500 soil density gage. This device is useful for continuous measurement of the percentage content of soil

and silt in a dredge pumpline, but may also be employed to advantage in monitoring the passage of other materials through any pipeline or duct. It consists of a radioactive emitter (Co^{60}) housed inside special lead shielding, and an ionization chamber operating in unison with the dynamic electrometer. The chamber is made available for silt pumplines of 750 and 500 mm diameters.

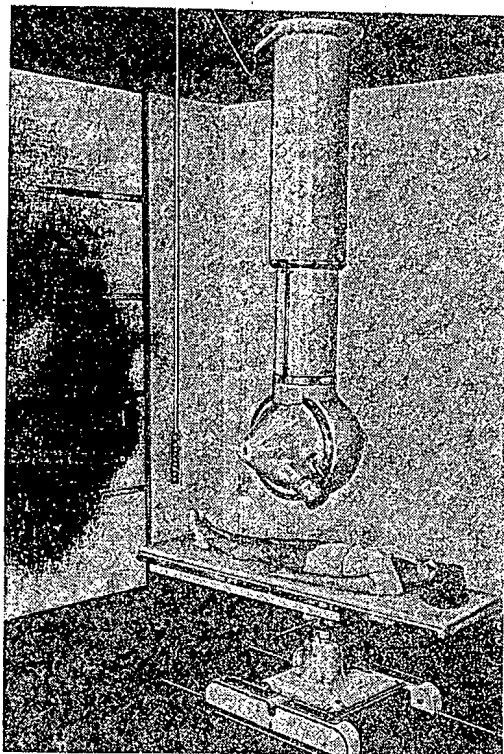


Fig. 2. The Chisotron irradiator facility.

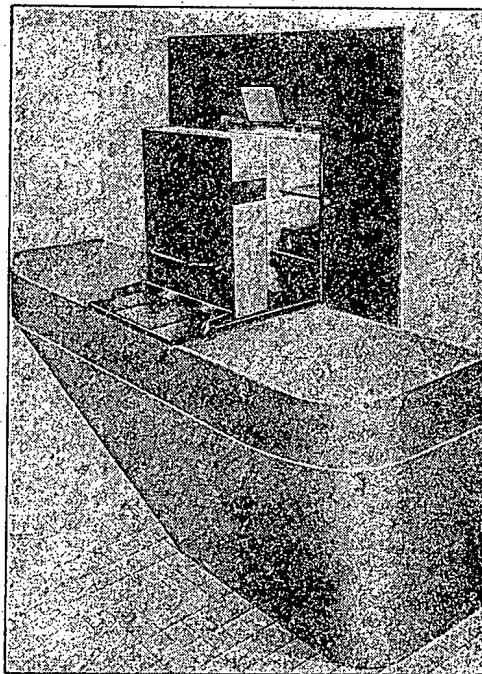


Fig. 3. T-1000 type lead isotope storage unit.

A line of well-logging and radiometric instruments designed for geological exploration, analysis, and ore processing operations stimulated quite a bit of interest. Of these instruments, we note first an ore-grading type RSR-0.4 gamma-radiometer employed in radiometric grading of active material traveling on a conveyer belt, and in metering ore feed onto the belt. The device may also be utilized for process control and flaw detection. The RAR-0.4 type rapid analysis gamma-radiometer is designed for continuous measurement of the amount of radioactive material moving on a conveyer belt. In addition to these instruments, the well-logging radiometer KPR-0.2, the RKS-0.5 radiometer, the PPR-0.1 beta-gamma-radiometer, and the SMZ-0.1 alpha-radiometer were also on display.

Practically all of the basic shielding, operating, and auxiliary instrumentation needed for handling radioactive isotopes is supplied by domestic Czechoslovak industry. The most interesting items in this line were radioisotope irradiator facilities, in particular the Cezioterax machine designed for experimental and clinical near-focusing therapy, using Cs^{137} as the source of ionizing radiation (activity 200 C). The design of a shielded storage unit for radioactive preparations provides for reliable attenuation of gamma radiation. The dose rate over the emitter surface does not exceed 8 mr/hr. The Chisotron Co^{60} irradiator (Fig. 2) is used for therapeutic applications. The exposure dose rate is 1000 r/hr. The "Betatron" type irradiator facility is designed for industrial applications in flaw detection. It belongs to a line of irradiator facilities using particle accelerators as sources of ionizing radiation. The energy of the emitted particles is subjected to smooth control over the 3 to 15 Mev range.

Also on display were the L2 101 type manipulator enclosure designed for medical purposes, a dust-tight plexiglass hood, a safe (Fig. 3) for storing radioisotopes, a needle sterilizer unit, and other devices for handling radioactive preparations.

The exhibit displayed only a limited line of instruments. The exhibits were so selected to provide a clear picture of the general state of ability in the manufacture of nucleonic equipment in the Czechoslovak Socialist Republic.

P. Yavorski

IAEA CONFERENCE ON ELECTRONICS IN NUCLEONICS

Translated from Atomnaya Énergiya, Vol. 11, No. 5,
pp. 467-468, November, 1961

A conference on electronics in nucleonics, sponsored and organized by the International Atomic Energy Agency, was held in Belgrade (Yugoslavia) during May 1961. Over 300 specialists from 26 nations and 4 international bodies were in attendance.

About 150 reports were delivered to the conference, and were discussed at 10 sessions devoted to scintillation counters and Cherenkov counters; luminescence chambers; photomultipliers and image converters; ionization gas and liquid detectors; semiconductor detectors and their use in recording nuclear radiations; pulse-height converters, multi-channel analyzers, and automation of experimental data processing; classical electronics; millimicrosecond electronic techniques; various experimental circuits; accelerators; dosimetric instruments.

Over 20 papers were devoted to the development and operation of scintillation counters, discussing both the properties of scintillating materials and phototube multipliers, and various circuitry improvements in the functioning of scintillation counters.

Papers dealing with the development and study of the properties of gas scintillation counters stimulated much interest at the conference. Gas scintillation counters have opened up new possibilities both in the area of recording and spectrometry of neutron flux and heavy charged particles, and in experiments requiring high-level time resolution, because of the rapid response of gas counters and their low sensitivity to light particles.

Five papers submitted to the conference were addressed to the problem of Cherenkov counters. The description of liquid and gas counters designed for high-energy particle research was accompanied by the description of the exploitation of the Cherenkov effect to solve practical problems arising in determinations of the presence of beta-active substances (yttrium and strontium) in water reservoirs.

Reports on luminescence chambers were devoted predominantly to applications of these instruments in solving concrete problems encountered in high-energy physics.

At the session on ionization detectors, problems related to the development of new ionization chambers and Geiger-Müller counters and to improvements on old ones, and the use of such devices as personnel radiation monitors for monitoring contamination of air, etc. were discussed. Some light was also shed on the development of spark counters and spark chambers. The papers on spark counters, which took up counter geometry, composition of the counting gas, physics of the glow discharge, and the use of spark chambers in physical experiments, were listened to with close attention.

Over 20 papers were read at the session on semiconductor detectors, attesting to the close attention presently focused on this relatively new aspect of nuclear-radiation detectors. Despite the fact that some of the papers submitted to the conference had appeared previously in the published periodical literature, a lively discussion broke out on the conference floor. The recording and spectrometry of high-energy particles and fast neutrons by various types of semiconductor detectors, the effect of external conditions, temperature, and high radiation dosage on the capabilities and parameters of semiconductor detectors, figured among the topics discussed. The information provided on the production technology of semiconductor detectors was very meager indeed, even though many of the authors had fabricated their detectors independently in their own laboratories.

The collection, analysis, and processing of experimental data are acquiring steadily increasing significance because of the mounting complexity of physical experiments. That explains why most of the 35 papers read to the session on pulse-height converters and multichannel analyzers dealt with such complicated systems as multidimensional analyzers and complex systems for collecting and processing data. Conventional counting instrumentation and single-channel pulse-height analyzers, except for high-speed items, were completely out of the picture. Multichannel pulse-height analyzers, their components, methods for extracting information from them, and the use of analyzers in experiments formed the subject matter of 8 reports. Multichannel time-of-flight analyzers and their components were the topic of 7 of the conference reports. The remaining reports of the session dealt with multidimensional data collection, analysis, and processing systems.

Twenty five reports were made to the session on classical electronics, which discussed the development of various transistorized circuits employed in nuclear electronics and the design of electronic circuits capable of identifying particles by pulse shape, with the aid of scintillation counters.

Problems arising in the development of millimicrosecond electronic circuitry were touched upon in 20 reports. Most of the interest was centered in the papers which discussed ultrafast circuits using tunnel diodes. These papers discussed the theory of the functioning and circuit design of discriminators, scalars, and coincidence circuits. Time- and pulse-height conversion problems were given their full share of attention, but a semiconductor converter was described in only one report.

Eleven papers were presented to the session on dosimetric systems and instruments, describing instruments developed in recent years for measuring surface contamination, air contamination, individual exposures to service personnel, prospecting of radioactive ore deposits, etc.

The proceedings of the conference will be published by IAEA in early 1962.

Running concurrently with the conference on nuclear electronics was an exhibit on the premises of the Belgrade fair grounds, where a large selection of instruments and equipment used in physics laboratory research in several countries was on display.

V. Matveev

ALL-UNION SEMINAR ON THE USES OF RADIOACTIVE ISOTOPES IN MEASUREMENTS AND INSTRUMENTATION

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5, pp. 468-470, November, 1961

An expanded conference of the All-Union Seminar on the Uses of Radioactive Isotopes in Measurements and Instrumentation, organized by the Division of Technical Sciences of the USSR Academy of Sciences and the Isotopes Control Board of the State Committee of the USSR Council of Ministers on the Uses of Atomic Energy was held during June 1961 at Frunze (Kirghiz SSR). Over 100 delegates were in attendance at the seminar sessions. Topics related to the applications, development, and efficiency of automatic controls incorporating radioactive isotopes and nuclear radiations were discussed at the seminar.

Over 50 reports and communications presented by various research and development organizations were presented in the course of the seminar.

N. N. Shumilovskii, B. I. Verkhovskii, and L. V. Mel'tser presented the primary trends apparent in the field of radioactive measurements techniques and instrumentation.

N. N. Shumilovskii, V. A. Yanushkovskii, Yu. V. Gushchin, V. D. Kiryukhin, and V. N. Pozdnikov reported on "A standardized automatic-control device employing modulated radioactive radiation," wherein they noted the development of a standardized system using a radioactive automatic-control technique based on the use of frequency-pulse-modulated radioactive radiation. This system, derived from a suggestion originating in the Institute of Automation and Remote Control of the USSR Academy of Sciences, is useful for the solution of such problems as automatic monitoring of rate of fluid flow, shaft speed, metering of a present quantity of product, etc.

B. I. Verkhovskii and M. I. Podgoretskii, in their report "Statistical characteristics of instruments with a radiation source in the feedback loop" discussed the minimization of errors introduced by instability of equipment parameters into the results. The authors apply the concept of a radiation-source feedback to a system in which the signal acts either directly on the intensity of radiation incident upon the radiation sensor or on an instrument parameter on which the number or height of the pulses recorded depends. The report encompassed a technique for estimating error associated with such a feedback device, and showed, for example, that the size of the instrumental error is reduced in a system with a compensating ionization chamber, while the size of the fluctuation error is not affected thereby.

M. Yu. Borukhov and V. N. Vapnik, in their report "Radioisotope sensors in automatic-control systems," discussed the principles underlying the choice of types of controller and optimization of relations between the controlled variables, controller parameters, and radioisotope sensor parameters. The considerable inertia in the response of some radioisotope sensing and measuring devices, a factor which is often quite commensurable, sometimes even exceeding the response time of the controlled system, places special difficulties in the way of the successful use of standard controller systems. It is shown in the report that proportional controllers and proportional-pulse-derivative controllers in automatic-control loops using radioisotope sensors do not always assure process stability. The controller variables and transients of automated systems with various control objects and types of controllers are cited, derived from the conditions of maximum speed of response of a system, at sensor response times exceeding the response time of the controlled object.

S. G. Purtov reported on the economic savings achieved in the operation of rolling mills using radioactive thickness gages.

Many reports were made to the conference on the use of radioactive isotopes for monitoring the composition of various media.

N. N. Shumilovskii, L. V. Mel'tser, and A. A. Naumov presented, in their report "The combined use of various processes of interaction between radiation and matter for the automatic monitoring of the composition of multi-component mixtures," a procedure for monitoring the composition of complex media by means of nuclear radiations. The use of these processes, as the scientists noted, does not always provide sufficient precision in determining the amount of the various constituents present. This drawback led to a discussion of means for improving the accuracy attainable in determining the content of constituents in a mixture. The approaches given consideration include the method of maximum plausibility, a method for determining the coefficients of unknowns in terms of standard mixtures, and the use of combined gamma-, beta-, bremsstrahlung, and other modes of radiation interacting with the medium under study. The development of improved measuring equipment with increased stability and efficiency in recording radiations stimulated intense interest in delegates primarily concerned with a higher level of experimental precision.

The practical use of techniques of these types was discussed in reports by V. A. Stonikov and G. L. Belkin, "Monitoring lead content in industrial products and concentrates," D. Abdulaev and E. M. Lobanov, "Note on determination of the composition of two- and three-component mixtures by backscattering of beta rays," etc.

The exploitation of neutron activation analysis to determine the composition of media was discussed in papers by E. M. Lobanov and A. P. Novikov, "Activation techniques in determining copper in rocks," I. D. Naskidashvili, L. M. Mogulishvili, V. V. Gvakhariya, K. A. Abashidze, N. V. Bogdavdze, and T. L. Chantladze, "Neutron activation analysis of manganese ore." The use of neutron activation analysis for quantitative copper content determinations in coreless drilling well holes demonstrated the high efficiency of that technique (up to 0.1% accuracy in determinations of copper content). Use of this technique in determining manganese content made it possible to cut the time of one analysis from 1.5-2 hrs down to 5-6 min; the maximum deviation from the mean value of manganese concentration did not exceed 0.1-0.15%.

Neutron techniques for moisture determination in various media were treated in reports by L. G. Belykh, V. T. Betin, B. I. Verkhovskii, and F. A. Kurmaev, "Neutron monitoring of furnace charge humidity," N. I. Skvortsova and Ya. E. Chudars, "On the possibility of determinations of peat humidity by the neutron method." A neutron humidity gate using a Po-Be source has been developed for monitoring the moisture of a charge. A bank of 11 SNM-5 type counters records thermal neutrons. Tests of a prototype of the device at the Magnitogorsk metallurgical combine showed that measurement errors were kept within 0.3 absolute percentage of humidity (in the determination of humidity by desiccation of samples).

The analysis of the composition of gaseous products was the subject of papers by M. I. Korsunskii, A. S. Logunov, and L. P. Baivil' "The use of radioactive isotopes to monitor the parameters of flowing wet steam," I. P. Sklyarenko, M. D. Krivitskii, F. E. Krigman, "A method for analyzing ternary mixtures in ionization gas analyzers." It was pointed out that determination of steam moisture in the later stages of a steam turbine is an important problem in modern power engineering. The determination of steam moisture is performed by sensing absorption of beta radiation emitted by isotopes S^{35} and Ta^{204} . The essence of the technique proposed for analysis of ternary gas mixtures is varying the geometry of the ionization chamber to make it possible to utilize only a fraction of the energy of the ionizing particles at the end of their range for ionizing the gas in the effective counter volume. This is achieved by removing

* Figure omitted in Russian text.

the radiation source from the effective counter volume, leaving the former at varied distances from the latter. This approach has served as a basis for the development, fabrication, and successful testing of a down-hole complex analyzer for methane and carbon dioxide gas.

Monitoring the composition of fluid products provided subject matter for papers by A. M. Drobiz, "Method and instrument for automatic analysis of composition of three-component liquids," Yu. G. Khachturov, "Radioactive technique and device for analyzing environmental medium and liquid petrochemicals," M. Yu. Borukhov, V. N. Ivashev and V. F. Kleimenov, "Radioisotope slurry concentration gage," etc. The method proposed for automatic analysis of three-component liquids was a combined use of the phenomena of absorption and reflection of beta particles emitted by the radioactive source, by the test medium. The device incorporates indicating, recording, and control functions. The circuitry of the device is self-compensating. A radioactive technique for sulfur determination in liquid hydrocarbons is based on measurement of absorption of soft x-radiation in the liquid to be analyzed. With this technique, it becomes possible to analyze low sulfur concentrations (as low as tenths of a percent). Exploitation of this technique has been facilitated by the design of the AZhS-1 scintillation counter unit, with a sensitivity to 0.1% sulfur content.

Papers by L. K. Tatochenko, "Statistical characteristics of transients in radioactive relays," I. S. Zhitomirskii, A. G. Vasil'ev, K. S. Klempner, "Statistical reliability of relay units in steady-state and transient operation," discussed the determination of statistical characteristics of radioactive relay transients. It was shown that the problem of establishing the distribution pattern describing the distribution density of the time of first relay operation and evaluating the stability of changes in the state of the relay in the transient mode requires solution of integral equations by means of high-speed electronic computers.

The use of gamma-ray relays in automatic monitoring and control systems was taken up in papers by L. M. Gerber, M. L. Gol'din, and V. D. Rutgaizer "Gamma-relays for small radiation-intensity drops," M. Yu. Borukhov, A. P. Vakulyuk, V. N. Ivashev, and T. G. Tsoi, "New types of radioactive isotope relays and level gages."

The paper "Radioactive slurry and silt density gage," by L. I. Fainberg, I. I. Kotik, and I. Ya. Serebrennikov, discusses the design of the PR-1014 radioactive density gage designed for measuring and controlling the density of pulps and other fluids. The functioning of the device is based on comparison of the flux of radiation passing through the medium being monitored with the monitor radiation flux. A scintillation counter is used as radiation detector. The device is capable of measuring the density of pulp over a 0.75 to 3.5 g/cm³ range with any desired breakdown into subintervals starting with 0.25 g/cm³. Measurements error stays within $\pm 2\%$ of the subinterval.

An interesting technique for determining the amount of solid phase present in a two-phase suspension was outlined in a paper by I. G. Grinman, É. K. Dzhasybekova, G. I. Blyakh, and V. M. Oshchenskii, "Possible applications of the radioactive technique in ore beneficiation process control." An activation technique was proposed for measuring rate of flow, the gist of the method being measurements of induced activity due to neutron bombardment of the process medium. This method facilitates determination of the rate of flow of one of the constituents of the mixture.

A paper by V. N. Afanas'ev, "Fixed-radiation-source servo level gage," goes into the design of a level gage with a fixed radiation source adjusted to the upper limit of the measurements range. The device was engineered for recording the fill level of burden in blast furnaces.

Papers dealing with the design of systems for recording radioactive radiations and radiation sensors included A. V. Pugachev's "Electronic transducers for measurement of ionization currents," E. Ya. Ovcharenko's "Light-pipe scintillation counters in process-control instrumentation," A. D. Tumul'kan's "Performance details of radioactive sensors on halide counters in relay-action devices," and others. The use of ionization chambers as sensors of ionizing radiations in radioactive monitors requires concomitant use of complicated special-purpose amplifying equipment. The first paper takes up some simplified circuitry for transducer-amplifier types: the multivibrator type, controlled-rectifier circuits, and a grid-current varying circuit. Experiments carried out, as reported by E. Ya. Ovcharenko, showed that light pipes of plastic glass of cylindrical shape, and silicon light pipes may meet with practical applications in radiation monitors. The paper refers to uses of light pipes in radioactive density and level monitoring instruments. The paper by A. D. Tumul'kan cites findings of experimental researches on discharges in STS-5 type low-voltage halide counters.

P. A. Polonik delivered a paper on industrial applications of radioisotopes and nucleonic devices, "Applications of alpha-emitters and beta-emitters for coping with electrification in the textile industry." Other papers in the same

category were presented by V. É. Banashek, D. Yu. Dekhtyar, A. Ya. Dombur, V. P. Rogachev, V. N. Pozdnikov, and V. A. Yanushkovskii, "Use of radioactive relay-action devices in process control loops in the chemical industry of the Latvian SSR Council of the National Economy," A. I. Yakovlev, "Radioactive tracer applications in cementing the footings of large-scale hydropower installations," V. P. Kaplin, V. N. Pozdnikov, and A. S. Shabunin, "On a possible automatic separation of potato tubers from clumps of attached soil on potato-digging machines," etc. A. I. Yakovlev reported on design details of a density gage for monitoring the make-up of cement mortar (a two-phase suspension) and experience in the use of the instrument at construction sites.

The reports read at the seminar and the text of the floor discussion is scheduled to appear in print in the format of a symposium.

Ya. K.

TENTH SESSION OF THE COMMISSION ON DETERMINATION OF ABSOLUTE AGE OF GEOLOGICAL FORMATIONS

Translated from *Atomnaya Énergiya*, Vol. 11, No. 5,
pp. 470-472, November, 1961

The tenth session of the Commission on Determination of Absolute Age of Geological Formations was held at Kiev during June 1961. The meetings of the session were devoted to means of refining the precision of the scale of the absolute time-table in geology and in the geochronology of individual regions of the earth.

Over 60 papers and reports were heard at the session. The number of participants reached 150. Scientists from foreign countries were also in attendance at the session. Delegates were afforded the opportunity of visiting the Institute of Physical Chemistry of the Ukrainian SSR Academy of Sciences, and of familiarizing themselves with the work of the Prof. A. I. Brodskii Isotopes Laboratory.

Two reports (N. P. Semenenko, A. P. Vinogradov, and A. I. Tugarinov) dealt with the problem of refining the scale of absolute age for the Pre-Cambrian era. These reports reviewed current data on the determination of the absolute age of Pre-Cambrian formations. Despite the pronounced differences in approach to evaluating age values arrived at, and contradictions evident in the dating of individual geological formations by different methods (the U-Th-Pb method or the A-K method), the basic subdivision of the Pre-Cambrian coincided quite closely under both interpretations. For example, the Pre-Cambrian 1 or the Katarchean (3.6 to 2.7 billion years ago) was arrived at with unanimous agreement, the Pre-Cambrian 2 or the Archean (from 2.7 to 1.9 billion years ago) likewise, as well as the Pre-Cambrian 3 or Lower Proterozoic (from 1.9 to 1.1 billion years ago), and finally the Pre-Cambrian 4, or Upper Proterozoic (from 1.1 billion to 570 million years ago). The Riphean, or Sinian, is in fact the analog of the Proterozoic, according to this scheme.

A report by A. P. Vinogradov and A. I. Tugarinov represented an attempt, based on a reasonably-large number of reported measurements, of the age of Lower Pre-Cambrian rocks, to correlate stratigraphic sections through the Proterozoic in the various continents throughout the world. A correlation of this type would afford the possibility of clearly demonstrating the existence of certain cycles of sedimentation in the Proterozoic-Riphean age (Pre-Riphean 1.9 to 1.7 billion yrs., Early Riphean 1.7 to 1.4 billion yrs. ago, Mid-Riphean 1.4 to 1.1 billion yrs., Late Riphean 1.1 billion to 570 million years ago), the discontinuities between the ages being accompanied by magmatic manifestations.

These cycles are characterized by the development of geosynclinal zones with fairly thick strata making their appearance in each instance on a new plane in complete independence of one another, speaking in the territorial sense. For example, while appreciably thick sedimentations of all Riphean series are present in the Urals and the Yenisei mountain range, only slight covers of the Upper Riphean are present on the territory of the Russian continental platform, and Mid-Riphean series are known to be present only in the internal depressions.

The Upper Riphean is entirely absent, on the other hand, in the western portion of North America (Belt series) and in western China (Sinian), while the Mid-Riphean and Lower Riphean are profusely abundant, represented by strata several kilometers thick.

Age researches consequently enable us, at the present state of knowledge, to feel out the evolutionary pathways of ancient folded zones and depressed regions, accompanied by inversion and magmatism in the Late Pre-Cambrian age.

The boundary of the Proterozoic and Archean was unanimously accepted as an epoch of intense magmatism spanning a long time interval from 2.1 to 1.8 billion years in the past, with a peak in magmatic activity at about 1.9 billion years ago.

One characteristic fact is that the overwhelming bulk of the metamorphic complexes showed similar age by the A-K method, thus confirming the planetary all-embracing nature of metamorphism in that epoch.

The question of the age of sedimentation of rocks of the Krivoi Rog and Kursk series evoked a lively discussion. A multiplicity of measurements by the argon-potassium method on micas of the crystalline shales belonging to these series indicate an age of 1.8 to 1.9 billion years, in combination with some peculiarities of geologic structure (intersecting position of meridional structures of the Krivoi Rog basin with respect to structures of the northwest strike of chertites whose age has been determined at 2.1 billion years); these data have stimulated N. P. Semenenko and other Ukrainian geologists to consider the time interval of 1.8 to 2.1 billion years ago as the time during which sedimentation of the Krivoi Rog series occurred.

However, measurements of the age of arkoses belonging to the lower suites of the Krivoi Rog and Kursk series by the U-Pb technique, in studies by A. I. Tugarinov, E. V. Bibikova, and S. I. Zykov, were found to yield strikingly similar results in individual cases, with respect to all isotopic relations, dating to 2.6 billion years back. These data fit well with the results obtained by the same authors for zircons from migmatites of the crystalline base underlying the Krivoi Rog series (2,850 million years ago).

It is a curious fact that findings of galenites of anomalous lead isotope composition in the same arkoses, as well as individual cases of discrepant age values obtained in determinations by different isotope relations, attest to a metamorphism and loss of uranium from the arkoses sometime about two billion years ago, a conclusion which is in exact agreement with respect to time with the intensive intrusive activity in that region.

Another highly interesting achievement in the field of geochronological studies of the Ukrainian Pre-Cambrian has come forth as a result of an investigation of a block of Dneprov migmatites and gneisses (region including Kremenchug and Sineľ'nikovo, Dnepropetrovsk) carried out by a team consisting of Prof. L. V. Komlev (Radium Institute of the Academy of Sciences, RIAN), M. N. Ivantishin, N. P. Shcherbak, F. I. Kotlovskaya (Ukrainian SSR Academy of Sciences). In this district, blocks of rock species dating back 3.0 to 3.6 billion years with the smallest age of surrounding metamorphic host rock dated at 2.7 billion years, have been discovered among the foundation rocks.

Another highly intriguing fact is that the maximum age of these rocks was obtained by the argon-potassium method with respect to amphiboles, while biotites in some cases yielded far smaller age values. In the course of the discussion, all the participants at this session came to agreement on the point that similar discrepancies in age for two minerals of the same species may be traced to metamorphism. However, the question still remains obscure whether or not this effect is related to the usual losses of argon by micas upon heating, which has no effect on amphiboles, or whether a metasomatic replacement of the amphibole by micas takes place in the course of metamorphism. Further study of this phenomenon should therefore be continued both by way of chronological measurements and by way of petrographic observations.

Among the very interesting reports heard at the session was one paper by É. K. Gerling and coworkers, demonstrating that the basic igneous rocks of Monchegorsk pluton, which are genetically related to nickel deposits, which in turn are always considered to be proterozoic since they intruded in contact with the crystalline base and Imandra-Varzuga stratum, were found by A-K age determinations to be more ancient (dating back beyond 3 billion years). Furthermore, the argon-potassium method indicated an age of 6.2 billion years for xenoliths and peridotites belonging to the same complex.

The natural question arises as to whether or not the enormous age values reported are due to experimental error in the determinations introduced by the small potassium contents involved. This conjecture does not hold, since xenoliths of these peridotites are always distinguished from pyroxenite, despite the far lower potassium content in the former than in pyroxenite (0.04% K), by the presence of much larger amounts of argon.

The discovery of rocks dating back 6 billion years in the earth's crust places a shadow of doubt on the previously-established age of 4.5 billion years for the earth. É. K. Gerling offered the conclusion that this latter figure

refers properly only to the age of the earth's crust, to the time of differentiation of the crust, while the substance of the earth's mantle to which belongs the xenolith of peridotites cored from the depths of the earth indicates an age for the earth which is possibly much greater than hitherto supposed.

Many of the reports were addressed to other topics than the geochronology of the Pre-Cambrian era, such as age determination of rocks belonging to meso-paleozoic provinces.

For example, S. I. Zykov, N. I. Stupnikova and others carried out an extensive series of age determinations by the Pb-U-Th technique on various radioactive minerals of granitic and alkaline intrusions, for the Urals, the Tuva, and the Sayan area. These workers discovered the excellent quality of the mineral thorianite for age determinations. The presence of caledonides in association with Hercynides was proved for the Tuva region, as well as the existence of later regenerated Huttonite type minerals corresponding to the closing stages of metamorphism for the entire region. L. V. Firsov cited thoroughly-detailed materials relating to the northeastern section of the USSR. Relying solely on the argon-potassium method, L. V. Firsov revealed the presence of the Pre-Cambrian (1.64 billion years ago) on the north shore of the Sea of Okhotsk, the existence of blocks of median masses (the Omolon and Kolyma massives) belonging to the Hercynian age (260-280 million years ago) among folded zones dating back some 90 million years and corresponding to the Laramie folding and characterizing the age of tin deposits in the northeastern USSR as well. Nevertheless, L. F. Firsov came up against the effect, already quite familiar to many geochronological scholars, known as "rejuvenation" of rocks, a phenomenon encountered in using the argon-potassium method, when rocks known beforehand to be Pre-Cambrian gneisses show an age value of 100-120 million years.

A paper by H. Faul (USA) citing new data for median masses of Hercynides in Europe is in essence devoted to the same effect. Having established the Hercynian age (300-350 million years) for major intrusions in southwest England (the Dartmoore massive), Brittany, and the central plateau of France, the Schwarzwald, and Vosges, with references to similar determinations made by A. P. Vinogradov et al. for Saxony and Bohemia, H. Faul advances the suggestion that all of the more ancient formations were so intensely metamorphized and digested in the course of the Hercynian magmatism that it is at the present time entirely impossible to come across any traces of the ancient substrate. As a supplementary proof for this contention, H. Faul cites several dozen age determinations of rocks in the Mont Blanc district which yield values ranging from 12 to 140 million years. Then, as the author himself notes, the greater the tectonic change suffered by the rock, the "younger" its age appears to be. To the question which naturally follows: "Just what are we measuring in that case?" H. Faul provides the laconic answer: "The time when the rate of accumulation of products of radioactive decay began to exceed the rate of removal of radioactive decay products from the minerals."

This question stole the spotlight in the discussion following several papers, since numerous researches on uranium-thorium minerals have indicated that losses of radioactive decay products are not uniquely characteristic of potassic minerals. A whole series of zircons from the Kola peninsula (report by V. V. Zhirova et al.) showed a very ancient age (~2.7 billion years) with respect to the Pb^{207}/Pb^{206} isotope ratio, varying only slightly as the mineral lost its lead and uranium. However, the same minerals yielded strikingly low values with respect to Pb^{206}/U^{238} , Pb^{207}/U^{235} , and Pb^{208}/Th^{232} isotope ratios, ranging 100 to 200 million years, and attesting to a very recent process of intense loss of radiogenic lead.

A similar phenomenon was observed experimentally in its time with respect to pitchblende. This was indeed one of the reasons for the halation of radiogenic lead near uranium deposits, a phenomenon now put to good use in uranium prospecting.

A thorough and exhaustive study of the strontium-rubidium method of absolute age measurements, carried out by E. K. Gerling, Yu. A. Shukolyukov et al., revealed another and no less alarming peculiar feature specific to the method in question, namely the exceptional mobility of rubidium. As a consequence, in regions featuring a relatively high rubidium content in separate deposits (pegmatites of the Kola peninsula), migration of the rubidium leads to an appreciable "rejuvenation" of the surrounding rocks as seen in the light of Sr-Rb method data. Conversely, in the Stanovaya Gora district intensive migration of potassium, argon, and rubidium brought about by a mesozoic process of diaphoresis of ancient strata (with the original age established by the Pb-U-Th method at 1.9 billion years), resulted in a noticeable "rejuvenation" of the rocks according to data obtained by the A-K method (age values down to 250 million years) and a hyperbolic "aging" according to the Sr-Rb method (pushing the age back to 4 billion years).

All of these results, some of which have been obtained earlier, posed one principal problem, meriting the most serious attention, before the participants of the session. This question involves a rigorous evaluation of just what

variable the radioactive geochronological techniques enable us to measure: the age of the rocks, their time of metamorphism, their degree of metamorphism, or, more probably, the result of the superposition of all of these factors ? It has become perfectly clear that reliance on any one of these methods alone (e.g., the argon-potassium method) is explicitly an inadequate procedure for obtaining reliable values of geochronological age.

The simplest cases of comparatively slightly altered rocks and minerals which yield closely coinciding age values when the competing methods are used are relatively rare, since rocks, and especially ancient rocks, must necessarily have experienced some alterations during their geological lifetime. The principal problem has accordingly become that of combining the various methods available in an attack on rocks and minerals known beforehand to have undergone metamorphism, and hitting upon penetrating interpretations based on the disparate age values arrived at.

This quite naturally requires not only high precision in analytic research studies carried on at all geochronological laboratories throughout the Soviet Union, which have already attained a high level of proficiency, as shown by the determinations of standard specimens performed for demonstration purposes by different laboratories at the session of control determinations, but also requires must more painstaking and exhaustive geological and mineralogic investigations of all objects of study brought in from the field. The session recommended precisely this avenue of research as the most fruitful for the redoubled efforts of all the participants and all geochronological laboratories in the USSR.

A. I. Tugarinov

BRIEF COMMUNICATIONS

Translated from Atomniya Énergiya, Vol. 11, No. 5, pp. 473-475, Nov., 1961

USSR. The upper and lower reactor support plates and the reactor pressure vessel have been laid into place at the Belyi Yar nuclear electric power station. The lateral pipe and tube galleries are now completed and the top and bottom guide standpipes are in place. Work on the underground rooms is proceeding in full swing.

Bulgaria. Construction work on the country's first nuclear research reactor has been completed. The Bulgarian Telegraphic Agency has announced that test runs have shown the reactor to be operating normally.

The reactor equipment was furnished by the Soviet Union.

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REVIEW OF BOOKS RELEASED BY THE STATE ATOMIC PRESS
(GOSATOMIZDAT) DURING 1960-1961

Translated from Atomnaya Énergiya, Vol. 11, No. 5,
pp. 476-488, November, 1961

Nuclear Radiation Shielding

Radiobiology. Under this heading we list two groupings of books: items devoted to biophysical, radiological, and medical problems, and books taking up problems of radiation hygiene and health physics other than those topics relating specifically to reactor facilities (for which see the section on Nuclear Power Engineering).

One of the most important topics directly related to the operation of nuclear reactors, production of nuclear materials, radioactive isotopes, etc., is that of determining the magnitude of a safe dose for chronic exposure. The book Fonovoe obлучenie chelovecheskogo organizma [Background irradiation of the human organism], by Yu. V. Sivintsev, 1960, 96 pages, based on published experimental data, computes the magnitudes of separate components of external and internal background exposure of the human organism in irradiation with nuclear radiations, and determines the doses caused by background in the gonads, bone tissues, and lungs. Despite the limited volume of the text, it manages to discuss over 225 published papers.

A symposium, Biologicheskoe deistvie radiatsii i voprosy raspredeleniya radioaktivnykh izotopov [Biological effects of radiation and abundances of radioactive isotopes], edited by A. V. Lebedinskii and Yu. I. Moskalev, 1961, 192 pages, contains the texts of researches on the effects of both external and internal exposures on the organism. It takes up radiation effects on the turnover of nucleic acids in animal tissues and on the functional state of the circulatory system. New data are reported on radiation-sickness treatment by injections of bone marrow. Much space is given over to papers dealing with studies of the behavior of radioisotopes in animal organisms. Data are presented on storage and distribution of Pu²³⁹ in the organism, and elimination of Pu²³⁹ from the organism. Investigations of the migration of radioactive isotopes in farm animal organisms are of considerable practical interest.

M. I. Shal'nov has authored the monograph Tkanevaya doza neitronov [Neutron tissue dose], 1960, 218 pages, which draws inferences from published literature as well as the author's own researches on topics related to neutron exposure effects on biological tissues. The first two chapters provide brief descriptions of the properties of neutrons, methods of neutron production, and the general laws governing interactions between neutrons and matter. Subsequent chapters develop the interaction of neutrons of all energy ranges with biological tissue, and discuss the basic problems relative to the biological effectiveness of nuclear radiations as they affect the organism. An interpolative method for determining the relative biological effectiveness is described, and the problem of critical tolerance doses for humans is treated. The concluding chapter describes methods and instrumentation in neutron dosimetry.

Various aspects of the biological effects of ionizing radiations are presented in a popular style accessible to most readers in D. E. Grodzenskii's Radiobiologiya (Biologicheskoe deistvie ioniziruyushchikh izlucheni) [Radiobiology (Biological effects of ionizing radiations)], 1961, 130 pages. The book takes up the physical properties of ionizing radiations, their chemical effects, their effect on the cell, and on the organism as a whole. Chemical radiation shielding is included in the topics discussed. The book provides a concept of the current status of development in radiobiological research.

The biological sequelae of radiation exposures to radioactive fallout are described in G. Davidson's Biologicheskie posledstviya obshchego gamma-oblucheniya cheloveka [Biological consequences of total-body gamma-irradiation of the human organism], 1960, 108 pages, translated from the English. Based on Blair's theory of radiation injury and recovery, it computes mathematically the relationship between injury and recovery processes at work in the human organism in response to penetrating radiations. Some practical hints on radiation shielding are appended.

One of the radiobiological topics undergoing intensive development at the present stage is the problem of the nervous system response to effects of ionizing radiations. An attempt at a survey of currently-entertained concepts on the effects of ionizing radiations on the nervous system is made in Vliyanie ioniziruyushchikh izlucheni na nervnyuyu

sistemu [The effect of ionizing radiations on the nervous system], 1960, 188 pages, by A. V. Lebedinskii and Z. N. Nakhil'nitskaya.

The first chapter of this book discusses work related to the history of the discovery of the phenomenon constituted by the response of the nervous system to effects of ionizing radiations. The second chapter is devoted to investigations of effects of ionizing radiations on the peripheral nervous system, the central nervous system, the vegetative nervous system, and the cerebral cortex in the large hemispheres.

Biofizicheskaya radiologiya Rentgenovskoe izluchenie i radioaktivnost' [Biophysical radiology, X-radiation and radioactivity], by G. Schreiber, 1960, 367 pages, translated from the German, is based on a lecture course given by the author at the Humboldt University in Berlin. The book throws light on an ample selection of topics related to the nature of ionizing radiations, their basic properties, and particular features. In particular, it presents the fundamental concepts of wave theory, examines the phenomenon of corpuscular radiation, x-radiation, and natural and artificial radioactivity.

The book Radiatsionnaya meditsina [Radiation medicine] edited by A. I. Burnazyan and A. V. Lebedinskii, 1960, 314 pages, is a handbook for physicians and medical students. The book contains nine chapters written by different authors. The first chapter of the reference book tells of the nature of radioactive radiations and methods of dosimetric monitoring. It then proceeds to an account of the pathogenesis of radiation sickness, the toxicology of radioactive substances, and protection of the organism from the effects of ionizing radiations by means of chemical compounds. The concluding chapter of the handbook deals with the pathological anatomy of radiation injuries.

Of those releases dealing with the second grouping under this heading, we may begin by mentioning Sanitarnye pravila raboty s radioaktivnymi veshchestvami i istochnikami ioniziruyushchikh izluchenii [Health and safety regulations governing handling of radioactive substances and sources of ionizing radiations], 1960, 118 pages. These rules are official documents approved by the Ministry of Public Health of the USSR and the State Committee of the USSR Council of Ministers on the Uses of Atomic Energy. They outline the requirements and specifications to be observed in the organization and arrangement of laboratories, institutions, and industrial organizations licensed for handling radioactive substances, requirements to be observed in handling sealed and open sources, ventilation and heating specifications, water supply and garbage disposal rules, collection and decontamination of rooms and equipment, pickup, removal, and burial of solid and high-level liquid wastes; instructions on individual protective measures and personal hygiene standards. Approved critical dose levels for ionizing radiations and critical tolerance concentrations of radioactive materials are an inseparable part of the body of regulations.

This documentation is supplemented by Pravila perevozki radioaktivnykh veshchestv [Regulations governing transportation and carrying of radioactive materials], 1961, 64 pages. This body of regulations is the officially-issued document replacing all previous regulations and instructions at all levels of jurisdiction, all-Soviet, ministerial, and departmental, on transportation of radioactive substances.

The recommendations of the International Commission on Radiological Shielding with respect to tolerance doses of internal irradiation for the organism are quoted in Otchete Komiteta II o dopustimnykh dozakh vnutrennego oblucheniya [Report of Committee II on internal exposure tolerance doses], 1961, 262 pages. The first portion of the book provides information on the composition and activities of the Commission, and a survey of the recommendations it has issued. The second, larger, portion contains the report of Committee II of this Commission, consisting of five sections as follows: introduction; basic fundamental standards (regulations) on critical tolerance doses for internal exposure; critical tolerance magnitudes for professional exposure; calculation of critical tolerance dosage; factors required in calculating the levels of critical tolerance concentrations. The end of the book provides reference material in tabulated form.

The book Zashchita ot deistviya pronikayushchei radiatsii [Shielding against effects of penetrating radiations], 1961, 86 pages, by U. Ya. Margulis, is devoted to radiation-safety problems. It presents an account of the nature of effects on penetrating radiations and shielding measures designed to expedite safety in handling radioactive materials. The book is intended for a broad reader audience with no particular specialist training. Toward this end the book goes briefly into such topics as the structure of the atom and the nature of interactions between radiations and matter.

A new reference handbook Zashchitnoe oborudovanie i prispobleniya dlya raboty s radioaktivnymi veshchestvami [Protective equipment for handling radioactive materials] (compiled by G. N. Lokhanin, V. I. Sinitsyn,

A. S. Shtan'), 1961, 130 pages, presents a description of and concise technical data on various types of protective equipment and accessories used in handling of radioactive materials.

The symposium Khimicheskaya zashchita organizma ot ioniziruyushchikh izluchenii [Chemical protection of the organism against ionizing radiations] edited by V. S. Balabukh, 1960, 152 pages, offers a brief survey of the current status of progress in chemical protection of the organism. The second part of the symposium is devoted to this topic whose significance has advanced greatly in recent years owing to contamination of the atmosphere, soils, and plants by radioactive fallout, i.e., the problem of removing radioactive isotopes from the organism. The entire symposium includes 14 articles by different authors.

Contamination and decontamination of air affected by radioactive aerosols is discussed in two books by S. A. Prechistenskii: "Radioaktivnye vybrosy v atmosferu [Radioactive wastes vented to the atmosphere], 1961, 176 pages, and Tsentrifugirovanie aerorozolei v TsRP [Centrifuging aerosols in the centrifugal dust trap], 1960, 144 pages. The first book supplies general information on aerosols and discusses advanced methods of air purification. It also presents basic information needed in planning air-cleaning facilities. The second book outlines the theoretical fundamentals of the operation of the centrifugal rotatory dust collector employed to decontaminate exhaust discharges and flue gases carrying aerosols.

The problem of determining the proper tolerance level of radon and radon daughters in air circulating through uranium mines is the subject of a book by J. Holliday, D. Rushing, R. Coleman et al., Rn²²² Problema radona v uranovykh rudnikakh [Rn²²² and the radon problem in uranium mines] translated from the English, 1961, 100 pages. The book discusses three factors underlying the choice of a tolerance level: 1) results of the effect of inhaled radon daughters on the organism; 2) results of experiments using animals, and 3) amount of tissue dose in the lungs.

Radioactive and Stable Isotopes

Books in this category are classified as reference manuals, science and engineering literature, or popular science literature, since a breakdown by subject content would be somewhat more difficult than in other categories listed here, because of the broad range of topics discussed in many of these books.

Reference manuals. The publication during 1959 of the catalog Izotopy [Isotopes] was intended to familiarize research workers and industrial technicians with the nomenclature of isotopes and tagged compounds produced in the USSR. Data were given (compound, specific activity, radiochemical purity, type of packing for shipping, weight of a single delivery item, etc.) for all stable and radioactive isotopes in production, as well as tagged compounds.

A direct outgrowth of this work is the reference publication appearing in 1961, Tekhnicheskie usloviya na radioaktivnye izotopy [Technical data radioisotopes], 1961, 188 pages, as well as the handbook prepared by G. M. Fradkin, Istochniki al'fa-, beta - gamma - i neitronnykh izluchenii dlya kontrolya i avtomatizatsii proizvodstvennykh protsessov [Alpha, beta, gamma, and neutron sources for process control and monitoring], 1961, 160 pages.

The first of these contains technical data relating to isotopes produced by pile neutron irradiation (irradiated batches), data on raw materials and semifinished products with short-lived isotopes obtained by neutron irradiation, and radioactive radiation sources. Included are provisional technical specifications for isotopes obtained from a mixture of fission products, for wholesale shipments of compounds and preparations labeled by radioisotopes, for shipments of solid targets with hydrogen isotopes, for shipments of polonium-beryllium and radium-alpha-beryllium sources, and radium-gamma sources.

The second item provides the characteristics (shape, size, activity, etc.) of alpha, beta, gamma, and neutron sources used in process control instrumentation, information on mineral prospecting equipment, and high-level irradiation facilities. These two releases will fill a need for persons engaged in the production and use of isotopes and labeled compounds.

The symposium Metody polucheniya i izmereniya radioaktivnykh preparatov [Techniques in the production and measurement of radioactive preparations] edited by V. V. Bochkarev, 1960, 308 pages, consists of three sections. The first contains 16 articles devoted to the production of inorganic radioactive preparations, including carrier-free preparations, some colloids, and other preparations fulfilling combined functions; it also includes a description of the production technology of some preparations based on short-lived isotopes. The second section on production of labeled organic compounds includes 15 articles; these discuss a variety of techniques for synthesizing organic compounds including isotope-exchange techniques, biosynthesis, neutron irradiation of finished reactive compounds, etc. The third section (eight articles) is devoted to absolute and relative activity measurements and radiometric analysis of preparations; also offered are descriptions of particular instruments and practical hints on measurements techniques.

A book by W. B. Mann and G. G. Seliger, Prigotovlenie i primenenié étalonnykh radioaktivnykh preparatov [Preparation and use of standard radioactive preparations], translated from the English and edited by V. V. Bochkarev, 1960, 104 pages, constitutes a survey issued by the USA National Bureau of Standards serving as the official reference manual in the area of the production, standardization, and use of standard radioactive preparations.

Popular science literature on isotopes. Some popular science brochures dealing with several radioactive isotopes were published during 1960 and 1961. These brochures made available the basic characteristics of the given element, methods for producing its isotopes and compounds labeled with the isotopes; describe accessory equipment and methods for determining the isotope concentration and recording of radiations; point to the most important examples in the practical utilization of isotopes; and outline safety techniques observed in handling radioactive isotopes. This category includes the following titles: L. S. Kozyreva-Aleksandrova, N. I. Temnikova: Radioaktivnyi izotop ioda-¹³¹I [The radioactive isotope iodine-131]; N. S. Serebryakova, M. A. Grachev: Radioaktivnye izotopy zolota-Au¹⁸⁸ i Au¹⁸⁹ [The radiogold isotopes Au¹⁸⁸ and Au¹⁸⁹]; V. A. Sokolov, E. A. Tikhomirova, N. A. Kosolapova: Radioaktivnyi izotop sery-S³⁵ [The radioactive isotope of sulphur S³⁵]; V. A. Sokolov, I. K. Kulagina, Radioaktivnyi izotop kal'tsiya-Ca⁴⁵ [Radiocalcium-45]; D. N. Trifonov: Élement 61 (devoted to the discovery and properties of promethium-61); I. F. Tupitsyn: Radioaktivnyi uglerod-C¹⁴ [Radiocarbon-14]; V. I. Sinitsyn: Radioaktivnyi kobal't-Co⁶⁰ [Radiocobalt-60]; B. A. Zaitseva, A. I. Grivkova: Radioaktivnyi tsezii-Cs¹³⁷ (Radiocesium-137); G. V. Korpusov, S. N. Oziraner, Radioaktivnyi strontsii-Sr⁹⁰ [Radiostrontium-90].

The popular style brochure Stabil'nye izotopy vokrug nas [Stable isotopes in our midst] by S. P. Potapov and K. I. Sakodinskii, 1961, 68 pages, gives an account of the principles underlying physico-chemical techniques in the separation of some stable isotopes, and also sheds light on several trends apparent in the practical use of isotopes obtained by these methods. An item by I. F. Tupitsyn, Tyazhelye izotopy vodoroda - deiterii i tritii [Hydrogen's heavy isotopes - deuterium and tritium] discusses the basic principles involved in the production of deuterated and tritiated compounds, their physico-chemical properties, and cites particular examples of the use of deuterated compounds in scientific research and industrial projects.

Élementy s neobychnoi sud'boi [Elements with a strange destiny] by D. N. Trifonov, 1961, 96 pages, is a book which renders an account of the history of three elements in the periodic table - technetium, astatine, and francium, whose existence was predicted by D. I. Mendeleev.

Science and engineering literature. Primenenié radioaktivnykh izotopov v defektoskopii [Radioisotope applications in nondestructive testing], 1960, 294 pages, is a book by S. V. Rumyantsev which generalizes experience acquired in the industrial use of sources of radioactive radiation, going back to 1947. The book is in four parts. The first part outlines the physics and engineering fundamentals of applications of sources of ionizing radiations in non-destructive testing; the second part discusses the photoradiographical method of flaw detection, describes various gamma-ray flaw detection facilities, and makes a presentation of the principles of the ionization and xerography methods in gamma-ray nondestructive testing; this part also discusses opportunities opening up for the use of electronic image converters and closed-circuit television systems in these applications; the third part of the book is devoted to work safety problems in gamma-radiography; the fourth part deals with the effect of the detected flaws on the mechanical properties of parts and weldments. This book by S. V. Rumyantsev may be supplemented with available data on selection of radiographic films and processing of films, use of screens, techniques for reproducing x-ray shots, etc., provided by the symposium Promyshlennaya radiografiya [Industrial radiography], translated from the English, 1960, 330 pages.

Another item devoted to practical applications of radioisotopes is L. K. Tatochenko's Radioaktivnye izotopy v mashinostroenii [Radioactive isotopes in machine and tool design], 1960, 336 pages. This book goes into the physical principles and theoretical fundamentals of the design and calculations of various kinds of instruments whose functioning is based on the use of radioactive isotopes and nuclear radiations. The five sections of this book deal with interaction between radiation and matter, describe radiation detectors (gas-discharge counters, ionization chambers, scintillation counters), various circuits for radiation detectors, and their modes of operation; present techniques and fundamentals in calculating errors and reliability in such instruments; discuss various classes of available instruments.

Another item of significant interest is Radioaktivnye izotopy v analiticheskoi khimii [Radioisotopes in analytical chemistry], by L. M. Mikheeva and N. B. Mikheev, 1961, 100 pages.

Still another interesting release, which may be of great assistance to research workers and designers engaged in research and development work on irradiation facilities for radiation processing of materials is Izotopnye gamma-

ustanovki [Isotope gamma-ray facilities] by A. V. Bibergal', V. I. Sinitsyn, and N. I. Leshchinskii, 1960, 138 pages. This book covers the topics of radiation sources suitable for use in irradiation facilities, descriptions of individual facilities, their design features, and methods for calculating source fields of a variety of source geometries.

The basic trends in the uses of radioactive isotopes are elucidated in a rather popular but detailed treatment by F. Leau, Radioaktivnye izotopy na sluzhbe cheloveka [Radioactive isotopes in the service of mankind], translated from the French, 1961, 110 pages.

Popular science books of a general nature. The book by V. Fedorov, 15 dnei v Zheneve [15 days at Geneva], 1960, 80 pages, gives an account of the largest international scientific forum to take place in recent years, the Second International Conference on the Peaceful Uses of Atomic Energy, held at Geneva in September of 1958. Scientists, engineers, observers converged on the conference to share their observations, ideas, and conclusions relating to the utilization of atomic power for peaceful ends. The reader gets a fairly complete presentation of the circumstances in which the work of the conference proceeded, of the scientific research investigations reported on at the conference and on the significance of these research efforts in the further development of various branches of applications of atomic energy.

Yarche tysyachi solnts [Brighter than a thousand suns] by R. Jung, translated from the English, 1960, 280 pages, reports in detailed fashion on the way in which science's great discovery, atomic energy, was used by American politicians and the military for selfish and inhuman ends. The physicists and scientists are the heroes of the book. They are the ones who form the substance of the book, their lives, hopes, and disappointments, their scientific work leading to the creation of the atomic bomb, the dissensions between them in the field of ideas, and the psychological blind alley in which many of them find themselves.

Accounts of the discovery and harnessing of atomic energy form the subject of the book Biografiya atoma [Biography of the atom] by Yu. Koryakin, 1961, 206 pages. Each chapter is devoted to a particular major stage in the history of the development of the science of atomic energy or its applications. The book shows the reader personalities who devoted their life to the service of science and made their contribution to the biography of the atom. An entire gallery of scientists of different generations and nationalities passes before the eyes of the reader, with their discoveries and mistakes, their successes and failures. The procession of discoveries in the field of unlocking the secrets of matter is still going on. The author strives to present to his reader a precise picture of the succession of concepts and models of the atom, and the consistent threads in the development of knowledge of the atom.

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B. Bvasil: Approximate determination of tolerances of characteristic dimensions of the periodic structure of a high-frequency linear accelerator, and compensation.

J. Ralková: Measurement of low-level radioactivity in water.

J. Tomáš: Monitoring radon decay product content in the atmosphere.

Hladik: Measuring equipment for noncontacting continuous weight determination of tubes and some product shapes, with tracer applications.

Abstracts, Correspondence, Information, Survey of Literature.

SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY
ENCOUNTERED IN SOVIET PERIODICALS

FIAN	Phys. Inst. Acad. Sci. USSR
GDI	Water Power Inst.
GITI	State Sci. -Tech. Press
GITTLL	State Tech. and Theor. Lit. Press
GONTI	State United Sci. -Tech. Press
Gosenergoizdat	State Power Press
Goskhimizdat	State Chem. Press
GOST	All-Union State Standard
GTTI	State Tech. and Theor. Lit. Press
IL	Foreign Lit. Press
ISN (Izd. Sov. Nauk)	Soviet Science Press
Izd. AN SSSR	Acad. Sci. USSR Press
Izd. MGU	Moscow State Univ. Press
LEIIZhT	Leningrad Power Inst. of Railroad Engineering
LET	Leningrad Elec. Engr. School
LETI	Leningrad Electrotechnical Inst.
LETIIZhT	Leningrad Electrical Engineering Research Inst. of Railroad Engr.
Mashgiz	State Sci. -Tech. Press for Machine Construction Lit.
MEP	Ministry of Electrical Industry
MES	Ministry of Electrical Power Plants
MESEP	Ministry of Electrical Power Plants and the Electrical Industry
MGU	Moscow State Univ.
MKkTI	Moscow Inst. Chem. Tech.
MOPI	Moscow Regional Pedagogical Inst.
MSP	Ministry of Industrial Construction
NII ZVUKSZAPIOI	Scientific Research Inst. of Sound Recording
NIKFI	Sci. Inst. of Modern Motion Picture Photography
ONTI	United Sci. - Tech. Press
OTI	Division of Technical Information
OTN	Div. Tech. Sci.
Stroiizdat	Construction Press
TOE	Association of Power Engineers
TsKTI	Central Research Inst. for Boilers and Turbines
TsNIEL	Central Scientific Research Elec. Engr. Lab.
TsNIEL -MES	Central Scientific Research Elec. Engr. Lab. - Ministry of Electric Power Plants
TsVTI	Central Office of Economic Information
UF	Ural Branch
VIESKh	All-Union Inst. of Rural Elec. Power Stations
VNIM	All-Union Scientific Research Inst. of Metrology
VNIIZhDT	All-Union Scientific Research Inst. of Railroad Engineering
VTI	All-Union Thermotech. Inst.
VZEI	All-Union Power Correspondence Inst.

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us. -Publisher.

Soviet Journals Available in Cover-to-Cover Translation

ABBREVIATION	RUSSIAN TITLE	TITLE OF TRANSLATION	PUBLISHER	TRANSLATION BEGAN					
				Vol.	Issue	Year			
AĖ	Atomnaya ėnergiya	Soviet Journal of Atomic Energy	Consultants Bureau	1	1	1956			
Akust. zh.	Akusticheskii zhurnal	Soviet Physics - Acoustics	American Institute of Physics	1	1	1955			
	Antibiotiki	Antibiotics	Consultants Bureau	4	1	1959			
Astr(on). zh(urn).	Astronomicheskii zhurnal	Soviet Astronomy-AJ	American Institute of Physics	34	1	1957			
Avto(mat). svarka	Avtomaticheskaya svarka	Automatic Welding	British Welding Research Association (London)			1959			
	Avtomatika i Telemekhanika	Automation and Remote Control	Instrument Society of America	27	1	1956			
	Biofizika	Biophysics	National Institutes of Health*		1	1957			
	Biokhimiya	Biochemistry	Consultants Bureau	21	1	1956			
Byull. ėksp(erim). biol. i med.	Byulleten' ėksperimental'noi biologii i meditsiny	Bulletin of Experimental Biology and Medicine	Consultants Bureau	41	1	1959			
DAN (SSSR)	Doklady Akademii Nauk SSSR	The translation of this journal is published in sections, as follows:	American Institute of Biological Sciences	106	1	1956			
Dokl(ady) AN SSSR }				American Institute of Biological Sciences	112	1	1957		
	Life Sciences	Doklady Biochemistry Section Doklady Biological Sciences Sections (Includes: Anatomy, biophysics, cytology, ecology, embryology, endocrinology, evolutionary morphology, genetics, histology, hydrobiology, microbiology, morphology, parasitology, physiology, zoology sections)	American Institute of Biological Sciences	112	1	1957			
				Chemical Sciences	Doklady Botanical Sciences Sections (Includes: Botany, phytopathology, plant anatomy, plant ecology, plant embryology, plant physiology, plant morphology sections)	American Institute of Biological Sciences	112	1	1957
							Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology	Consultants Bureau	106
	Earth Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Chemistry Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry Doklady Earth Sciences Sections (Includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections)	Consultants Bureau	106	1	1956			
				Mathematics	Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry Proceedings of the Academy of Sciences of the USSR, Sections: Geology	Consultants Bureau	106	1	1956
							Doklady Soviet Mathematics	Consultants Bureau	112
	Physics	Soviet Physics-Doklady (Includes: Aerodynamics, astronomy, crystallography, cybernetics and control theory, electrical engineering, energetics, fluid mechanics, heat engineering, hydraulics, mathematical physics, mechanics, physics, technical physics, theory of elasticity sections)	American Institute of Physics	124	1	1959			
				Physics	Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections)	Consultants Bureau	106-	1	1956-
							117	1	1957
Derevoobrabat. prom-st'.	Derevoobrabatyvayushchaya promyshlennost'	Wood Processing Industry	Consultants Bureau Timber Development Association (London)			9 1959			
Ėntom(ol). oboz(renie)	Ėlektrosvyaz	Telecommunications	Massachusetts Institute of Technology*			1 1957			
Farmakol. (i) toksikol(ogiya)	Ėntomologicheskoe obozrenie	Entomological Review	American Institute of Biological Sciences	38	1	1959			
FMM	Farmakologiya i toksikologiya	Pharmacology and Toxicology	Consultants Bureau	20	1	1957			
Fiziol. zhurn. SSSR	Fizika metallov i metallovechenie	Physics of Metals and Metallography	Acta Metallurgica*	5	1	1957			
(im. Sechenova)	Fiziologicheskii zhurnal im. I. M. Sechenova	Sechenov Physiological Journal USSR	National Institutes of Health*		1	1957			
Fiziol(ogiya) rast.	Fiziologiya rastenii	Plant Physiology	American Institute of Biological Sciences	4	1	1957			
FTT	Geokhimiya	Geochemistry	The Geochemical Society		1	1958			
Izmerit. tekh(nika)	Fizika tverdogo tela	Soviet Physics-Solid State	American Institute of Physics	1	1	1959			
Izv. AN SSSR,	Izmeritel'naya tekhnika	Measurement Techniques	Instrument Society of America		1	1959			
O(td). Kh(im). N(auk)	Izvestiya Akademii Nauk SSSR: Otdelenie khimicheskikh nauk	Bulletin of the Academy of Sciences of the USSR: Division of Chemical Sciences	Consultants Bureau		1	1952			

continued

Izv. AN SSSR, O(td), T(ekhn), N(auk): Met(ali), i top.	(see Met. i top.)			
Izv. AN SSSR Ser. fiz(ich).	Izvestiya Akademii Nauk SSSR: Seriya fizicheskaya	Bulletin of the Academy of Sciences of the USSR: Physical Series	Columbia Technical Translations	1 1954
Izv. AN SSSR Ser. geofiz.	Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya	Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series	American Geophysical Union	1 1954
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Kauch. i rez.	Kauchuk i rezina	Soviet Rubber Technology	Research Association of British Rubber Manufacturers	18 1 1959
	Kinetika i kataliz	Kinetics and Catalysis	Consultants Bureau	1 3 1960
	Koks i khimiya	Coke and Chemistry USSR	Coal Tar Research Association (Leeds, England)	1 1958
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	Kristallografiya	Soviet Physics - Crystallography	American Institute of Physics	2 1 1957
Metalov. i term. obrabot. metal.	Metalovedenie i termicheskaya obrabotka metallov	Metal Science and Heat Treatment of Metals	Acta Metallurgica	6 1 1958
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Met. i top.	Metallurgiya i topliva	Russian Metallurgy and Fuels	Eagle Technical Publications	1 1960
Mikrobiol.	Mikrobiologiya	Microbiology	American Institute of Biological Sciences	26 1 1957
OS	Optika i spektroskopiya	Optics and Spectroscopy	American Institute of Physics	6 1959
	Pochvovedenie	Soviet Soil Science	American Institute of Biological Sciences	1 1958
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Prikl. matem. i mekh.	Prikladnaya matematika i mekhanika	Applied Mathematics and Mechanics	American Society of Mechanical Engineers	1 1958
PTÉ	(see Pribory i tekhn. eks.)			
Radiotekh.	Problemy Severa	Problems of the North	National Research Council of Canada	
Radiotekh. i élektronika	Radiotekhnika	Radio Engineering	Massachusetts Institute of Technology*	12 1 1957
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	Stanki i instrument	Machines and Tooling	Production Engineering Research Assoc.	1 1959
	Stal'	Stal (In English)	Iron and Steel Institute	1 1959
Stek. i keram.	Steklo i keramika	Glass and Ceramics	Consultants Bureau	13 1 1956
Svaroch. proiz-vo	Svarochnoe proizvodstvo	Welding Production	British Welding Research Association	4 1959
Teor. veroyat. i prim.	Teoriya veroyatnosti i ee primeneniye	Theory of Probability and Its Applications	Society for Industrial and Applied Mathematics	1 1956
Tsvet. Metall	Tsvetnye metally	Nonferrous Metals	Primary Sources	1 1960
UFN	Uspekhi fizicheskikh Nauk	Soviet Physics - Uspekhi (partial translation)	American Institute of Physics	66 1 1958
UKh	Uspekhi khimii	Russian Chemical Reviews	The Chemical Society (London)	1 1960
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Usp. fiz. nauk	(see UFN)			
Usp. khim(ii)	(see UKh)			
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Usp. sovr. biol.	Uspekhi sovremennoi biologii	Russian Review of Biology	Oliver and Boyd	48 1959
Vest. mashinostroeniya	Vestnik mashinostroeniya	Russian Engineering Journal	Production Engineering Research Assoc.	4 1959
Vop. gem. i per. krovi	Voprosy gematologii i perelivaniya krovi	Problems of Hematology and Blood Transfusion	National Institutes of Health*	1 1957
Vop. onk.	Voprosy onkologii	Problems of Oncology	National Institutes of Health*	1 1957
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Zav(odsk), lab(oratoriya)	Zavodskaya laboratoriya	Industrial Laboratory	Instrument Society of America	25 1 1959
ZhAKh Zh. anal(it), khimii	Zhurnal analiticheskoi khimii	Journal of Analytical Chemistry USSR	Consultants Bureau	7 1 1952
ZhETF	Zhurnal éksperimental'noi i theoreticheskoi fiziki			
Zh. éksperim. i teor. fiz.		Soviet Physics-JETP	American Institute of Physics	28 1 1955
ZhFKh Zh. fiz. khimii		Russian Journal of Physical Chemistry	The Chemical Society (London)	7 1959
ZhMEI Zh(urn), mikrobiol.	Zhurnal fizicheskoi khimii	Journal of Microbiology,		
épidemiol. i immunobiol.	Zhurnal mikrobiologii, épidemiologii i immunobiologii	Epidemiology and Immunobiology	National Institutes of Health*	1 1957
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Zh(urn), neorgan(ich). khim(ii)	Zhurnal neorganicheskoi khimii	The Russian Journal of Inorganic Chemistry	The Chemical Society (London)	1 1959
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Zh(urn), obshch(ei) khimii	Zhurnal obshchei khimii	Journal of General Chemistry USSR	Consultants Bureau	19 1 1949
ZhPKh				
Zh(urn), prikl. khimii	Zhurnal prikladnoi khimii	Journal of Applied Chemistry USSR	Consultants Bureau	23 1 1950
ZhSKh				
Zh(urn), strukt. khimii	Zhurnal strukturnoi khimii	Journal of Structural Chemistry	Consultants Bureau	1 1 1960
ZhTF				
Zh(urn), tekhn. fiz.	Zhurnal tekhnicheskoi fiziki	Soviet Physics-Technical Physics	American Institute of Physics	26 1 1956
Zh(urn), vyssh. nervn. deyat. (im. Pavlova)	Zhurnal vysshei nervnoi deyatel'nosti (im. I. P. Pavlova)	Pavlov Journal of Higher Nervous Activity	National Institutes of Health*	1 1958

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by A. I. Shatenshtein

Director, Karlov Physicochemical Institute.

Translated from Russian

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