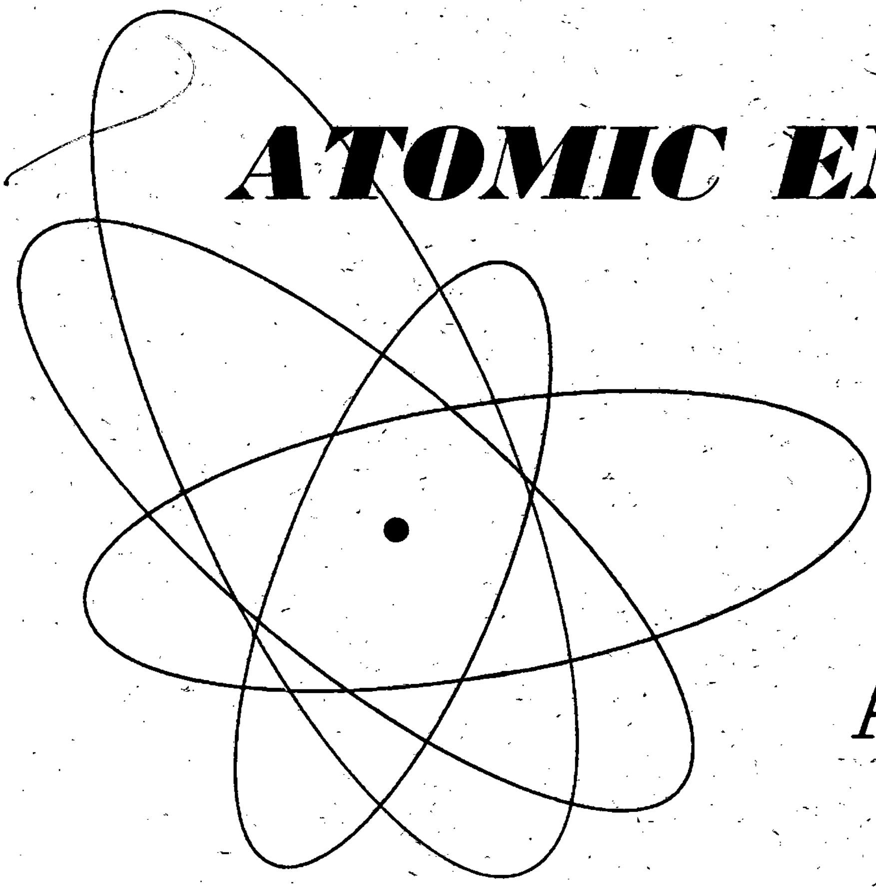
Volume 11, No. 3

March, 1962

THE SOVIET JOURNAL OF
ATOMIC ENERGY

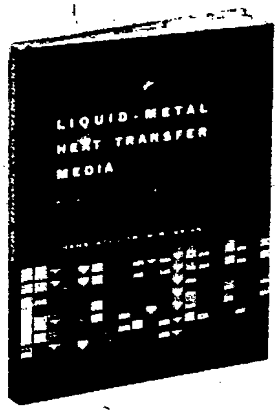


Атомная
энергия

TRANSLATED FROM RUSSIAN

CONSULTANTS BUREAU

THE LATEST SOVIET RESEARCH — IN TRANSLATION



LIQUID-METAL HEAT TRANSFER MEDIA

by S. S. Kutateladze, V. M. Borishanskii, I. I. Novikov and O. S. Fedynskii

This informative volume is devoted to the problems of utilizing liquid-metal heat transfer media in nuclear power. Data on the study of heat removal by liquid metals, obtained during the past ten years in the USSR as well as abroad, in connection with problems of nuclear power are both systematized and generalized in this work. The book will be of considerable assistance to scientific workers and engineers in the field of reactor design and nuclear power and in other fields of technology where liquid-metal coolants can be utilized.

cloth 150 pp. illus. $22.50

CORROSION OF CHEMICAL APPARATUS

by G. L. Shvartz and M. M. Kristal

"... the book is concerned with stress corrosion cracking and intercrystalline corrosion, especially in connection with process equipment ... a judicious mixture of facts, practice, and theory ... It contains a good deal of Shvartz's own work, and, indeed, is useful for the many pertinent Soviet references ... collects in one place much of the current Soviet thinking in this field ... the chapter on methods of testing and the one on methods of retardation are particularly effective ... Not only do they contain more detail than is usually found in such books, but they are clear and concise, and should prove useful to the practicing corrosion engineer ..." —Chemical & Engineering News

cloth 250 pp. $7.50

DENDRITIC CRYSTALLIZATION

by D. D. Saratovkin

"Translated from Russian, this 2nd edition has been revised to include fresh material derived from observations under the stereoscopic microscope. The bulk of this volume contains many original and unpublished ideas and observations, and is an example of the modern microscopic approach to the crystalline state by an experienced worker concerned with the infinite variety of real crystals. Line diagrams and sets of stereoscopic photographs are included." —Journal of Metals

cloth 126 pp. illus. $6.00

CONSULTANTS BUREAU

227 West 17th Street, New York 11, N.Y.

THE SOVIET JOURNAL OF
ATOMIC ENERGY

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

(Russian original dated September, 1961)

Vol. 11, No. 3 March, 1962

CONTENTS

LETTERS TO THE EDITOR

NEWS OF SCIENCE AND TECHNOLOGY

Annual subscription	$ 75.00
Single issue	20.00
Single article	12.50

CONTENTS (continued)

NOTE

The Table of Contents lists all materials that appear in Atomnaya Énergiya. Those items that originated in the English language are not included in the translation and are shown enclosed in brackets. Whenever possible, the English-language source containing the omitted reports will be given.

Consultants Bureau Enterprises, Inc.

ACCELERATION OF He_3 UP TO 35 Mev IN THE ONE AND ONE-HALF METER CYCLOTRON

N. I. Venikov, G. N. Golovanov, V. P. Konyaev,
N. V. Starostin, and N. I. Chumakov

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 213-216, September, 1961
Original article submitted January 30, 1961

A method is described for accelerating He_3^{2+} to 35 Mev in a cyclotron. A beam of 30μa with an energy spread of ± 0.3% was obtained on a target 12 m from the cyclotron. Due to the use of a gas recycling system, the loss of He_3 was decreased by two orders and was approximately 5 cm^3/hr.

Lately there has been great interest in the utilization of accelerated He_3 nuclei as bombarding particles. There have been reports concerning He_3 acceleration in the Los Alamos [1] and Birmingham [2] cyclotrons. Until the present, there have been no attempts to accelerate He_3 in Russian cyclotrons. In usual cyclotron operation, where the amount of running gas pumped out of the vacuum chamber and exhausted to the atmosphere reaches 0.5 liter/hr, the expenditure of He_3 is very great. In order to use the available supply of gas repeatedly, a special gas recycling system was developed by the authors and used on the cyclotron of the I. V. Kurachatov Order of Lenin Institute of Atomic Energy.

The Gas Recycling System

A diagram of the gas recycling system is given in Fig. 1. Gas is pumped from the cylinder by a special mercury pressure regulator of the automatic-acting pump-type into the system to a pressure of 100-200 mm of Hg. Then the cylinder is cut off and the gas is bled through a needle valve into the ion-source discharge chamber. Gas flow to the cyclotron could be adjusted remotely from a control panel by a servomotor system.

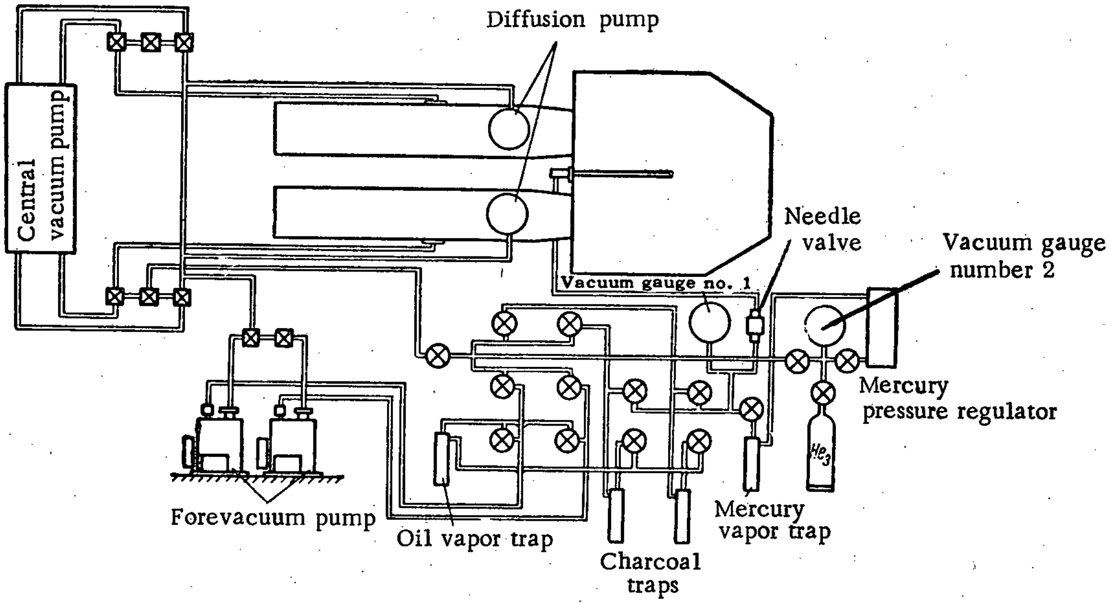


Fig. 1. Diagram of the recycling system.

On entering the cyclotron vacuum chamber, a small amount of the gas will be lost through nuclear reactions and sorption on the chamber material. However, the main part of the gas is pumped out along with other gases by the two diffusion pumps followed by mechanical forevacuum pumps. The pumped gas-vapor mixture proceeds through a system of traps, is compressed to the required pressure and returned to the system with the pure He_3.

One trap, which is chilled by liquid nitrogen, freezes out easily condensed substances (oil, water, and outgasing products). The second trap, which is designed for the absorption of nitrogen and oxygen, is filled with activated charcoal and also chilled with liquid nitrogen. There is also a trap for mercury vapor from the pressure regulator.

The charcoal trap's absorption capacity is 10-15 liter of air at normal pressure, consequently the service period of such a trap with the usual vacuum system* leak rate, approximately 0.1 cm^3/min, is several days. When a pressure increase in the system warns of a decrease in the charcoal's absorption capability, it is possible to switch to a previously readied second charcoal trap of the same type. Preparation of the pump for service is accomplished by heating it to 200 °C for several hours in a special electric furnace while simultaneously pumping on it with forevacuum pumps. There is a reserve mechanical pump in the system also.

In order to reduce He_3 losses on dismantling the system and with certain other operations (such as switching from one pump to another), the dimensions of the separate parts of the system have been reduced to a minimum. The chief harmful volume (the exhaust chamber of the mechanical pump) was significantly diminished by a fiberglas ballast in the pump's exhaust chamber.

An additional careful packing of the mechanical pumps was carried out and a special water-cooled oil baffle was introduced to decrease the oil entering the system with the He_3 from the mechanical pump. The mercury regulator supplied gas from the cylinder to make up the losses. The average loss of He_3 during the experiment was about 5 cm^3/hr at atmospheric pressure.

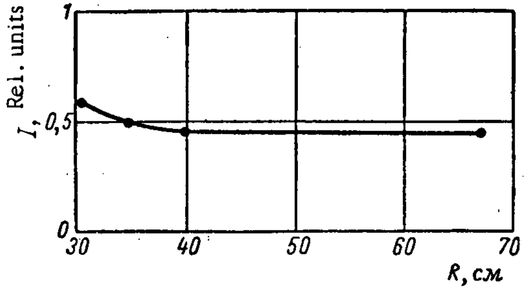


Fig. 2. Ion current dependence on the acceleration radius.

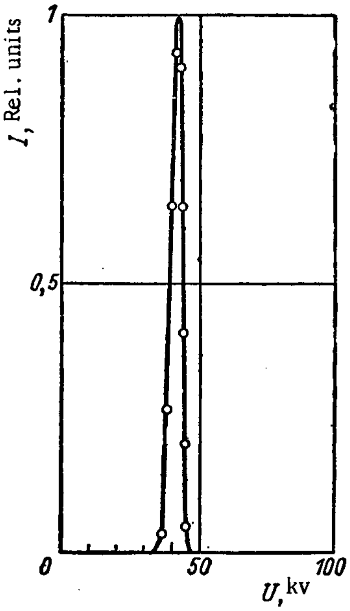


Fig. 3. Target ion current dependence on the deflecting system potential.

Acceleration of He_3

The maximum possible energy of the accelerated He_3 ions in the cyclotron was determined by the highest resonance frequency attainable, 11.2 Mc. This frequency corresponds to a magnetic field intensity H = 11,000 oe. The ultimate energy of the twice ionized He_3 ions in this case is about 35 Mev at the 67 cm radius.

The magnetic field was shimmed to secure adequate vertical ion focusing and so that the potential difference between the dees was 160 kv (i.e., it was lower than the breakdown voltage). A pulsed ion source supply was employed which increased the output of twice ionized helium by three-five times.

To decrease the ion losses during their acceleration and exit from the magnetic field, a focusing diaphragm was designed and employed on the dees which on the one hand strongly increased the ion focusing along the vertical

---

* The volume of the cyclotron vacuum system is about 5000 liter.

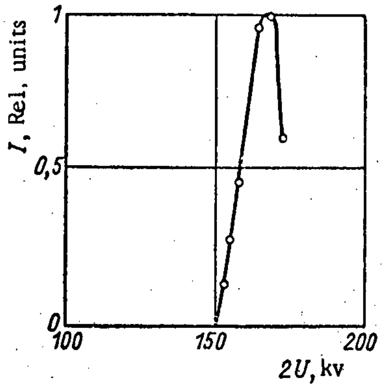


Fig. 4. Target ion current dependence on the dee potential difference.

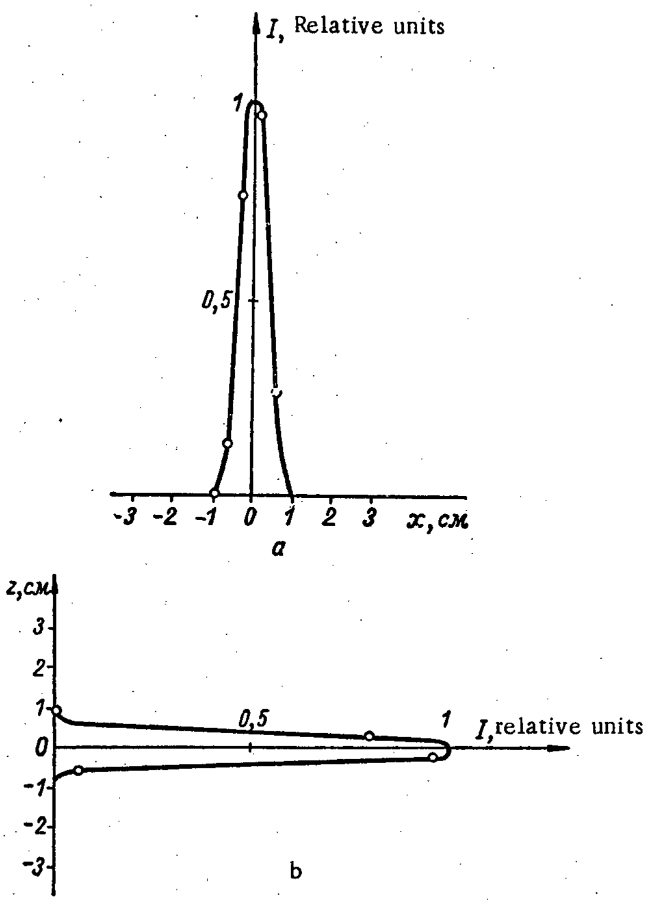


Fig. 5. Ion current intensity distribution at the target along the horizontal (a) and vertical (b) distance from the target center: x along the horizontal; z along the vertical.

in the cyclotron's central plane (where magnetic focusing is practically absent) *, while on the other blocked undesirable ions which in any case would have been lost during acceleration and exit. This decreased the load on the high frequency oscillator, reduced ion losses and consequently also the background and induced activity. The ion source was displaced to a previously calculated distance from the center of the magnetic field. The ion current dependence on the acceleration radius is given in Fig. 2. It is obvious from the figure that there are no ion losses beyond a 40 cm radius. The ion delivery coefficient from the deflecting system was 70%.

To deflect the ions, a system was designed employing hyperbolic electrodes which permitted beam focusing in the horizontal plant [4], more precisely, which compensated for the defocusing action of the bending magnet's field. Similar systems to improve ion beam parameters have been used in other acceleration systems.

Figure 3 shows the target ion current dependence on the deflecting system potential and Fig. 4 the dependence on the dee potential difference. The following parameters were obtained for the He_3^{2+} ion beam at the target situated 12 m from the cyclotron: He_3 ion energy, measured by the range in aluminum, was 35 Mev; half width of the beam energy spectrum, measured by a magnetic analyzer – not more than ± 0.3%; beam half width in the horizontal plane at the target – 8 mm, in the vertical plane –less than 8 mm.

The ion current intensity distribution at the target along the horizontal and along the vertical is given in Fig. 5. The average ion current intensity at the target was 30 μa. Usually work had been conducted with an average target current of 10 μa.

Using the third subharmonic of the high frequency, a sizeable He_4^{1+} ion beam with an energy of 5.4 Mev was accelerated and extracted on the target. To do this it was necessary to alter the potential between the dees (without changing the resonant circuit tuning) and to decrease H_0 to 10,000 oe. This result shows that subharmonic acceleration does not drastically reduce the accelerated ion current.

The authors wish to express their deep appreciation to N. A. Vlasov and S. P. Kalinin for the continuing interest in the project; to V. I. Lamunin and N. N. Khaldin for constructing the gas recycling system; to N. V. Kartashov for tuning the pulsed ion source; to the staffs of the operating group and machine shop who assisted in the preparation of the apparatus and cyclotron inlet system.

---

* A similar diaphragm is described in reference [3].

LITERATURE CITED

1. H. Wegner, W. Hall, Rev. Scient. Instrum., 29, No. 12, 1100 (1958).
2. I. Sremlin, W. Hardy, H. Shaylor. J. Scient. Instrum., 36, No. 9 390 (1959).
3. A. Morton, W. Smith. Nucl. Instrum. and Methods, 4, 37 (1959).
4. A. A. Arzumanov, E. S. Mironov, Atomnaya Énergiya 6, No. 2, 202 (1959).

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.**

SILICON COUNTERS FOR NUCLEAR SPECTROMETRY

S. M. Ryvkin, L. V. Maslov, O. A. Matvee, N. B. Strokan
and D. V. Tarkhin

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 217-220, September 1961
Original article submitted March 18, 1961

Laboratory models of surface-barrier and diffusion-type silicon n-p counters were developed which were suitable for nuclear spectrometry. The counters have linear pulse height-energy dependence for particles with 60 μ paths (in particular, for α-particles with energies up to 10 Mev), and ~ 0.5% resolution for an E of 5.5 Mev (with units of small area).

A series of papers [1-4] appeared in foreign publications during 1960 in which spectrometric counters of nuclear particles based on silicon n-p junctions were described. The semiconductor n-p counters operate on the principle of the ionization chamber, but the pulse resolution of the best units exceeds the resolution of an ionization chamber, being 0.25% or 14 kev for 5.5 Mev α-particles [3,4]. Among other qualities of n-p counters, there should be noted the relative insensitivity to magnetic fields, the small size, the reliable detection of strongly ionizing particles in a background of weakly ionizing particles (for example, fission fragment nuclei in a background of α-, β-, and γ-radiation), the linear dependence of pulse height on energy, and the high counting rate.

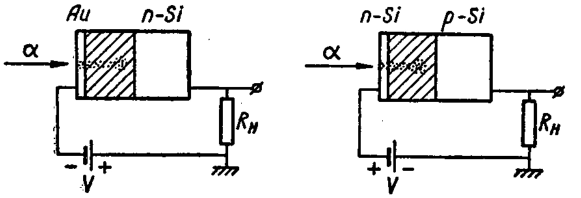


Fig. 1. Construction of a semiconductor counter and circuit diagram (shaded portion – space-charge region of n-p junction, the sensitive layer).

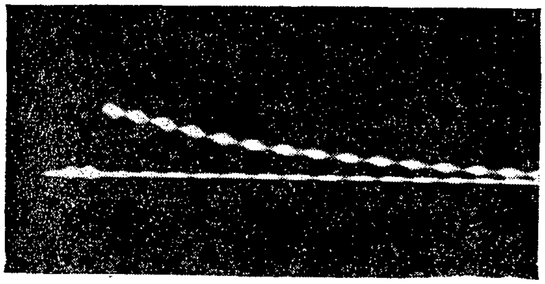


Fig. 2. Oscillogram of Pu^{238} α-pulses (0.2 μsec markers).

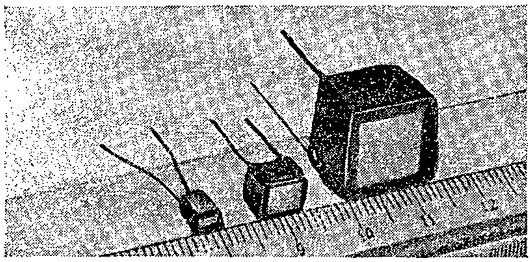


Fig. 3. External view of the Physico-technical Institute counters.

The sensitive layer of the counter – the space-charge region of an n-p junction – is formed in the immediate neighborhood of the irradiated surface. The original silicon can be of either the n- or p-type. In the first case, a film of gold several hundred atom layers thick is deposited to obtain an n-p junction; in the second case, diffusion of phosphorus produces an n-region 0.1-1μ thick. These counters are schematically represented in Fig. 1.

Particles incident on the counter give rise to ionization, creating electron-hole pairs. These pairs are separated by the field in the space-charge layer, and the released ionization charge Q is collected by the layer capacitance C and assembly capacitance C_M. Through this, the capacity is charged to a potential difference

$$\Phi = \frac{Q}{C_{\text{м}} + C}. \qquad (1)$$

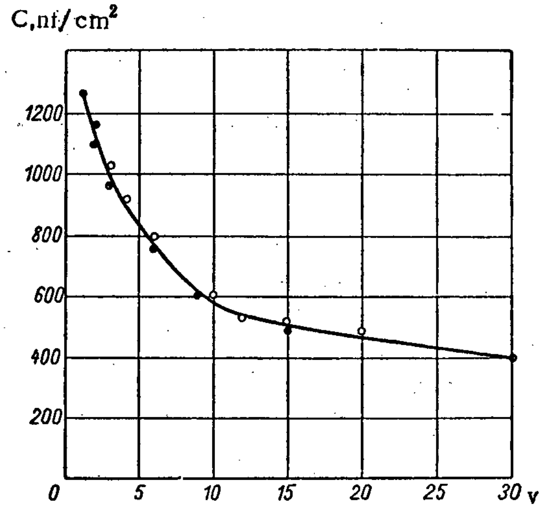


Fig. 4. Dependence of counter capacity on applied voltage (unit numbers: o –103; ● – 90).

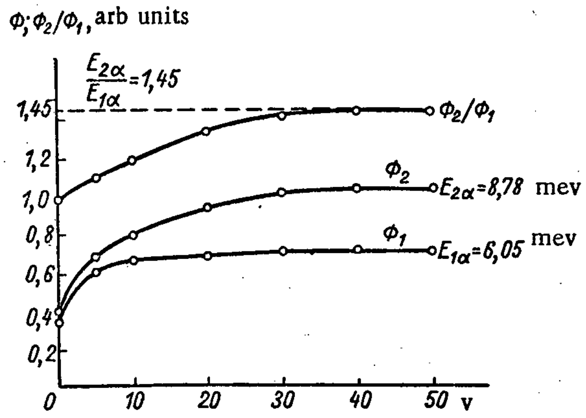


Fig. 5. Dependence of pulse height and ratio of pulse heights on applied voltage for α-particles with energies of 8.78 and 6.05 Mev.

Better peak resolution is obtained when practically the entire particle track is contained in the space-charge region the depth d of which is determined by the relation

$$d = 1{,}4\cdot 10^{-6}\sqrt{(V_0+V)\varrho\mu}\ \text{см}, \tag{2}$$

where V_0 is the contact potential difference of the n and p regions (v); V is the applied bias voltage (v); ρ is the specific resistance of silicon (ohm-cm); μ is the current-carrier mobility (cm^2-v-sec).

The characteristics of counters which were developed during 1960 at the A. F. Ioffe Physico-technical Institute of the USSR Academy of Sciences are described in this paper.

Small area counters had a pulse height ~1mv/Mev and a resolution of less than 1% for E_a = 5.5 Mev. The pulse shape is shown in Fig. 2. The counters were made by deposition of gold on n-type silicon and by diffusion of phosphorus into p-type silicon. The working area of both types of counters had values of 2 x 2, 5 x 5, and 10 x 10 mm (Fig. 3)

In what follows, results of the investigation of the following counter characteristics are presented: 1) voltage-current characteristics; 2) dependence of capacity on bias voltage; 3) pulse height; 4) dependence of pulse height on α-particle energy; 5) resolution.

1. The voltage-current characteristics of the units have the usual shape for n-p junctions. The inverse current was 0.5-0.05 μa at 40 v for a group of units 2 × 2 mm^2 in area. For units with 5 x x and 10 x 10 mm^2 areas, the current increased in proportion to the area. The breakdown voltage varied from 50 to 60 v.

2. An important parameter of the counter is the capacity of the sensitive layer – the space-charge region. In the first place, the magnitude of the capacity determines the pulse height; in the second place, it is easy to determine the thickness, d, of the sensitive layer from the value of the capacity. It is obtained in a manner similar to that for a plane condenser

$$d = \frac{\varepsilon_0 S}{4\pi C}, \tag{3}$$

where S is the area of the unit; ϵ_0 is the dielectric constant. Since $d \sim \sqrt{V + V_0}$, the capacity must decrease as $(V + V_0)^{-\frac{1}{2}}$ with increase in applied voltage. This dependence was fulfilled with satisfactory precision by our units. The dependence C = f (V) calculated for a unit 1 cm^2 in area is indicated by the solid line in Fig. 4.

3. Pulse height for a given capacity is determined by the free particle charge Q = eN where N is the number of ion pairs which, in turn, is determined by the average energy for pair formation (ϵ) and the energy of the ionizing particle. In previous work (for example, [4]), it has been established that ϵ does not depend on the nature and energy

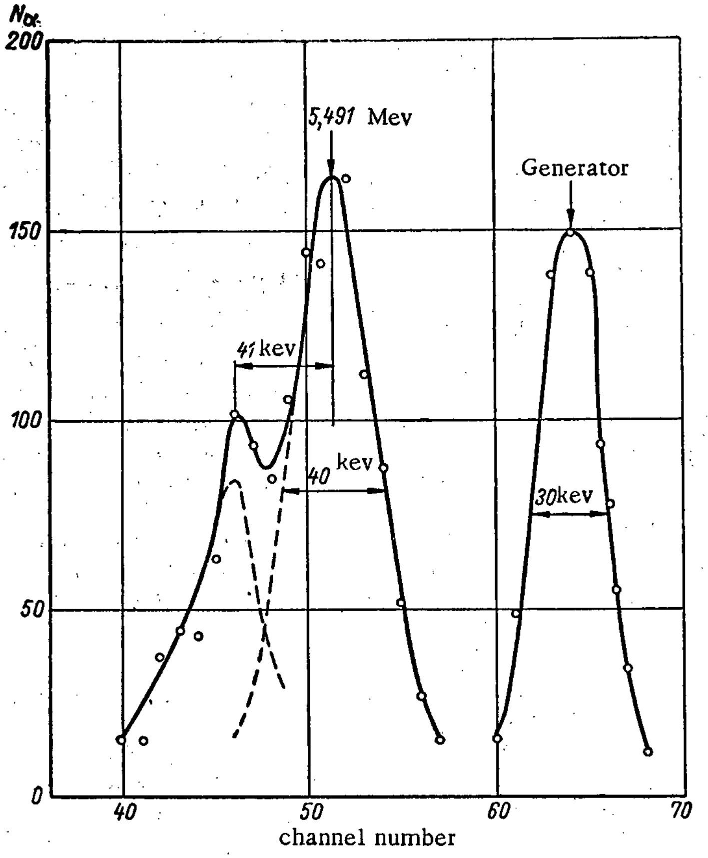


Fig. 6. Pulse height spectrum of Pu^{238} α-particles (Peak half-width after subtracting instrumental noise was 27 kev or 0.5%.

of the ionizing particle, and has a value ~3.5 ev for silicon. For Pu^{238} α-particles, we obtained $Q = 2.5 \cdot 10^{-13}$ k, i.e., $\epsilon = 3.53 \pm 0.15$ ev, with our counters. Therefore, charge was collected just as completely as in counters described earlier.

4. It follows from formula (1) that pulse height is proportional to charge collected. Therefore, by irradiating the counters with α-particles of different energies, and collecting all the resulting charge, we ought to obtain a linear dependence of pulse height on particle energy. Since α-particles with different energies have different path lengths, one should expect that complete charge collection will occur for different sensitive layer thicknesses, i.e., for different voltages. The dependence of the pulse height Φ on counter voltage V is shown in Fig. 5 for α-particles with energies of 8.78 and 6.05 Mev. It is clear that pulse height reaches a saturation value for the short-path group at ~ 15 v. However, in this situation, the thickness of the sensitive layer is still insufficient for complete collection of the charge created by the more penetrating particles with an energy of 8.78 Mev. Saturation is achieved at ~ 35 v for the more penetrating group. In addition, the ratio of pulse heights is equal with great precision, to the ratio of energies which testifies to the linear dependence of $\Phi(E_\alpha)$. We were unable to check linearity for higher energies, but one can predict that linearity will be maintained at V = 60 v for α-particles with energies up to 10 Mev, or for other particles with 60 μ paths.

5. We studied the value of peak resolution by standard methods using a 100-channel analyzer. Signal distortion because of noise and instrumental instability was taken into account with the help of a pulse generator. The spectrum of Pu^{238} α-particles measured with a $2 \times 2\,mm^2$ counter is shown in Fig. 6. From the figure, it can be seen that two groups of α-particles were resolved whose energies differ by 41 kev. The absolute value of the resolution after allowing for instrumental noise was 27 kev or 0.5%. It is necessary to point out that the resolution depended strongly on the area of the unit. Thus, for $5 \times 5\,mm^2$ counters, the resolution was 1%, and for $10 \times 10\,mm^2$ counters, 10%. Such a dependence is apparently explained by the fact that the characterisitics of various portions of a large surface will be non-uniform because of the non-uniformity of the silicon used, leading to a spread in pulse heights. Units $10 \times 10\,mm^2$ in area prepared by us were used also at the Joint Institute for Nuclear Research in Dubna for detecting

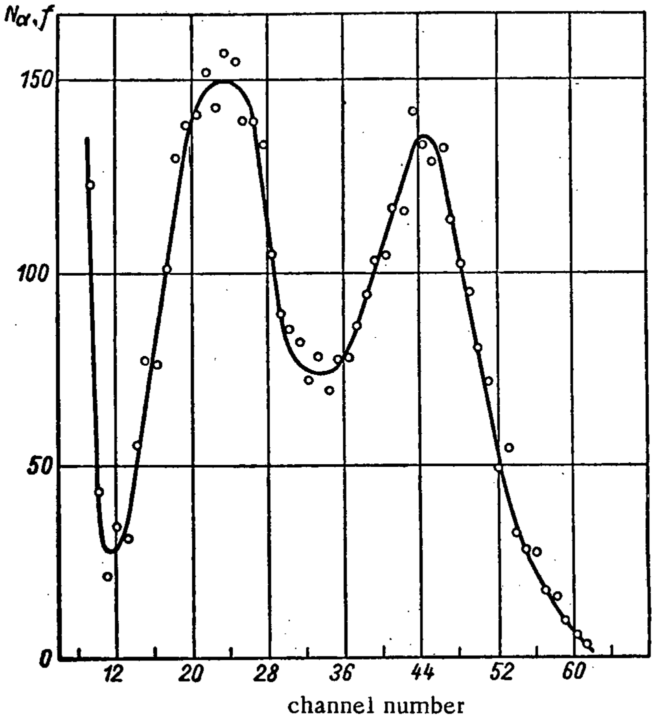


Fig. 7. Pulse height spectrum of U^{233} fission fragments in the presence of α-particle background of 10^4 sec^{-1}.

fission fragments from U^{233} in the presence of a high α-particle background (10^4 sec^{-1}). The resolution of two main groups of fragments is clearly demonstrated in Fig. 7 which was kindly furnished us by our associates in the laboratory of G. N. Flerov, corr. mem. Acad. Sci. USSR. The voltage on the unit needed for reducing α-particle pulse heights while taking the spectrum was not given.

The results presented in this paper on the counting of α-particles and fission fragments do not exhaust all the possibilities for counter development. For example, n-p counters can be used for counting fast and slow neutrons if nuclear reactions with neutrons which form heavy charged particles are employed.

The authors consider it a pleasure to thank engineer G. V. Khozov, technicians I. A. Lebedeva and G. D. Gusarina, and machinist P. I. Gorshkov for helping greatly in this work.

LITERATURE CITED

1. J. Blankenship, C. Borkowski, Bull. Amer. Phys. Soc., ser. II, 5, No. 1, 38 (1960.
2. S. Friedland, L. Mauer, J. Wiggins, Nucleonics, 18, No. 2, 54 (1960).
3. J. McKenzie, J. Waugh. Bull. Amer. Phys. Soc., ser. II, 5, No. 5, 355 (1960).
4. M. Halbert, J. Blankenship. Nucl. Instrum. and Methods, 8, No. 1, 106 (1960).

TWO-DIMENSIONAL BOUNDARY PROBLEM FOR TWO-DIMENSIONAL SQUARE LATTICES*

L. Trlifai

Institute of Nuclear Studies, Czechoslovakian Academy of Sciences, Prague

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 221-229, September 1961

The present article is concerned with the density distribution of thermal neutrons on the surface of lumps in two semi-infinite two-dimensional square lattices that are separated by a plane. The solution of this problem can be reduced to the solution of the Riemann boundary problem, which can be expressed in closed form. According to an analysis of the approximate solution for cases of practical importance, the asymptotic neutron density and its derivative are continuous at the boundary if the lattices are replaced by a homogenized medium. A similar solution of this problem for a lattice with an infinite reflector (moderator) is considered.

Introduction

In calculating a multizone heterogeneous reactor, it is necessary to determine the conditions for the neutron density at the boundary between two zones or at the boundary between the reactor core and the reflector. If the dimensions of individual zones and the curvature radius of the boundary are large, the necessary conditions can be determined by solving the problem of the neutron density distribution in two infinite lattices which are separated by a flat boundary.

For the sake of simplicity, we shall assume that both lattices are square, that the spacing is a, and that the boundary between the lattices, is equal to the distance $a/2$ from the boundary lumps of both lattices. The lumps are cylindrical, unbounded, and located at the nodes of the lattices. If we use the assumptions of the heterogeneous method, which has been developed by A. D. Galanin, S. M. Feinberg, et al., the thermal neutron density N(ka) at the surfaces of lumps will be determined by the equation [1].

$$(1+p_0)N(ka)=\sum_{k'=-\infty}^{-1}H_0(|k-k'|a)N(k'a)+ \\ +\sum_{k'=0}^{\infty}H_1(|k-k'|a)\text{ for } k<0; \tag{1a}$$

$$(1+p_1)N(ka)=\sum_{k'=-\infty}^{-1}H_0(|k-k'|a)N(k'a)+ \\ +\sum_{k'=0}^{\infty}H_1(|k-k'|a)N(k'a)\text{ для } k\geqslant 0, \tag{1b}$$

where

$$H_j(|k|a)= \\ =\frac{a}{2Lq_{0j}}\left[\eta_j\exp\left(\frac{\tau}{L^2}\right)-1\right]\exp\left(-\frac{|k|a}{L}\right)- \\ -\frac{a}{2\sqrt{\pi}Lq_{0j}}\eta_j\exp\left(\frac{\tau}{L^2}\right)\int_0^{\frac{\tau}{L^2}}\times \\ \times\frac{dx}{\sqrt{x}}\exp\left(-x-\frac{k^2a^2}{4L^2x}\right) \tag{2a}$$

and

$$p_j=\frac{q_{1j}}{q_{0j}}-\frac{a^2}{12L^2q_{0j}}$$

---

* This article has been received from the Czechoslovakian Socialist Republic.

for j equal to 0 or 1.

In Eqs. (1a) and (1b), it is assumed that the symmetry is such that the neutron density is equal in all lattice nodes that lie in a plane parallel to the lattice boundaries. These nodes are characterized by the integer k. The lattice with type-1 lumps fills the half space with $k \geq 0$, and the lattice with type-0 lumps fills the half space with $k < 0$. The properties of the moderator are characterized by the moderation length $\sqrt{\tau}$ and the diffusion length L. The constants q_{0j} and q_{1j} denote the internal and the external lump effects in lattices with type-0 and type-1 lumps, respectively; η_j is the effective value of the number of secondary neutrons in lump j.

From physical considerations, it is clear that, at a certain distance from the boundary between the lattices, the solution N(ka) of Eqs. (1a) and (1b) in both lattices approaches the asymptotic solution A_j, (ka), which is determined by the equation

$$\begin{gathered}(1+p_j)\,A_j(ka) = \\ = \sum_{k'=-\infty}^{\infty} H_j(|k-k'|\,a)\,A_j(k'a)\end{gathered} \tag{3}$$

for j equal to 0 or 1.

The general solution of Eq. (3) is well known [1]; it contains two constant factors, the values of which are not determined. However, in the case under consideration, the asymptotic regions are connected with the boundary region, so that only two of the four constant factors in Eq. (3) will be independent. The elimination of these two indeterminate constants leads to the boundary conditions for the asymptotic curve of the thermal neutron density; the determination of these conditions is important in heterogeneous reactor design. The derivation of equations on the basis of the above considerations is given below.

Let us break up the solution N(ka) of Eqs. (1a) and (1b) into two portions:

$$\left.\begin{aligned} N(ka) &= A_0(ka) + n_0(ka) \quad \text{for} \quad k < 0; \\ N(ka) &= A_1(ka) + n_1(ka) \quad \text{for} \quad k \geqslant 0. \end{aligned}\right\} \tag{4}$$

The η_j (ka) values play a more important role only in the boundary region, while, with an increase in | k| , their absolute value drops very quickly (for instance, it drops more rapidly than the value of $\beta \exp(-|k|\alpha)$, where α and β are positive numbers). According to expressions (1a), (1b), and (3), the values of n_j (ka) satisfy the following equations:

$$\begin{aligned}(1+p_0)\,n_0(ka) = \sum_{k'=-\infty}^{-1} H_0(|k-k'|\,a)\,n_0(k'a) + \\ + \sum_{k'=0}^{\infty} H_1(|k-k'|\,a)\,n_1(k'a) + \\ + \sum_{k'=0}^{\infty} [H_1(|k-k'|\,a)\,A_1(k'a) - \\ - H_0(|k-k'|\,a)\,A_0(k'a)];\end{aligned} \tag{5a}$$

$$\begin{aligned}(1+p_1)\,n_1(ka) = \sum_{k'=-\infty}^{-1} H_0(|k-k'|\,a)\,n_0(k'a) + \\ + \sum_{k'=0}^{\infty} H_1(|k-k'|\,a)\,n_1(k'a) + \\ + \sum_{k'=-\infty}^{-1} [H_0(|k-k'|\,a)\,A_0(k'a) - \\ - H_1(|k-k'|\,a)\,A_1(k'a)].\end{aligned} \tag{5b}$$

I. Reduction of Equations (5a) and (5b) to the Riemann Problem

Since the values of n_j (ka) decrease fairly quickly with an increase in $|k|$, we can determine functions $\Phi^+(z)$ and $\Phi^-(z)$ of a complex variable $\underline{z}$, whose values on the unit-radius circle K with the center at the coordinate origin are determined by the following series:

$$\begin{aligned} \Phi^+(s) &= \sum_{k=0}^{\infty} s^k n_1(ka); \\ \Phi^-(s) &= \sum_{k=-\infty}^{-1} s^k n_0(ka). \end{aligned} \tag{6}$$

Since the points $\underline{s}$ are located on the unit-radius circle, it can be assumed that s = exp(iaw). Thus, relationships (6) can be considered as Fourier series for the function of the (real) variable $\underline{w}$ with the period $2\tau/a$ of the inverse lattice.

After multiplying Eqs. (5a) and (5b) by s^k and performing summation with respect to $\underline{k}$ according to expression (6), we obtain after certain transformations:

$$\begin{aligned} &[1+p_1-F_1(s)]\,\Phi^+(s) = \\ &= -[1+p_0-F_0(s)]\,\Phi^-(s) + S(s) \\ &\text{for} \quad s=\exp(ia\omega), \end{aligned} \tag{7}$$

where

$$F_j(s) = \sum_{k=-\infty}^{\infty} s^k H_j(|k|a) \tag{8}$$

and

$$\begin{aligned} S(s) = {} & \sum_{k=1}^{\infty} s^{-k} \sum_{k'=0}^{\infty} [H_1(|k+k'|a)\,A_1(k'a) - \\ & - H_0(|k+k'|a)\,A_0(k'a)] + \\ & + \sum_{k=0}^{\infty} s^k \sum_{k'=-\infty}^{-1} [-H_1(|k-k'|a)\,A_1(k'a) + \\ & + H_0(|k-k'|a)\,A_0(k'a)]. \end{aligned} \tag{9}$$

We shall find two functions of the complex variable $\underline{z}$ which satisfy the linear relationship (7) on a circle with unit radius, namely, the function $\Phi^+(z)$, which is an analytic function in the inside region K^- of the circle K, and the function $\Phi^-(z)$, which is analytic in the external region K^- of the same circle, including $z = \infty$. Then, the subsequent solution of E. (7) will be reduced to the solution of the nonhomogeneous Riemann boundary problem. In this, we shall follow the terminology and notation used in [2].

In order to solve the Riemann problem, it is necessary to determine the form of the function S(s) in Eq. (7), which is determined by expression (9), where $A_j(ka)$ are solutions of Eq. (3). As was mentioned before, the solution of Eq. (3) is well known [1]. With the accepted notation, we can write:

$$A_j(ka) = A_j z_j^k + B_j z_j^{-k}, \tag{10a}$$

where A_j and B_j are constants, and z_j is the root of the equation

$$1 + p_j - F_j(z_j) = 0. \tag{10b}$$

The $F_j(z)$ function is expressed by the Laurent series (8). For an active medium, $z_j = \exp(i\kappa_j a)$, while, for an inactive medium, $z_j = \exp(\kappa_j a)$, where κ_j are real parameters [3]. For a critical medium, Eq.(10b) has a double root which is equal to unity, and the corresponding solution of Eq. (3) will be given by $A_j(ka) = A_j + B_j ka$.

The summation of the series in expression (9) is given in the Appendix (see end of article). The obtained result can be written in the following form:

$$S(s)=\sum_{j=0}^{1}(-1)^{j+1}[1+p_j-F_j(z_j)]\times \tag{11}$$
$$\times\left(\frac{1}{sz_j-1}A_j+\frac{z_j}{s-z_j}B_j\right).$$

After dividing both sides of Eq. (7) by $1 + p_1 - F_1(s)$, we obtain the usual form of the Riemann problem. The coefficient of this problem and its free term [2] satisfy the Helder condition on circle K, with the exception, perhaps, of the points z_1 and z_1^{-1}. At the points z_0 and z_0^{-1}, the coefficient of the problem may be equal to zero. From this point of view, the following three cases are of interest.

1. Media 0 and 1 are Active. In this case, we can write Eq. (7) on the circle K in the following form:

$$\Phi^+(s)=\frac{s^2-\left(z_0+\frac{1}{z_0}\right)s+1}{s^2-\left(z_1+\frac{1}{z_1}\right)s+1}G(s)\Phi^-(z)+g(s). \tag{12}$$

The G(s) coefficient is real, bounded, and different from zero on the circle K, since, according to Eq. (7),

$$G(s)=\frac{[1+p_0-F_0(s)]\left[s^2-\left(z_1+\frac{1}{z_1}\right)s+1\right]}{\left[s^2-\left(z_0+\frac{1}{z_0}\right)s+1\right][1+p_1-F_1(s)]} \tag{13a}$$

and, according to (8),

$$F_j(s)=F_j\left(\frac{1}{s}\right)=F_j^*(s).$$

The index of the coefficient G(s) is then equal to zero. The free term g(s) in expression (12) is equal to

$$g(s)=\frac{1}{s+\frac{1}{s}-\left(z_1+\frac{1}{z_1}\right)}\left\{G(s)\left[A_0\left(\frac{1}{z_0}-\frac{1}{s}\right)+\right.\right.$$
$$\left.+B_0\left(z_0-\frac{1}{s}\right)\right]+A_1\left(\frac{1}{z_1}-\frac{1}{s}\right)+ \tag{13b}$$
$$\left.+B_1\left(z_1-\frac{1}{s}\right)\right\}$$

and it has poles at the same points as the coefficient in front of $\Phi^-(s)$ in expression (12), while the order of magnitude of the free term poles does not exceed the order of magnitude of the poles of this coefficient.

The Riemann boundary problem of this type has been solved in [2], and, therefore, we shall write only the final results. The solution has the following form:

$$\Phi^+(s)=\frac{X^+(s)}{s^2-\left(z_1+\frac{1}{z_1}\right)s+1}[\Psi^+(s)+P_1(s)]; \tag{14a}$$

$$\Phi^-(s) = \frac{X^-(s)}{s^2-\left(z_0+\frac{1}{z_0}\right)s+1}\left[\Psi^-(s)+P_1(s)\right], \tag{14b}$$

$$X^{\pm}(s) = \exp\left(\Gamma^{\pm}(s)\right), \text{where } \Gamma^{\pm}(s) = \\ = \pm\frac{1}{2}\ln G(s) + \frac{1}{2\pi i}\int\limits_K \frac{\ln G(t)}{t-s}\,dt;$$

$$\Psi^{\pm}(s) = \pm\frac{1}{2}\left[s^2-\left(z_1+\frac{1}{z_1}\right)s+1\right]\frac{g(s)}{X^+(s)} + \\ + \frac{1}{2\pi i}\int\limits_K\left[t^2-\left(z_1+\frac{1}{z_1}\right)t+1\right]\frac{g(t)}{X^+(t)}\frac{dt}{t-s}. \tag{14c}$$

The function $P_1(s)$ is a first-power polynomial with indeterminate coefficients. In system (14), this function represents the solution (12) of the corresponding homogeneous Riemann problem. The power of the polynomial is determined in such a manner that $\Phi^-(z)\to 0$ for $|z|\to\infty$ in correspondence with expression (6). The integrals in system (14) are considered as Cauchy integrals.

If we know $\Phi^+(s)$ and $\Phi^-(s)$, we can determine the values of $n_j(ka)$. According to expression (6),

$$n_0(ka) = \frac{1}{2\pi i}\int\limits_K ds s^{-k-1}\Phi^-(s) \\ \text{for}\quad k<0;\; n_1(ka) = \\ = \frac{1}{2\pi i}\int\limits_K ds s^{-k-1}\Phi^+(s) \quad\text{for}\quad k\geqslant 0. \tag{15}$$

The expressions under the integral sign in these equations must be functions that can be integrated. In correspondence with Eqs. (14a) an d (14b), this can be secured by putting

$$\Psi^+(s)+P_1(s)=0 \text{ for } \quad s \text{ equal to } \quad z_1 \text{and} \frac{1}{z_1}, \\ \text{and}\quad \Psi^-(s)+P_1(s)=0 \quad\text{for}\quad s \quad\text{equal to}\quad z_0 \text{and} \frac{1}{z_0}. \tag{16}$$

Moreover, the thermal neutron density and the other physical parameters must be real quantities, and, consequently, the expressions (15) for $n_j(ka)$ must also be real. On the basis of expression (15), it can readily be shown that this requirement is satisfied if the coefficients of the polynomial in system (14) are real. On the basis of the same considerations, we must assume that, in the case under consideration, $B_j = A_j^*$, where the asterisk denotes a complex conjugate quantity.

Thus, the thermal neutron density on the surfaces of lumps can be expressed by means of Eqs. (14), (10a), (10b), and (15). The corresponding expressions contain six constant real numbers ($a_j = A_j + A_j^*$, $b_j = i(A_j + A_j^*)$, where j is equal to 0 or 1, and two real coefficients in $P_1(s)$. These constants are related by the four conditions (16), i.e., only two out of the six constants are independent. For the independent constants, it is convenient to choose a_j and b_j, which pertain to the asymptotic density in the medium j; the asymptotic in the medium $j \neq j$, i.e., a'_j and b'_j, will then be determined. If, in the asymptotic density $A_j(ka)$, we use continuously varying coordinates by means of the substitution $ka\to y$, the independent constants a_j and b_j can be eliminated, and we can obtain the boundary conditions for homogenized media, which relate the asymptotic thermal neutron densities to their derivatives at the boundary between the two media.

We shall prove the latter conclusion by considering an example of lattices where neutron moderation does not take place. The latter assumption was made in connection with the fact that we have still not succeeded in deriving from Eq. (15) any simple analytic expression for the general case. In this case,

$$F_j(z) = -\frac{a}{Lq_{0j}}\left[\eta_j\exp\left(\frac{\tau}{L^2}\right)-1\right]\times \\ \times\frac{\sin h\frac{a}{L}}{z+\frac{1}{z}-2\cos h\frac{a}{L}} \tag{17}$$

i.e., according to Eq. (13a), $G(s) = -(1+P_0)/1+P_1$. The integrals in expression (14c) can now readily be determined by using the Riemann formula:

$$\left.\begin{aligned} &\frac{1}{2i}\left(z_j-\frac{1}{z_j}\right) \equiv \sin \varkappa_j a; \quad X^-(s)=1; \\ &X^+(s) = -\frac{1+p_0}{1+p_1}; \quad \Psi^-(s) \equiv 0; \\ &\Psi^+(s) = -a_0(1-s\cos\varkappa_0 a) - \\ &-b_0 s \sin\varkappa_0 a - \frac{1+p_1}{1+p_0}\times \\ &\times[-a_1(1-s\cos\varkappa_1 a) - b_1 s \sin \varkappa_1 a]. \end{aligned}\right\} \tag{18}$$

From the second of conditions (16), it follows that $P_1(s) \equiv 0$. By using the first of the conditions (16), we shall determine the values of a_0 and b_0 in dependence on a_1 and b_1:

$$\begin{aligned} &a_0 = \frac{1+p_1}{1+p_0}a_1; \; b_0 = \frac{1+p_1}{1+p_0}\times \\ &\times\left(\frac{\cos\varkappa_0 a - \cos\varkappa_1 a}{\sin\varkappa_0 a}a_1 + \frac{\sin\varkappa_1 a}{\sin\varkappa_0 a}b_1\right). \end{aligned} \tag{19}$$

However, for these a_0 and b_0 values, $\psi^+(s) \equiv 0$. According to expression (15), this means that the asymptotic solution

$$A_j(y) = a_j \cos\varkappa_j y + b_j \sin\varkappa_j y, \tag{20}$$

where $y = ka$, while the a_0 and b_0 values are determined by Eq. (19), is the exact solution of the problem. Considering y as a continuously changing variable, we can express the independent constants a_1 and b_1 in terms of the values of functions $A_j(y)$ and their derivatives $A'_j(y)$ at certain points y_j:

$$A_1(y_1)\cos\varkappa_1 y_1 - A'_1(y_1)\frac{\sin\varkappa_1 y_1}{\varkappa_1} = a_1 = \frac{1+p_0}{1+p_1}\left[A_0(y_0)\cos\varkappa_0 y_0 - A'(y_0)\frac{\sin\varkappa_0 y_0}{\varkappa_0}\right]; \tag{21a}$$

$$\begin{aligned} &A_1(y_1)\sin\varkappa_1 y_1 + A'_1(y_1)\frac{\cos\varkappa_1 y_1}{\varkappa_1} = b_1 = \\ &= \frac{1+p_0}{1+p_1}\left[-A_0(y_0)\frac{\cos\varkappa_0(y_0+a) - \cos\varkappa_0 y_0\cos\varkappa_1 a}{\sin\varkappa_1 a} + A'_0(y_1)\frac{\sin\varkappa_0(y_0+a) - \sin\varkappa_0 y_0 \cos\varkappa_1 a}{\varkappa_0 \sin\varkappa_1 a}\right]. \end{aligned} \tag{21b}$$

These relationships express the boundary conditions for the homogenized media 0 and 1 for certain definite y_j values. The most rational choice will be $y_0 = y_1 - a/2$. The boundary conditions (21a) and (21b) then assume the following form:

$$\left.\begin{aligned} &(1+p_0)\cos\frac{\varkappa_0 a}{2}A_0\left(-\frac{a}{2}\right) = \\ &= (1+p_1)\cos\frac{\varkappa_1 a}{2}A_1\left(-\frac{a}{2}\right); \\ &\frac{(1+p_0)}{\varkappa_0}\sin\frac{\varkappa_0 a}{2}A'_0\left(-\frac{a}{2}\right) = \\ &= \frac{1+p_1}{\varkappa_1}\sin\frac{\varkappa_1 a}{2}A'_1\left(-\frac{a}{2}\right). \end{aligned}\right\} \tag{22}$$

Since the relationships $(1 - p_j) \times \cos k_j a /2 \simeq 1$ and $(1 + p_j)\, \kappa_j^{-1} \sin k_j a /2 \simeq a/2$ hold for lattices that are usually encountered in practice, conditions (22) signify that the thermal neutron density and its derivative are continuous at the boundary. It seems to us that this statement will also remain valid in the case where the moderation of neutrons is taken into account if only the type-0 and type-1 lattices do not greatly differ from each other with respect to their physical properties.

2. Medium 0 is Inactive and Medium 1 is Active. Equations (7) and (11) can be written in the following form:

$$\Phi^+(s) = \frac{G(s)}{s^2 - \left(z_1 + \frac{1}{z_1}\right)s + 1}\,\Phi^-(s) + g(s), \tag{23}$$

where

$$G(s) = -\frac{\left[s^2 - \left(z_1 + \frac{1}{z_1}\right)s + 1\right][1 + p_0 - F_0(s)]}{1 + p_1 - F_1(s)} \tag{24a}$$

and

$$\begin{gathered} g(s) = \frac{1}{s^2 - \left(z_1 + \frac{1}{z_1}\right)s + 1} \times \\ \times \left[G(s)\left(\frac{1}{sz_0 - 1}A_0 + \frac{z_0}{s - z_0}B_0\right) + \right. \\ \left. + \left(\frac{s}{z_1} - 1\right)A_1 + (sz_1 - 1)A_1^*\right]. \end{gathered} \tag{24b}$$

The index of the coefficient of G(s) is equal to unity. The solution of the corresponding Riemann problem is expressed by means of the equations [2]

$$\begin{gathered} \Phi^+(s) = \frac{X^+(s)\,[\Psi^+(s) + C]}{s^2 - \left(z_1 + \frac{1}{z_1}\right)s + 1} \\ \text{and}\quad \Phi^-(s) = X^-(s)\,[\Psi^-(s) + C], \end{gathered} \tag{25a}$$

where

$$\begin{gathered} X^+(s) = \exp[\Gamma^+(s)], \quad X^-(s) = s^{-1}\exp[\Gamma^-(s)], \\ \Gamma^\pm(s) = \pm\frac{1}{2}\ln[s^{-1}G(s)] + \frac{1}{2\pi i}\int_K \frac{\ln[t^{-1}G(t)]}{t - s}\,dt; \\ \Psi^\pm(s) = \pm\frac{1}{2}\left[s^2 - \left(z_1 + \frac{1}{z_1}\right)s + 1\right]\frac{g(s)}{X^+(s)} + \\ + \frac{1}{2\pi i}\int_K dt\left[t^2 - \left(z_1 + \frac{1}{z_1}\right)t + 1\right]\frac{g(t)}{X^+(t)}\,\frac{1}{t - s}. \end{gathered} \tag{25b}$$

The symbol C denotes the constant which must be real $(C = C^*)$.

The values of $n_j(ka)$ are determined by using Eqs. (15), in which $\Phi^+(s)$ must be a function that can be integrated, we assume that

$$\Psi^+(s) + C = 0 \text{ for } \quad s \text{ equal to } \quad z_1 \text{ and } \frac{1}{z_1}. \tag{26}$$

If we now calculate all constants that were not determined up to now, we obtain five real constants in the problem: C, A_0, B_0, $a_1 = A_1 + A_1^*$, $b_1 = i(A_1 - A_1^*)$. According to conditions (26), we shall eliminate two of these constants, which will leave us with three independent constants, which contradicts the physical considerations. This contradiction can be eliminated in the following manner. Since the first portion of the asymptotic solution (10a) corresponds to an inactive medium 0, i.e., $A_0\exp(+\kappa_0 ka)\,(\kappa < 0)$ is not asymptotic from the mathematical point of view, we shall assume that $A_0 = 0$. However, this portion will now be automatically included in the expression for $n_0(ka)$, which is determined by Eq. (15). The contradiction can be avoided in a different way by adding the following condition to conditions (26):

$$\lim_{z\to\frac{1}{z_0}} \Phi^-(z)\left(z-\frac{1}{z_0}\right)=0, \tag{27}$$

which means that $n_0(ka)$ does not contain terms of the type $A_0 \exp(\kappa_0 ka)$ for $k<0$.

According to conditions (26) and (27), the asymptotic density $A_j(ka)$ will now depend only on two real constants. By eliminating these constants, we can derive the boundary conditions for the asymptotic thermal neutron densities and their derivatives in the corresponding homogenized media. (The reasoning followed in section 1 applies also here.) If we neglect neutron moderation, we can obtain the boundary conditions (22), with the difference, however, that $i\kappa_0$ instead of κ_0 should be substituted in Eqs. (22) for the inactive medium.

3. Media 0 and 1 are Inactive. This case does not essentially differ from the two preceding cases. Instead of Eqs. (12) and (23), we have:

$$\Phi^+(s)=G(s)\Phi^-(s)+g(s), \tag{28}$$

where

$$G(s)=-\frac{1+p_0-F_0(s)}{1+p_1-F_1(s)};$$

$$g(s)=G(s)\left(\frac{A_0}{sz_0-1}+\frac{B_0z_0}{s-z_0}\right)+\frac{A_1}{sz_1-1}+\frac{B_1z_1}{s-z_1}. \tag{29}$$

The index of the coefficient G(s) is equal to zero, so that the solution of the boundary problem is given by

$$\Phi^{\pm}(s)=X^{\pm}(s)\left[\pm\frac{1}{2}\frac{g(s)}{X^+(s)}+\frac{1}{2\pi i}\int\limits_K \frac{g(t)}{X^+(t)}\frac{dt}{t-s}\right], \tag{30a}$$

where

$$X^{\pm}(s)=\exp(\Gamma^{\pm}(s)), \tag{30b}$$

$$\Gamma^{\pm}(s)=\pm\frac{1}{2}\ln G(s)+\frac{1}{2\pi i}\int dt\,\frac{\ln G(t)}{t-s}.$$

The expressions for $n_j(ka)$ are determined by Eqs. (15). The two dependent constants are eliminated by using conditions which are similar to condition (27);

$$\lim_{z\to\frac{1}{z_0}} \Phi^-(z)\left(z-\frac{1}{z_0}\right)=0; \tag{31}$$

$$\lim_{z\to z_1}\Phi^+(z)(z-z_1)=0.$$

Hereafter, the reasoning and the conclusions given above are repeated.

II. Lattice with a Reflector

At the beginning of the article we have touched upon the problem concerning the conditions at the boundary between the half space that is occupied by the lattice and the half space that is occupied by the moderator. This problem can be described by using Eqs. (5b) and (3), assuming that $n_0 = A_0 = H_0 = 0$. Therefore, it will not be necessary to ascribe the index 1 to the lattice. The problem for a critical medium (lattice) has been solved in [1]. The method used in section I of the present article can be used for solving the problem for a general medium.

We shall denote

$$h(s) = -\sum_{k=0}^{\infty} s^k \sum_{k'=1}^{\infty} H[(k+k')a]\,A(-k'a);\qquad q(s) = \sum_{k=0}^{\infty} s^k n(ka) \tag{32}$$

and, in correspondence with data from [4], write:

$$\sum_{k'=0} H(|k-k'|a)\,n(k'a) = \frac{1}{2\pi i}\int_K ds\,s^{-k-1}F(s)\,q(s), \tag{33}$$

where the function F(s) is given by Eq. (8). If we now multiply Eq. (5b) by s^K and perform summation with respect to $k \geq 0$, we obtain:

$$(1+p)\,q(s) = = \sum_{k=0}^{\infty} s^k \frac{1}{2\pi i}\int_K dt\,t^{-k-1}F(t)\,q(t) + h(s). \tag{34}$$

In the internal region of the circle $K(s \in K^+)$, the order of summation and integration can be interchanged in the first term of expression (34). After performing the summation with respect to k in (34), we shall return to the point s on the circle K by changing the limits. If we now use Sokhotskii's formulas, the sum (34) can be written thus:

$$\sum_{=0}^{\infty} s^k \frac{1}{2\pi i}\int_K dt\,t^{-k-1}F(t)\,q(t) = \Phi^+(s) = = \frac{1}{2}F(s)\,q(s) + \frac{1}{2\pi i}\int_K dt\,\frac{F(t)\,q(t)}{t-s}, \tag{35}$$

where $\Phi(z) = \frac{1}{2\pi i}\int_K dt\,\frac{F(t)\,q(t)}{t-z}$ is a sectionally-analytic function. By using Sokhotskii' formulas, we can also write $F(s)\,q(s) = \Phi^+(s) - \Phi(s)$, while Eq. (34) can be formulated as the Riemann boundary problem for finding $\Phi^{\pm}(z)$ on the circle K:

$$\Phi^+(s) = \frac{1+p}{1+p-F(s)}\,\Phi^-(s) + \frac{F(s)\,h(s)}{1+p-F(s)}, \tag{36}$$

while

$$\Phi^-(\infty) = 0$$

In order to solve this Riemann problem, we can apply the method used in [2]. The type of the equations to be used will depend on whether we deal with active, critical, or inactive lattices. The thermal neutron density on the surfaces of lumps in lattices will be determined by the expression

$$N(ka) = A(ka) + \frac{1}{2\pi i}\int_K ds\,s^{-k-1}\cdot\frac{\Phi^+(s) - \Phi^-(s)}{F(s)}. \tag{37}$$

On the basis of considerations similar to those given in section I of the present article, it can be shown that solution (37) depends only on a single independent variable and that the corresponding boundary conditions for asymptotic density can be derived.

CONCLUSION

Expressions for the thermal neutron density at the surfaces of lumps in lattices that are separated by a flat boundary have been obtained. The application of a complex variable and of the Riemann boundary problem proved to be useful in solving this problem. The main physical result is the conclusion that the asymptotic density and its derivative can be considered to be continuous for a suitable homogenization of the lattice. The conditions under which this conclusion is valid are expressed by relationships (22). Only one definite position of the flat boundary was considered. One can also visualize different boundary positions with respect to a square lattice, which would be interesting from the physical point of view, however, we consider that the basic results obtained here would thereby not be affected.

We take this opportunity to express our gratitude to I. Marek for the valuable discussions in assessing certain mathematical problems.

Appendix

Expressions (9) can be written in the following form:

$$S=\sum_{k=1}^{\infty}\exp(-ika\omega)\sum_{k'=k}^{\infty}\{H_1(k'a)A_1[(k'-k)a]-H_0(k'a)A_0[(k'-k)a]\}+$$
$$+\sum_{k=0}^{\infty}\exp(ika\omega)\sum_{k'=k+1}^{\infty}\{-H_1(k'a)A_1[(k-k')a]+H_0(k'a)A_0[(k-k')a]\}. \tag{A1}$$

We shall restrict our further considerations to active media, for which,

$$A_j(ka)=A_j\exp(i\varkappa_j ka)+B_j\exp(-i\varkappa_j ka). \tag{A2}$$

If we take into account only the first term in expression (2a) for $H_j(|k|\,a)$, the summation of the corresponding terms in expression (A1) will be very simple, and it will yield the following result:

$$S_1=\frac{a\sin h\frac{a}{L}}{4L\left(\cos h\frac{a}{L}-\cos\omega a\right)}\left\{\frac{1}{q_{01}}\left[\eta_1\exp\left(\frac{\tau}{L^2}\right)-1\right]\times\right.$$
$$\times\frac{A_1[\exp(-i\omega a)-\exp(-i\varkappa_1 a)]+B_1[\exp(-i\omega a)-\exp(i\varkappa_1 a)]}{\cos h\frac{a}{L}-\cos\varkappa_1 a}- \tag{A3}$$
$$\left.-\frac{1}{q_{00}}\left[\eta_0\exp\left(\frac{\tau}{L^2}\right)-1\right]\frac{A_0[\exp(-i\omega a)-\exp(-i\varkappa_0 a)]+B_0[\exp(-i\omega a)-\exp(i\varkappa_0 a)]}{\cos h\frac{a}{L}-\cos\varkappa_0 a}\right\}$$

For the summation in (A1) of terms corresponding to the second term in expression (2a), it is convenient to use the modified Poisson summation formula:

$$\sum_{n=m}^{\infty}\Phi(n)=\frac{1}{2}\Phi(m)+\sum_{\nu=-\infty}^{\infty}\int_{m}^{\infty}d\tau\exp(-2\pi i\nu\tau)\Phi(\tau). \tag{A4}$$

If we write only the terms with the constant a_1, then, by using (A4), we obtain:

$$S_2=S-S_1=-\frac{a\eta_1\exp\left(\frac{\tau}{L^2}\right)}{2\sqrt{\pi}\,Lq_{01}}A_1\left\{\frac{1}{2}\int_0^{\frac{\tau}{L^2}}\frac{dx}{\sqrt{x}}\sum_{\nu=-\infty}^{\infty}\int_{-\infty}^{\infty}dt\exp\left(-x-\frac{t^2a^2}{4L^2x}-2\pi i\nu t\right)\times\right. \tag{A5}$$

$$\times [\exp(-it\omega a)-\exp(-it\varkappa_1 a)]+\int\limits_0^{\frac{\tau}{L^2}}\frac{dx}{\sqrt{x}}\sum_{\nu=-\infty}^{\infty}\int\limits_{-\infty}^{\infty}dt\exp\left(-x-\frac{t^2a^2}{4L^2x}+i\varkappa_1 at-2\pi i\nu t\right)\times$$

$$\times\sum_{\mu=-\infty}^{\infty}\int\limits_0^{t}dv\exp(-iva\omega-iva\varkappa_1-2\pi i\mu v)\Big\}+\ldots$$

In the last term, we changed the order of integration. In expression (A5), we can now readily perform the integration with respect to v and t . As a result, we obtain:

$$S_2=-\frac{\eta_1\exp\left(\frac{\tau}{L^2}\right)}{q_{01}}\Bigg\{\frac{1}{2}\sum_{\nu=-\infty}^{\infty}\int\limits_0^{\frac{\tau}{L^2}}dx\exp(-x)\Bigg[\exp\left(-\frac{4\pi^2L^2x}{a^2}\left(\nu+\frac{\omega a}{2\pi}\right)^2\right)-$$

$$-\exp\left(-\frac{4\pi^2L^2x}{a^2}\left(\nu+\frac{\varkappa_1 a}{2\pi}\right)^2+\right. \tag{A6}$$

$$\left.+\sum_{\mu=-\infty}^{\infty}\frac{\exp\left(-\frac{4\pi^2L^2x}{a^2}\left(\nu+\frac{\varkappa_1 a}{2\pi}\right)^2\right)-\exp\left(-\frac{4\pi^2L^2x}{a^2}\left(\mu+\nu+\frac{\omega a}{2\pi}\right)^2\right)}{2\pi i\left(\mu+a\frac{\omega+\varkappa_1}{2\pi}\right)}\Bigg]\Bigg\}+\ldots$$

The summation with respect to μ or ν (nu) can be performed by using Eq. 1.445 (6) from [5], which can be written in the following form:

$$\sum_{\nu=-\infty}^{\infty}\Big[\mu-\nu+\frac{a}{2\pi}(\omega+\varkappa)^{-1}=\pi\operatorname{ctg}\frac{a}{2}(\omega+\varkappa). \tag{A7}$$

If we now consider that, in (A3),

$$\frac{\exp(-i\omega a)-\exp(-i\varkappa_j a)}{\left(\cos h\frac{a}{L}-\cos\omega a\right)\left(\cos h\frac{a}{L}-\cos\varkappa_j a\right)}=$$

$$=\left[1+i\operatorname{ctg}\frac{a}{2}(\omega+\varkappa_j)\right]\times$$

$$\times\left(\frac{1}{\cos h\frac{a}{L}-\cos\omega a}-\frac{1}{\cos h\frac{a}{L}-\cos\varkappa_j a}\right) \tag{A8}$$

and that, with the accepted notation, Eq. (10b) can also be written in the form

$$1+p_j=F_j[\exp(\pm i\omega a)]_{\omega=\varkappa_j}\equiv$$

$$\equiv\frac{\eta_j}{q_{0j}}\sum_{\nu=-\infty}^{\nu=\infty}\frac{\exp\left[-\frac{4\pi^2\tau}{a^2}\left(\nu+\frac{a\omega}{2\pi}\right)^2\right.}{1+\frac{4\pi^2L^2}{a^2}\left(\nu+\frac{a\omega}{2\pi}\right)^2}-$$

$$-\frac{a}{2Lq_{0j}}\frac{\sin h\frac{a}{L}}{\cos h\frac{a}{L}-\cos\omega a},$$

where (A9)

$$\frac{a}{2L}\frac{\sin h\frac{a}{L}}{\cos h\frac{a}{L}-\cos\omega a}=$$

$$=\sum_{\nu=-\infty}^{\infty}\frac{1}{1+\frac{4\pi^2L^2}{a^2}\left(\nu+\frac{a\omega}{2\pi}\right)^2}.$$

We obtain the following result for the sum $S = S_1 + S_2$ (A1) after certain further transformations (integration with respect fo x in (A6), etc.):

$$\begin{aligned} S\,[\exp(ia\omega)] = {} & \frac{1}{2}\sum_{j=0}^{1}(-1)^j\left[1 + i\operatorname{ctg}\frac{a}{2}(\omega + \varkappa_j)\right] \times \\ & \times \{1 + p_j - F_j\,[\exp(ia\omega)]\}\,A_j \\ & + \frac{1}{2}\sum_{j=0}^{1}(-1)^j\left[1 + i\operatorname{ctg}\frac{a}{2}(\omega - \varkappa_j) \times \right. \\ & \times \{1 + p_j - F_j\,[\exp(ia\omega)]\}\,B_j. \end{aligned} \tag{A10}$$

A similar result can also be obtained for an inactive medium.

LITERATURE CITED

1. A. D. Galanin, Theory of Thermal Neutral Nuclear Reactors [in Russian] (Atomizdat, Moscow, 19590, 2nd ed.
2. F. D. Gakhov, Boundary Problems [in Russian] (Fizmatgiz, Moscow, 1958).
3. L. Trlifai and I Rocek, Atomnaya Énergiya, 9, No. 5, 336 (1960).
4. V. I. Smirnov, Calculus Course [in Russian] (Gostekhteoretizdat, Moscow, 1953, p. 179, Vol. 4, 3rd ed.
5. I. M. Ryzhik and I. S. Gradshtein, Tables of Integrals, Sums, Series, and Products [in Russian] (Gostekhteoretizdat, Moscow – Leningrad, 1951).

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.**

DIFFUSIVITY OF SODIUM AND LITHIUM

I. I. Rudnev, V. S. Lyashenko and M. D. Abramovich

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 230-232, September, 1961

The present article describes the design of a device for measuring the diffusivity of metals in the solid and liquid state at temperatures of up to 1000° C by using the temperature-wave method. The results obtained in measuring the diffusivity of sodium (in the temperature range from 350 to 880°C) and lithium (in the temperature range from 350 to 1000° C) are given.

The thermal conductivity coefficients are calculated on the basis of the experimental values of the diffusivity coefficient and the literature data on density and specific heat.

Molten alkali metals, which have high thermal conductivity and specific heat values and low specific weight, offer great possibilities as coolants for atomic power reactors, and the study of their caloric and physical parameters is of considerable interest.

The aim of the project described here was an experimental determination of the diffusivity of sodium and lithium in a wide temperature range according to Angstrom's method (the method of temperature waves), the theory of which was described in [1,2].

Description of the Device

In order to simplify the construction and to facilitate the performance of experiments, the design of the device described in the literature has been modified (see figure). In particular, excess pressure of the inert gas above the liquid metal surface was not provided; the flange with a free volume at the upper end of the tube with liquid metal was removed, and the photographic recording device was replaced by a self-recorder.

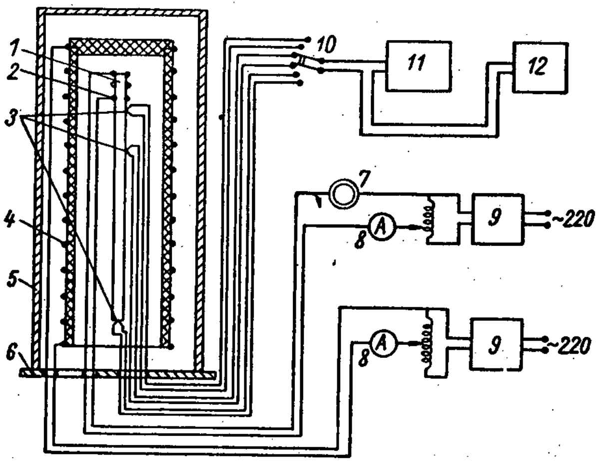


Diagram of the device; 1) specimen; 2) pulse heater; 3) thermocouples; 4) electric furnace; 5) vacuum hood; 6) base plate; 7) interrupter; 8) ammeter; 9) voltage stabilizers; 10) thermocouple switch; 11) potentiometer; 12) EPP-09 automatic electronic self-recording potentiometer.

The metals under investigation were poured in a vacuum of ~1 x 10^{-2} mm Hg into a thin-walled tube made of steel 1Kh 18N9T (length: 230 mm; diameter: 8.6 mm; wall thickness: 0.2 mm) through the upper plug which had an opening with a diameter of 3 mm. The lower and the upper steel-1Kh 18N9T plugs were hermetically joined to the tube by argon-arc welding. The necessary compensating volume was provided between the upper plug and the metal surface.

Sodium was first distilled, while lithium was filtered through a capillary with an inside diameter of 1.5 mm. The opening through which the tube was filled with metal was plugged with a tapered steel plug after filling, the specimen was withdrawn from the vacuum chamber, and the plug was made airtight by means of argon-arc welding. The specimen was placed in a vertical tubular electric furnace. A sufficiently uniform temperature field with temperatures of up to 1000° C could be secured in the furnace. In order to prevent the oxidation of specimens and to eliminate convective air flow, the furnace with the specimen was placed in a vacuum chamber.

The temperature was measured by means of chromel-alumel thermocouples, which had 0.1-mm diameters.

The constant component of the thermo-emf developed by the thermocouples, which characterized the average temperature level at a given point on the specimen, was measured by means of the potentiometer. The variable components of the thermo-emf's developed by the thermocouples were successively recorded on a strip chart by means of an ÉPP-09 potentiometer, which had a measurement range from 0 to 0.5 mv.

After completion of experiments on the determination of diffusivity, the specimens were taken out in vacuum, and the alkali metal was subjected to chemical analysis. The analysis results yielded the following impurity percentages (% by weight).

In Sodium:

O	$1.6\cdot10^{-2}$	Ni	$1.4\cdot10^{-2}$
K	$4\cdot10^{-2}$	Al	$<1\cdot10^{-3}$
Fe	$1.6\cdot10^{-1}$	Cu	$4.5\cdot10^{-4}$
Mg	$2.7\cdot10^{-4}$	Ag	$2\cdot10^{-4}$
Mn	$1.7\cdot10^{-3}$	Ti	$1.1\cdot10^{-3}$
Pb	$<2\cdot10^{-3}$	Ca	$3\cdot10^{-4}$
Cr	$4.9\cdot10^{-2}$		

In lithium:

N	$4.4\cdot10^{-3}$	Cu	$6\cdot10^{-2}$
C	$8\cdot10^{-2}$	Ag	$<3\cdot10^{-4}$
Na	$2.7\cdot10^{-1}$	Ni	$5.2\cdot10^{-2}$
K	$3\cdot10^{-3}$	Ca	$4.6\cdot10^{-3}$
Fe	$1.9\cdot10^{-1}$	Cr	$5\cdot10^{-2}$
Mn	$2.9\cdot10^{-3}$	Ba	$6\cdot10^{-3}$
Mg	$1.8\cdot10^{-1}$	Be	$<1\cdot10^{-3}$
Pb	$3.2\cdot10^{-2}$	In	$<1\cdot10^{-3}$
Sn	$2.3\cdot10^{-2}$	Co	$1\cdot10^{-2}$
Al	$3.7\cdot10^{-3}$	Zn	$<1\cdot10^{-2}$
Ti	$1.6\cdot10^{-2}$	Bi	$2\cdot10^{-3}$
V	$4.2\cdot10^{-3}$	Cd	$<1\cdot10^{-3}$
Mo	$5.8\cdot10^{-3}$	Sb	$<1\cdot10^{-2}$

Performance of the Experiments and the Results

After the winding-on of the pulse heater, three thermocouples were welded to the specimen by spot-welding. The distance between the first and the second thermocouple was measured by means of an IZA-2 horizontal length meter. The specimen was then fastened in the electric furnace and placed together with the furnace in the vacuum chamber. After a vacuum $\sim10^{-4}$ mm Hg was secured, the electric furnace and the pulse heater were switched on. After a heating period of 2 to 3 hr, which was necessary for securing steady-state conditions, the temperature vs time diagrams for two points on the specimen were successively recorded on the strip chart of ÉPP-09. This successive recording of the $T = f(\tau)$ curves for each temperature point was repeated six times. The obtained curves were processed by using the harmonic analysis method, and the first harmonic amplitudes and the phase differences were calculated for each pair of curves.

The diffusivity coefficient values ($a*$) for a stainless-steel tube filled with the metal under investigation was calculated from the formula [1,2]

$$a^* = \frac{\pi L^2}{\tau} \frac{1}{(\alpha_1 - \beta_1) \ln \frac{A_1}{B_1}}, \qquad (1)$$

where L is the distance between the thermocouples, τ is the period of the temperature wave's basic harmonic, α_1 and β_1 are the first-harmonic phases at the thermocouple welding points, and A_1 and B_1 are the first-harmonic amplitudes at the thermocouple welding points.

The diffusivity coefficient (a) for the metal under investigation was calculated by using the equation

$$a = a_* (1 + \Delta), \qquad (2)$$

where Δ is the correction which takes into account the effect of the stainless-steel jacket and which is determined from the expression

$$\Delta = \frac{\gamma_1 S_1 C_1}{\gamma_2 S_2 C_2} \left(1 - \frac{a_1}{a^*}\right). \qquad (3)$$

Here, a_1, C_1, γ_1, and S_1 are diffusivity, the specific heat, the density, and the cross-sectional area of stainless steel, respectively; C_2, γ_2, and S_2 are the specific heat, the density, and the cross-sectional area of the metal under investigation, respectively.

The expression (3) for Δ can be derived from the following assumptions. We have a bimetallic cylinder, the jacket of which is made of metal 1, while its central portion is made of metal 2. Then, the thermal conductivity λ^*, the specific heat C^*, and the density γ^* of such a cylinder will be determined by the following expressions:

$$\lambda^* = \frac{\lambda_1 S_1 + \lambda_2 S_2}{S_1 + S_2}; \tag{4}$$

$$C^* = \frac{m_1 C_1 + m_2 C_2}{m_1 + m_2}; \tag{5}$$

$$\gamma^* = \frac{\gamma_1 V_1 + \gamma_2 V_2}{V_1 + V_2}, \tag{6}$$

where λ_1, S_1, m_1, C_1, γ_1, V_1 are the thermal conductivity, the cross-sectional area, the mass, the specific heat, the density, and the volume of metal 1 respectively; λ_2, S_2, m_2, C_2 γ_2, V_2 are the same quantities which pertain to metal 2. From Eqs. (4)-(6), we obtain expression (2), where Δ is in the form given by (3).

Corrections for thermal expansion, which take into account the increase in the specimen's radius and the distance between the thermocouples with an increase in temperature, were introduced in the values of L in Eq. (1) and S_1/S_2 in Eq. (3).

The obtained diffusivity coefficient value was reduced to the average temperature between the points where the first and the second thermocouple were fixed.

In determining the diffusivity of sodium, 24 experimental points were obtained in the temperature interval from 350 to 876° C, while 54 experimental points in the interval from 345 to 1007°C were obtained for lithium. The analytical results obtained for sodium and lithium in these temperature ranges can be expressed by the following formulas:

$$a_{\mathrm{Na}} = 0{,}721 - 0{,}0174 \cdot 10^{-2} T \ \mathrm{cm}^2/\mathrm{sec}$$

$$a_{\mathrm{Li}} = 0{,}128 + 0{,}02844 \cdot 10^{-2} T - 0{,}000041 \cdot 10^{-4} \cdot T^2 \ \mathrm{cm}^2/\mathrm{sec}$$

where T is given in degrees centigrade.

The values of the diffusivity, specific heat, and density of steel 1Kh18N9T, which were necessary for introducing the correction that takes into account the jacket effect, were taken from manual [3]; for the density and specific heat values for sodium, we used the average of the values published in [3-6]. The lithium density values were borrowed from manual [3], while the specific heat values were taken from [7].

An analysis of errors and an estimate of inaccuracies showed that the maximum relative error $\Delta a/a$ was ~10%. The errors incurred in measuring the phases β_1 (~5%) and α_1 (~ 2%) and the amplitude B_1 (~2%) provided the greatest contribution to the over-all error.

On the average, the deviation of the results obtained in individual diffusivity measurements from the average value was ±2.5% for sodium and ±2.9% for lithium; the maximum deviations were 7.8 and 8.5%, respectively.

The thermal conductivity coefficients were calculated with respect to the obtained experimental values of diffusivity by using the density and specific heat values borrowed from the above-indicated sources. Analytically, they can be expressed by the following formulas:

$$\lambda_{\mathrm{Na}} = 0{,}224 - 0{,}0159 \cdot 10^{-2} T + 0{,}00058 \cdot 10^{-4} \cdot T^2 \ \mathrm{cal/cm \cdot sec \cdot deg.}$$

$$\lambda_{\mathrm{Li}} = 0{,}072 + 0{,}01271 \cdot 10^{-2} T - 0{,}00039 \cdot 10^{-4} T^2 \ \mathrm{cal/cm \cdot sec \cdot deg.}$$

The discrepancies between the obtained data on the diffusivity and thermal conductivity of sodium and the data published in the literature [4,5,8] did not exceed 4.5%.

A comparison between data on lithium and its diffusivity values that were published in [4] indicate that the results agree for temperatures from 350 to 400°C; however, at higher temperatures, the diffusivity values obtained in our experiments are higher, and, at 700°C, the difference attains 26%. For thermal conductivity, the difference at 700°C amounts to 18.5%. This discrepancy at high temperatures is difficult to explain. It is possible that it is caused by differences in the percentages of impurities (especially of oxides and nitrides). Data on the chemical analysis of lithium are not given in [4].

LITERATURE CITED

1. E. G. Shvidkovskii, Zh. Tekhn. Fiz., 8, No. 10, 935 (1938).
2. V. E. Mikryukov, Thermal and Electrical Conductivity of Metals and Alloys [in Russian] (Metallurgizdat, Moscow, 1959).
3. Thermal and Physical Properties of Matter [in Russian] (Gosenérgoizdat, Moscow, 1956).
4. N. A. Nikol'skii et al., Teploénergetika, No. 2, 92 (1950).
5. Liquid-Metal Coolants [in Russian] (Izd. Inostr. Lit., Moscow, 1958).
6. P. A. Andreev, A. A. Kanaev, and E. D. Fedorovich, Liquid-Metal Coolants for Nuclear Reactors [in Russian] (Sudpromgiz, Moscow, 1959).
7. T. Douglas et al. J. Amer. Chem. Soc., 77, No. 8, 2144 (1955).
8. I. I. Novikov et al., Atomnaya Énergiya, No. 4, 92 (1956).

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.**

Vasilii Savvich Lyashenko

Professor Vasilii Savvich Lyashenko, Doctor of Chemical Sciences and member of the Physicoenergetic Institute and State Committee on the Use of Atomic Energy, died on August 9, 1961 after a serious illness.

Lyashenko was born in 1908 in the village of Martovka in the Dnepropetrovsk region. He started work in 1926 as a lathe hand in the telegraph workshop in Nizhnedneprovsk.

In 1928 Lyashenko entered the Leningrad Metallurgical Institute. In 1935 he completed his training in the Department of Chemistry of the Leningrad Industrial Institute and remained there to teach. From 1939 to 1948 he taught in the Kuibyshev Aviation Institute as head of the Aviation Metallography Department. Besides his teaching activities, Lyashenko directed research in aviation technology.

From 1948 onwards Lyashenko was the senior member and head of a large scientific group. During this period he carried out investigations on the working of materials and the chemistry of metal alloys used in atomic technology.

Lyashenko was an outstanding scientist in the field of metal physics, who contributed much to the development of the working of nuclear materials. A materials-research "hot" laboratory was established and a series of fundamental investigations on the effect of radiation on the properties of materials carried out under his direction. His work on diffusion in zirconium and zirconium alloys is well known.

He devoted much time to teaching activities and the successful training of students.

Communist V. S. Lyashenko paid much attention to social work. He was elected several times to the leading party organs and was a member of the Main Committee of the Communist Party of the Soviet Union. In 1959-1961 Lyashenko was a deputy of the regional Soviet of Worker Deputies. The scientific and social work of the communist and scientist V. S. Lyashenko was acknowledged several times by government awards.

The memory of Vasilii Savvich Lyashenko, an outstanding specialist, patriotic scientist, capable director and considerate and responsive friend, will remain forever in the hearts of those who knew him.

A Group of Friends

PREPARATION OF HIGHLY PURE BERYLLIUM BY THE CHLORIDE METHOD

I. E. Vil'komiskii, G. F. Silina, A. S. Berengard,
and V. N. Semakin

Translated from Atomnaya Énergiya, Vol 11, No. 3, pp. 233-239, September, 1961
Original article submitted December 15, 1960

A method of producing highly pure beryllium by chlorination of beryllium oxide with carbon tetrachloride and electrolysis of a mixture of the beryllium chloride produced and sodium chloride at low temperature has been developed and put into practice on an industrial scale. The direct extraction of beryllium chloride during chlorination was 85.7% and the technological extraction with allowance for processing of the waste was 96%; the current yield during electrolysis was more than 80% and the direct extraction of beryllium with a cycle time of 90 days was 66.7%. This method was used to prepare several tons of highly pure beryllium, which did not require additional purification for use in nuclear technology.

A critical analysis of the possible methods of preparing beryllium shows that one of the promising methods for producing highly pure metal is the chloride process.

The substantial drawbacks to chlorination with gaseous chlorine (relatively high temperature and harmfulness of the process, contamination of the product as a result of corrosion of the apparatus, and the introduction of impurities with solid carbonaceous materials) were eliminated by using carbon tetrachloride as the chlorinating agent.

The reaction

$$2BeO + CCl_4 \rightarrow 2\,Be\,Cl_2 + CO_2$$

has been investigated previously [1-4]. A number of authors have expressed doubts on the possibility of the industrial production of beryllium chloride by this method. However, in recent years new data have been published and serious interest has been shown in the use of CCl_4 and the chloride process for producing beryllium as a whole both in the USSR and abroad [5-17].

Investigation of Chlorination Process

The starting material at the beginning of our investigations was beryllium oxide containing not more than 0.006% of heavy metals. The raw material was briquetted to make the charge permeable to gas, reduce the loss of unreacted material, and increase the use of the effective volume of the furnace. Strong briquettes were obtained only from calcined oxide containing not less than 28% of beryllium. A solution of sizing or dextrin whose ash content varied over the range of 0.15-0.30%, was used as a binder.

The charge was prepared in an aluminum lined paddle mixer and briquetted on a screw press. The briquettes which were 10 mm in diameter and 30-40 mm in length, were dried with a gradual rise in temperature to 200°C and then calcined in stainless steel containers at 600°C. The apparent porosity of the calcined briquettes varied over the range of 50-60%,the gas permeability equaled 0.046 liter/min, and the bulk weight was 0.45-05 g/cc.

For chlorination we used technical carbon tetrachloride, which was equivalent to pure material as regards the content of mineral impurities after filtration through glass cloth.

In large-scale laboratory investigations the reactor consisted of a quartz tube, 110 mm in diameter and 1350 mm in length (Fig. 1). The beryllium chloride was trapped in two nickel condensers: the first, which was heated to 300-350°C was 70 liters in volume (with a receiver for the chloride fixed to it) and the second, which was not heated, was 43 liters in volume.

The studies of the chlorination established that the degree of chlorination increased sharply with a rise in temperature from 500 to 700°C; a further rise in temperature did not have an appreciable effect (Fig. 2).

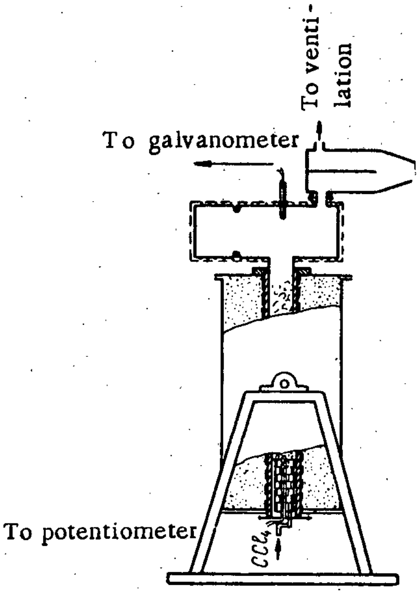


Fig. 1. Plan of large-scale laboratory apparatus for chlorination of beryllium oxide with carbon tetrachloride.

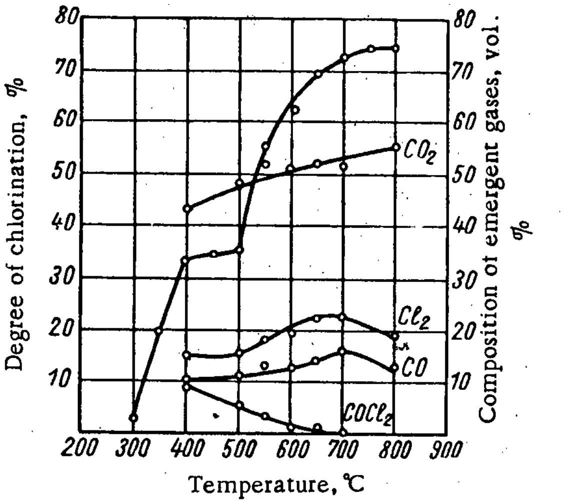


Fig. 2. Temperature dependence of the degree of chlorination of beryllium oxide and the composition of emergent gases.

With a chlorination temperature above 600°C the beryllium chloride was found to contain the product of incomplete thermal dissociation of carbon tetrachloride, namely, hexachloroethane. As a result of this, the optimal temperature of 650-700°c was selected. The best process indices were obtained with a carbon tetrachloride input of 25 g/min, which corresponds to a consumption of 2.4 kg/min per m^2 of furnace cross section.

The results of checking the effect of CCl_4 consumption on the degree of chlorination of beryllium chloride yield are given in Table 1.

In large-scale experiments we obtained beryllium chloride with the following impurities: iron 0.0005-0.006%; aluminum 0.0002-0.005%; silicon 0.0007-0.003%; nickel 0.003-0.03%; manganese 0.0002-0.0007%; copper 0.0003-0.0005%; water-insoluble residue 0.01-0.1%.

To select a material for the condenser, we tested samples of nickel (N-1) and its alloys with chromium, niobium, and zirconium; iron (St-3), stainless steel 1Kh18N9T, and aluminum (99.99%). It was found that nickel and alloys based on it were sufficiently stable materials in an atmosphere of chlorine, beryllium chloride, and carbon tetrachloride at a temperature of no higher than 300°C.

The results of laboratory and large-scale investigations of the chlorination made it possible to develop the production of highly pure beryllium chloride for preparation of the metal by electrolysis both from pure and technical beryllium oxide.

The chlorination furnace (Fig. 3) consisted of a steel casing lined with several layers of acid-resistant and thermal insulating material. The shaft was lined with polished, wedge-shaped bricks of fused quartz with silicate cement. The furnace was heated with an internal graphite heater consuming 17 kw.

The carbon tetrachloride entered the annular space between the heater and the furnace brickwork from a measuring tank. On the roof of the furnace was fixed a head with a connecting tube and loading hopper, made of stainless steel and lined with graphite; a nichrome heater with a power of 2 kw, protected with a quartz cover, was installed to prevent condensation of beryllium chloride inside the head.

The run of the furnace, which was determied by the life of the graphite heater, lasted for 25-30 days. Replacement of the heater required about 12 hr. The brickwork of the furnace lasted for approximately five months of continuous operation.

The first nickel condenser was heated to 300-320°C with hot air circulating in a steel jacket. From the second nickel condenser, which was heated to 200-250°C, the gases passed into a third (unheated) condenser of stainless steel 1Kh18N9T, fitted with an internal baffle. It trapped hexachloroethane (sublimation point 185.6°C), excess carbon tetrachloride, impurity chlorides ($FeCl_3$, $AlCl_3$, etc.), and a small amount of beryllium chloride entrained by them.

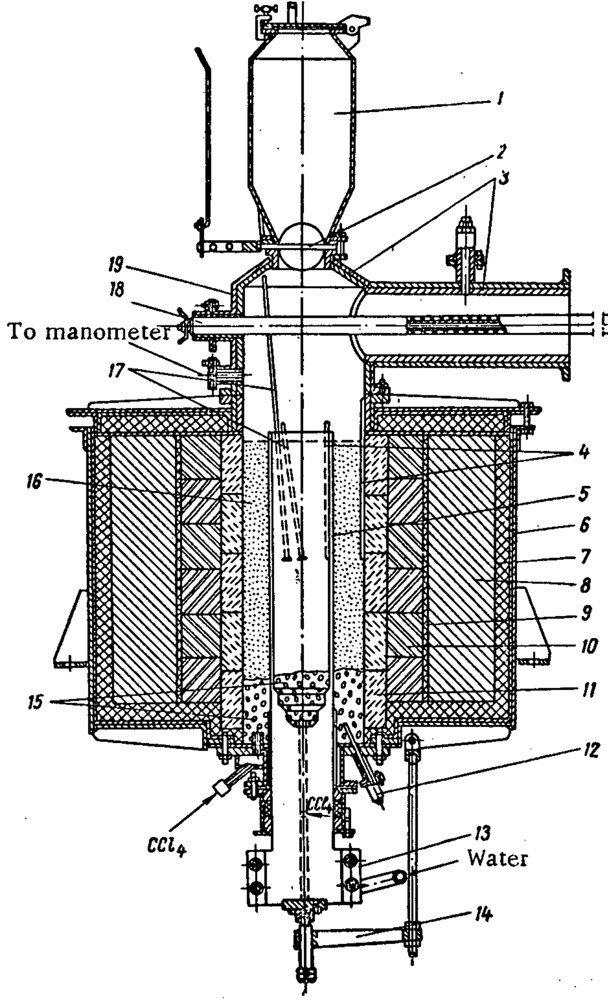


Fig. 3. Plan of industrial furnace for chlorination of beryllium oxide with carbon tetrachloride: 1) hopper; 2) baffle plate 3) graphite lining; 4) thermocouples; 5) graphite heater; 6) furnace casing; 7) diabase tiles; 8) foam chamotte brick; 9) diabase cement; 10) Dinas brick; 11) quartz brick; 12) thermocouple; 13) contact; 14) clamping device; 15) quartz; 16) briquette charge; 17) rods; 18) neck heater; 19) head with connecting tube.

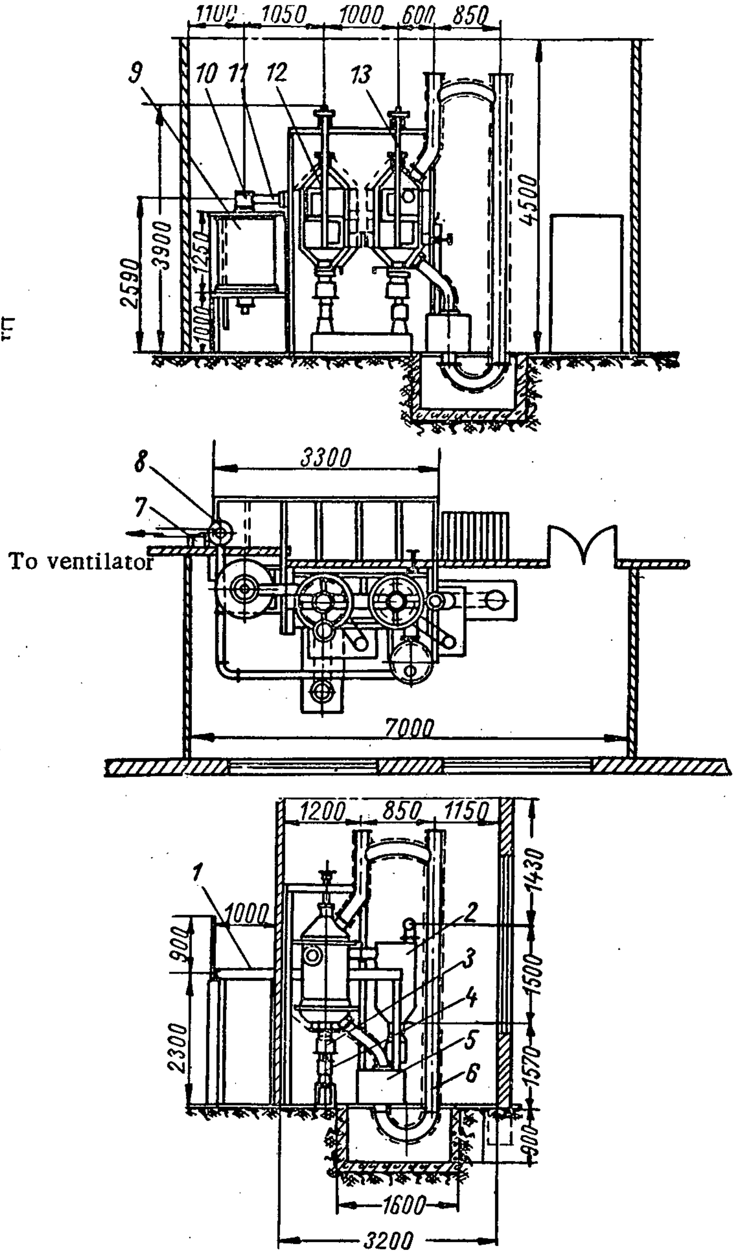


Fig. 4. Plan of industrial chlorination unit: 1) working platform; 2) third condenser; 3) container)20 liters; 4) mechanical clamp; 5) furnace for heating air; 6) air leads; 7) measuring tank; 8) scrubber; 9) furnace 185 mm in diamter and 1350 mm in height; 10) loading equipment; 11) connecting tube; 12) first condenser; 13) second condenser.

The beryllium chloride and impurities were separated from C_2Cl_6 and a small amount of CCl_4 by treatment of the product with carbon tetrachloride on a porcelain filter. The solution of hexachloroethane in CCl_4 was returned to chlorination and the residue of chlorides used for hydrometallurgical extraction of beryllium. The emergent gases passed through a polyvinyl chloride gas lead into a scrubber, irrigated with caustic soda solution; the purified gases were ejected into the atmosphere. The chlorination unit is shown in Fig. 4.

The furnace and condensers were heated in a stream of nitrogen; when the required temperature was reached, CCl_4 introduction was begun and the consumption was measured with a rotameter. After every six hours a portion of calcined briquettes was loaded into the furnace. The bulk of the beryllium chloride was trapped in the first condenser and discharged into receivers, hermetically connected to a discharge chute.

The unreacted residue, which contained a certain amount of beryllium chloride, was discharged from the furnace, extracted with water, dried, and added to the starting beryllium oxide. During the testing of the process, about 25 tons of beryllium chloride was prepared from pure and technical beryllium oxide. The following mean indices were attained: the consumption of CCl_4 per kg of $BeCl_2$ was 1.6 kg, the degree of condensation of $BeCl_2$ equaled 97.8% the direct yield of beryllium was 85.7% and the extraction with allowance for processing of the waste was 96%.

TABLE 1. Effect of Carbon Tetrachloride Consumption on the Degree of Chlorination of Beryllium Oxide and Chloride Yield (the CCl_4 input equaled 25 g/min)

Briquettes loaded		CCl_4 consumed		Beryllium chloride obtained		Chlorination residue		$BeCl_2$ yield, %	Degree of chlorination, %
weight, kg	Be content, kg	weight, kg	% of cal. requirement	weight, kg	Be content, kg	weight, kg	Be content, kg		
2,2	0.734	17,4	210	5,91	0,667	0,13	0,0424	90,8	94,2
2,5	0,784	11,2	120	6,14	0,694	0,15	0,0536	88,5	93,3
4,55	1,315	18.2	120	9,86	1,115	0,25	0,09	85,1	93,9
								Mean 86,8	Mean 93,6
4,0	1,28	16,0	100	10,59	1,197	0,20	0,0576	93,5	95,5
4,0	1,28	16,0	100	9,96	1,13	0,22	0,072	88,2	94,5
2.5	0,795	9,5	100	5,78	0,653	0,20	0,0647	82,3	92,0
								Mean 88,0	Mean 94,0

Investigation of Electrolysis Process

After laboratory investigations which established the optimal electrolysis conditions (cathode current density, temperature, conditions for electrolytic purification of melt, etc.), experiments were carried out on the preparation of beryllium of maximum possible purity. We used $BeCl_2$ obtained by chlorination of pure beryllium oxide (its composition is given above); the sodium chloride was "chemically pure" grade.

The crucible was made of nickel and the anode was a rod of special graphite with the minimal boron content. The removeable nickel cathode had openings in a checkered pattern along its whole height to facilitate the removal of electrolyte during the extraction of the metal. Both the crucible and cathode were plated with beryllium before electrolysis. The electrolyte was freed from impurities at a low cathode current density; the cathode was then replaced and electrolysis carried out at a temperature of 330-350°C. The cathode was replaced once a day. The beryllium was deposited in the form of lustrous dendrites and after the bulk of the adhering electrolyte had been washed away with water, they were washed successively with a 1% solution of chemically pure sodium hydroxide, a 4% solution of nitric acid, and finally with alcohol. The beryllium content by difference from the impurities determined was 99.966% in crystals of +3 mm and 99.937% in fine crystals (-3 mm); a full analysis of the metal after remelting is given in Table 2.

Semi-industrial experiments were carried out in quartz electrolysis crucibles holding 35 kg of electrolyte with a graphite anode 40 mm in diameter; the removeable cathode in the purification of the electrolyte was a bottomless nickel cylinder, 350 mm in diameter and 120 mm in height, and in the preparation of highly pure beryllium, a cylinder ending in a truncated cone with openings. The electrolyte was purified at a current strength of 25 amp and the beryllium prepared at 100 amp. The temperature was maintained at 340-360°C and raised to 330-390°C before removal of the cathode (once a day). Every 24 hr, the composition of the bath was adjusted and the metal removed. The process was carried on continuously for 20 days; the residual electrolyte was suitable for further use.

The metal was subjected to vacuum remelting for the removal of beryllium oxide, chlorine, and volatile impurities.

The considerable nickel content of the beryllium obtained was partly connected with corrosion of the cathode. Experiments were carried out with cathodes of other materials to eliminate this. The most interesting experiments were those with deposition of the beryllium on graphite plates, which were first plated with beryllium at a low current density with the graphite pores filled with beryllium. These experiments showed that in addition to yielding purer beryllium (with regard to nickel), the use of graphite cathodes made it possible to increase the cathode current density by a factor of eight to ten with the current yield remaining high (90% and more).

TABLE 2. Impurity Content of Beryllium after Vacuum Remelting,* %

Impurities	Large-scale laboratory experiments		Semi-industrial experiments		Impurities	Large-scale laboratory experiments		Semi-industrial experiments	
	+3 mm fraction	-3mm fraction	+ 3 mm fraction	- 3mm fraction		+3 mm fraction	- 3 mm fraction	+3mm fraction	- 3 mm fraction
B	$6,9\cdot10^{-5}$	$1,1\cdot10^{-4}$	$3\cdot10^{-5}$	$8\cdot10^{-5}$	Gd	N. D.***	N. D.***	$1\cdot10^{-6}$	$1\cdot10^{-6}$
Li	$2\cdot10^{-5}$	$2\cdot10^{-5}$	$4\cdot10^{-5}$	$4\cdot10^{-5}$	Sm	$1\cdot10^{-6}$	$1\cdot10^{-6}$	$1\cdot10^{-6}$	$2\cdot10^{-6}$
Hg+Ag	Not det.**	Not det.**	$1\cdot10^{-4}$	$1\cdot10^{-4}$	Cd	$2\cdot10^{-6}$	$2\cdot10^{-6}$	$2\cdot10^{-6}$	$2\cdot10^{-6}$
Cl	N. D. ***	N. D.***	$2\cdot10^{-3}$	$1\cdot10^{-3}$	Sn	Not det.	Not det.	N. D.***	N. D. ***
Mn	$1\cdot10^{-3}$	$1,1\cdot10^{-3}$	$7,7\cdot10^{-4}$	$1,2\cdot10^{-3}$	Ta	The same	The same	The same	The same
N	$1\cdot10^{-2}$	$1\cdot10^{-2}$	$9\cdot10^{-3}$	$6\cdot10^{-3}$	Nb	» »	» »	» »	» »
Ni	$5\cdot10^{-3}$	$4\cdot10^{-2}$	$1,5\cdot10^{-2}$	$3,4\cdot10^{-2}$	Sb	» »	» »	» »	» »
Cu	$1.2\cdot10^{-3}$	$3,6\cdot10^{-3}$	$1,5\cdot10^{-3}$	$2,5\cdot10^{-3}$	Bi	» »	» »	» »	» »
Cr	Not det.**	Not det.**	$3\cdot10^{-3}$	$3\cdot10^{-3}$	V	» »	» »	» »	» »
Fe	$4\cdot10^{-3}$	$4\cdot10^{-3}$	$1\cdot10^{-2}$	$1,1\cdot10^{-2}$	Co	$5\cdot10^{-5}$	$1,5\cdot10^{-4}$	$5\cdot10^{-5}$	$5\cdot10^{-5}$
Na	Not det.	Not det.	$5\cdot10^{-3}$	$5\cdot10^{-3}$	Ti	Not det.**	Not det.**	$5\cdot10^{-4}$	$5\cdot10^{-4}$
Zn	Not det.	Not det.	$1\cdot10^{-2}$	$1\cdot10^{-3}$	W	Not det.**	Not det.**	$2\cdot10^{-4}$	$2\cdot10^{-4}$
Mg	$1\cdot10^{-3}$	$1\cdot10^{-3}$	$1\cdot10^{-3}$	$1\cdot10^{-3}$	K	N. D. ***	N. D. ***	$1,6\cdot10^{-2}$	$1,6\cdot10^{-2}$
Ca	Not det.	Not det.	$1\cdot10^{-3}$	$1\cdot10^{-3}$	Mo	$5\cdot10^{-4}$	$5\cdot10^{-4}$	$5\cdot10^{-4}$	$5\cdot10^{-4}$
Si	$2\cdot10^{-3}$	$2\cdot10^{-3}$	$3\cdot10^{-2}$	$3,4\cdot10^{-2}$	S	Not det.**	Not det.**	$3\cdot10^{-3}$	$3\cdot10^{-3}$
Al	$1,2\cdot10^{-3}$	$1,3\cdot10^{-2}$	$7\cdot10^{-3}$	$1,2\cdot10^{-2}$	Ba	N. D. ***	N. D. ***	$1\cdot10^{-2}$	$1\cdot10^{-2}$
					Pb	Not det.**	Not det.**	$1\cdot10^{-2}$	$1\cdot10^{-3}$

The remelting to obtain a compact metal and remove chlorine, nitrogen, and oxygen was carried out by E. A. Kamenskaya and her co-workers.

** Not detected.

*** Not determined.

A change in the conditions for washing off the beryllium scales made it possible to reduce the content of some impurities, including oxygen.

Interesting experiments were carried out on a combination of electolysis and chlorination both with "soluble" anodes containing beryllium oxide and with the introduction of a charge containing beryllium oxide and carbon into the anode space. It was established that both variants of this process are fundamentally possible; the main problem in the first case is the determination of conditions for producing mechanically strong soluble anodes and in the second, finding methods of preventing sludge formation.

Electrolysis on an Industrial Scale

The industrial production of beryllium by electrolysis of a mixture of its chloride and sodium chloride in equal amounts by weight was carried out in a welded nickel crucible, hermetically sealed with a nickel lid; in its center was a graphite anode, fixed in an insulating bushing of soapstone.

The removeable cathodes for purification of the elctrolyte were nickel cyclinders, 500 mm in diameter and 900 mm in height; the cathodes for deposition of beryllium had bottoms and were perforated in a checkered pattern both on the bottom and up 2/3 of the height. The plan of the bath is shown in Fig. 5.

For fusion of the electrolyte, the bath was heated by passage of an alternating current through nichrome spiral, fixed in a nickel jacket. The beryllium chloride and freshly calcined sodium chloride were poured into the crucible in layers; charging was carried out as the material melted with periodic stirring. At the beginning of fusion there was foam formation, which ceased after a time.

The electrolysis to free the melt of impurities of electropositive metals and traces of moisture was carried out at a cathode current density of 2.4–2.8 amp/dm^2 (for 2 hr; thereupon there was deposited 60-100 g of sponge metal containing a large amount of impurities: hundredths of a percent of iron, manganese, magnesium, and copper; tenths of a percent of aluminum and nickel). As a result of the electrolytic purification, the iron content of the electrolyte was reduced by a factor of one and a half and the nickel by a factor of two.

After replacement of the cathode, electrolysis was carried out at 320-340°C for 20-22 hr. The heat liberated by the direct current was sufficient to maintain this temperature.

The optimal value of the initial cathode current density was found to be within the range of 6.5-7.5 amp/dm^2.

The bath composition was adjusted once a day by the addition of beryllium chloride and a certain amount of sodium chloride. At the beginning of the cycle, the electrolyte contained about 6wt.% and at the end, about 5.5. wt. % beryllium. The beryllium content fell practically linearly; the amount of impurities decreased sharply in the first three hours and then remained constant.

TABLE 3. Operating Indices of Electrolytic Bath

Time of operation	Current yield, %	Direct extraction of Be, %	Be in recovered chloride, % (sublimate)	Be in recovered solutions, %	Undetermined losses, %
50	81,5	58,1	2,5	27,9	11,5
93	82	66,7	1,45	25,4	6,45

The capacity of the bath per day was 2.0–2.2kg of metal. The beryllium was deposited on the walls of the bath in coarse crystals of various forms from scales 20 x 20 mm to needles about 60 mm long. The bath operated for a long time under constant conditions. Table 3 gives data on the operation of the bath on the 50th and 93rd days after starting up.

The undetermined losses were subsequently reduced to 4.3% by fitting a hydraulic seal filled with CCl_4 to the bath. The bulk of the $BeCl_2$ evaporating condensed on cold parts of the bath itself and were returned to it during the unloading of the metal.

For washing off the electrolyte, the cooled cathode with the metal was immersed in a rubberized tank containing water; the metal was then washed as described above and dried in vacuum at 70-80°C.

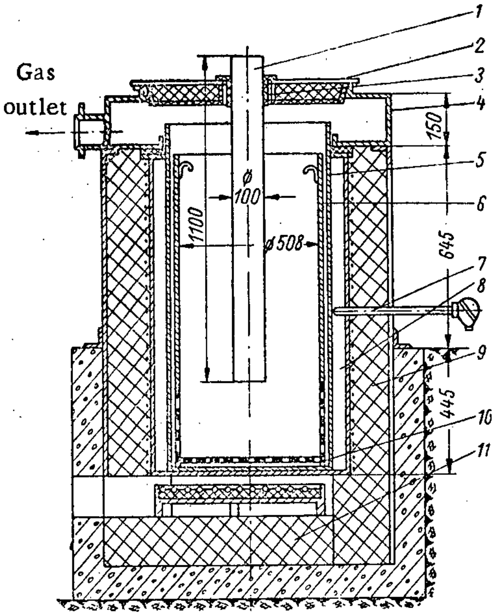


Fig. 5.Plan of industrial bath for electrolytic preparation of highly pure beryllium; 1) graphite anode; 2) nickel lid; 3) insulator (soapstone); 4) rim pump; 5) nickel bath; 6) nickel cathode; 7) thermocouple; 8; secondary jacket with heater; 9) slag wool lining; 10) electric plate; 11) foam chamotte lining.

An interesting refinement of the process was distillation of the beryllium chloride from the electrolyte adhering to the cathode from the bath. As a result of experiments we developed a design of vacuum apparatus in which the nickel cathode with the meatl was placed immediately after removal from the bath. Part of the electrolyte drained into a lower receiver; part of the beryllium chloride distilled; both products were returned fo the bath without treatment.

The final variant of the process adopted is simple and relatively safe and does not require special purification of the raw material or the use of expensive or scarce reagents. In the development of production on a large industrial scale, the chloride method may compete with the thermal reduction of beryllium fluoride as regards technical and economic indices and the purity of the metal obtained by the former method is considerably higher.

LITERATURE CITED

1. J. Matignon, M. Pietre C. r Acad. sci., 184, 853 (1927).
2. J. Besson, C. r. Acad. sci., 241, 861 (1942).
3. J. Besson. Bull. Soc. Chim., D16 (1949).
4. J. Jaeger. Metall, 4, 183 (1950).
5. The Metall Beryllium. ASFM, Cleveland, Ohio, 1955
6. G. A. Meerson el at, Proceedings of the International Conference on the Peaceful Use of Atomic Energy (Geneeva, 1955) [Russian translation] (Izs. AN SSSR, Moscow, 1955), Vol. 3 p. 125.

7. P. Dereham, D. Temple. Extraction and Refining of the Rarer Metals, Lond. Inst. of Mining and Metallurgy, 1957.
8. M. Kells et al., Report No. 717 presented by the United Kingdom at the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958).
9. Z. Williams, P. Eyre. Nucl. Energy, 3, No. 22 (1958).
10. A. V. Novoselova and K. N. Semenko; Z. Neorg. Khim., No. 9, 2213 (1958).
11. I. N. Dheiko and Yu. K Delimarskii, Ukr. khim. zh., 25, No. 3, 295 (1959).
12. L. A. Firsanova and A. I. Belyaev, Izv. Vyssh. uchebn. zavedenii, Tšvetnaya metallurgiya, No. 1, (1959).
13. A. S. Berengard and M. G. Glushkova, Trudy Giredmet, Vol. 1 (Gonti, Moscow, (1959).
14. M. V. Smirnov and N. Ya. Churkreev, Zh, neorg. khim., No. 11, 2536 (1959).
15. G. I. Pisitsina, Tsvetne metally, No. 4, 56 (1960).
16. G. F. Silina and L. L. Grinberg, Tsvetnye metally No. 6, 47 (1960).
17. G. F. Silina, Yu. I. Zarembo, and L. E. Bergina, Beryllium--Chemical Technology and Metallurgy [in Russian] (Atomizdat, Moscow, 1960).

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 SEPARATION FACTOR OF LITHIUM ISOTOPES DURING VACUUM DISTILLATION

S.G. Katal'nikov and B.M. Andreev

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 240-244, September, 1961
Original article submitted January 30, 1961

Distillation of lithium metal under vacuum may be considered a possible method of separating lithium isotopes. This report gives the results of experiments to determine the separation factor of lithium isotopes during the vacuum distillation of lithium metal. It is shown that the value of the effective separation factor in the region intermediate between the molecular and equilibrium regions of distillation is determined in particular by the geometric dimensions and the mutual location of the evaporation and condensation surfaces. The values of the effective separation factors of lithium isotopes were determined for temperatures of 543, 469 and 406°, corresponding to saturated vapor pressures of 10^{-4}, 10^{-3} and 10^{-2} mm Hg. The data obtained may be used for the calculation of columns for the separation of isotopes.

Distillation is used increasingly as a method of separating isotopic mixtures (see, for example, [1]). Because of the high boiling point of lithium metal, given as 1327-1400°C in various reports [2-5], it must be distilled under vacuum.

A distinction is drawn between normal (equilibrium) and molecular distillation. The character of distillation under vacuum is determined mainly by the ratio between the mean free path length λ of the molecules of vapor and the distance $\underline{d}$ between the evaporation and condensation surfaces. If λ is far smaller than $\underline{d}$, distillation has an equilibrium character. In the case of molecular distillation carried out under high-vacuum conditions the mean free path length of the residual gas molecules must be equal at least to the value $\underline{d}$ (better, if $\lambda > d$) [6,7]. During equilibrium distillation of ideal mixtures, such as mixtures of isotopes, the separation factor α_s is determined by the ratio of the saturated vapor pressures of the components at the distillation temperature:

$$\alpha_S = \frac{p_1^0}{p_2^0}, \tag{1}$$

where p_1^0 and p_2^0 are the saturated vapor pressures of the first and second isotopes respectively. In the case of molecular distillation the separation factor α_M is expressed by the ratio

$$\alpha_M = \frac{p_1^0}{p_2^0} \sqrt{\frac{M_2}{M_1}} = \alpha_S \sqrt{\frac{M_2}{M_1}}, \tag{2}$$

where M_1 and M_2 are the masses of the first and second isotopes respectively. From equation (2) it follows that molecular distillation can be used for separating substances with the same vapor pressures but different molecular weights.

It is not surprising that vacuum distillation has been considered a possible method of separating lithium isotopes, for which the difference in the masses is approximately 16%. The first suggestion that vacuum distillation could be employed for the separation of lithium isotopes was made in [8], which was a report on an investigation of the relation between the pressure of saturated lithium vapor and temperature. In [9] the separation factors of lithium vapor at 462, 525 and 550°C were determined under conditions where, in the authors' opinion, the pressure was entirely due to the saturated vapor pressure. At these temperatures the separation factors were 1.077, 1.069 and 1.055 respectively. In addition, in [9] a number of experiments on the direct measurement of the ratio between the pressures of saturated vapor of Li^6 and Li^7 were described. For this purpose an equilibrium still was constructed, as a result of the operation of which at pressures of 0.28-8.2 mm Hg it was found that $\frac{p_{Li^6}}{p_{Li^7}} = 1.002 \pm 0.004$. The same report gives the results of tests on a number of columns operating under non-selective conditions at various temperatures. The degree of separation obtained in these experiments characterizes the efficiency of operation of the individual plates rather than the single separation factors.

The results of an investigation [10] to determine the separation factor of lithium isotopes during vacuum distillation cannot be employed,unfortunately, because the experimental and calculated data in this report do not agree.

Experimental Procedure

The value of the separation factor of lithium isotopes during vacuum distillation was determined by the exhaustion method and was calculated by Rayleigh's equation. The apparatus for the determination of the separation factor consisted of a cylindrical still, a vacuum system for creating a vacuum in the latter, and a mechanical stirrer for mixing the molten lithium in the still. The metal was evaporated in a stainless steel vessel (Fig. 1). The lithium vapor condensed on the lid of the vessel, which was made in the form of a water-cooled cylindrical condenser. The vessel was designed in such a way that experiments with molecular evaporation could be carried out in it, in addition to normal (equilibrium) distillation.

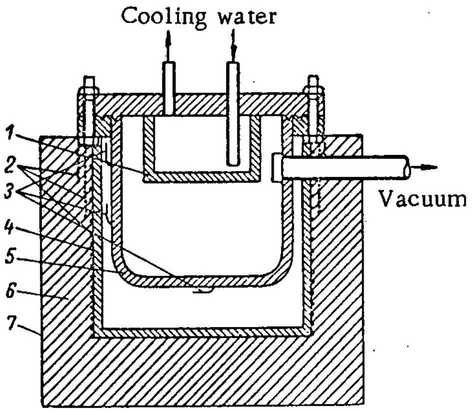


Fig. 1. Diagram of the still: 1) condenser; 2) heating coils; 3) thermocouple pockets; 4) chamotte envelope; 5) still; 6) thermal insulation; 7) jacket.

During operations the still was placed in a furnace with an electric heater. The furnace consisted of a chamotte envelope with three spirals of No. 2 alloy, located in a thermally insulated metal housing. The temperature was kept constant along the height of the furnace of the still by means of the windings of the furnace, each of which was fed independently. The temperature was measured by chromel-alumel thermocouples located in special pockets of the still. The accuracy of temperature control was ± 5°C.

The vacuum in the system was created by means of backing and diffusion pumps. As in [9, 10], the pressure in the still itself was not measured.

During high-vacuum distillation, evaporation was not accompanied by boiling. As a result, intense mixing of the liquid phase, which would have unified the composition during distillation, did not occur. To obtain improved mixing of the molten lithium, the still was placed together with the furnace in a special shaker.

Before the experiment the still and the lithium were degassed for some time. To accelerate degassing of the lithium and the walls of the still, the latter was heated to the melting point of lithium, with the stirrer switched on. When degassing had been completed and a residual pressure less than the vapor pressure of lithium at the working temperature had been reached, distillation of lithium was commenced (the required temperature having been established in the still).

The duration of evaporation was calculated in such a way that the unevaporated lithium residue was sufficient for isotopic analysis. After the experiment had been completed, the still was extracted from the furnace and cooled rapidly. The residue in the still was dissolved in water and titrated with hydrochloric acid to determine the amount of lithium left in it. The lithium chloride obtained was used for isotopic analysis by the flotation method. The absolute isotopic composition was measured with an accuracy of ± 0.03-0.04%, which was determined by the distribution of the crystals on flotation.

Results of the Experiments and Discussion

Three series of experiments, with different distillation temperatures (543, 469 and 406°C) and therefore with different pressures of the saturated lithium vapor (10^{-2}, 10^{-3} and 10^{-4} mm Hg) was carried out. Data on the relation between the pressure of saturated lithium vapor and temperature, from [2, 8, 11, 12], are given in Fig. 2. The most similar data are those represented by straight lines 1 and 4, the discrepancy between which gives a temperature difference of only 7-10°C at the given pressure. Since the temperature during the experiments was measured at the outer side of the still wall, the actual temperature in the still was somewhat lower. Taking this into account, the temperature at the outer side of the still was maintained at a temperature calculated by the authors from straight line 1. The results of the experiments are given in the Table.

Data on the Separation of Lithium Isotopes

Vaporization temperature, °C	Residual gas pressure, mm Hg	Charge of lithium, g	Lithium residue after vaporization, g	Rate of vaporization, g/hr*	Li^6 content in the residue**, %	Separation factor	Distance between evaporation and condensation surfaces (d), cm	Mean free path length (d), cm
543	$1 \cdot 10^{-3}$	149,2	9,5	7,7	6,92	1,026±0,002	6,5	1,60
543	$1 \cdot 10^{-3}$	134,6	14,4	15,0	6,96	1,028±0,002	6,5	1,60
543	$1 \cdot 10^{-3}$	110,6	0,68	10,0	6,41	1,030±0,002	6,5	1,60
469	$3 \cdot 10^{-3}$	51,2	0,85	1,27	6,51	1,033±0,002	7,5	2,48
469	$2 \cdot 10^{-3}$	47,2	0,44	1,56	6,17	1,042±0,002	7,5	3,14
406	$1 \cdot 10^{-3}$	22,4	3,94	0,308***	6,72	1,060±0,002	8,0	5,30

---

* The evaporation surface in the still was 177 cm^2.

** The Li^6 content in the standard was taken as 7.39%.

*** The theoretical rate of vaporization was 0.354 g/hr.

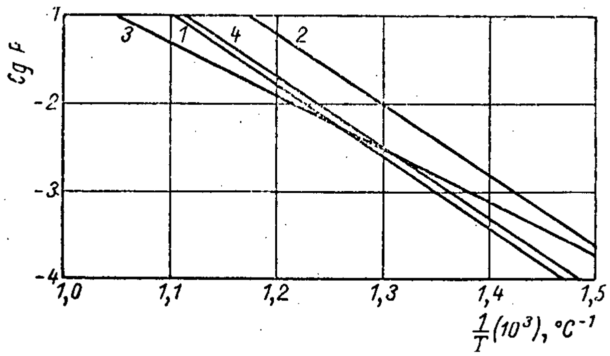


Fig. 2. Relation between the vapor pressure of lithium and temperature (1, 2, 3, 4 – relations obtained from the data of [2, 8, 11, 12] respectively).

To form a picture of the distillation character in each experiment, the mean free path lengths of lithium vapor were calculated under the conditions of each experiment. The free path lengths were calculated by Sutherland's formula [13]. In experiments at a temperature of 406 or 469°C the residual gas pressure was considerable compared with the pressure of saturated lithium vapor, therefore the presence of the residual gases was taken into account when the free path length of the molecules of lithium vapor was calculated.

From a comparison of the λ values with the distance between the evaporation and condensation surfaces (see Table) it follows that in all experiments, distillation took place in the region transitional between the molecular and equilibrium regions.

A quantitative description of the distillation process in the transitional region is very complex because of the interaction of the molecules in motion between the evaporator and the condenser. This process was examined in a somewhat simplified manner in [6].

The rate of distillation in [6] was determined by the equation

$$f = F + (1 - F)(2e^{-K} - e^{-2K}), \tag{3}$$

where f is the proportion of vaporized molecules reaching the condenser, which is determined by Langmuir's equation F is the ratio between the condensation surface and the total evaporation and condensation surface; $K = \frac{d}{k\lambda_E}$ (here λ_E is the mean free path length of the molecules of the evaporated substance at the distillation temperature in the equilibrium vapor; k is a factor representing the average distillation conditions in the space between the evaporation and condensation surfaces and depending on the geometry of the still).

Burrows [6] obtains equation (3) as the sum of the following three components: e^{-K}, the proportion of molecules reaching the condenser without collision; $(1-e^{-K})e^{-K}$, the proportion of molecules reaching the condenser after the first collision, and the term $F(1-e^{-K})^2$, determined by the proportion of molecules reaching the condenser after a number of collisions and therefore moving randomly in various directions. The separation effect during distillation in the transitional region will obviously be the overall effect of two processes: transfer to the condensation surface of a substance with a composition determined by separation, as a result of different evaporation rates, and transfer of substance as a result of normal, equilibrium distillation. Therefore the separation factor in the transitional region (α_{trans}) may be expressed as follows:

$$\alpha_{trans} = \alpha_M \nu + \alpha_p (1 - \nu), \tag{4}$$

where ν is the proportion of molecules taking part in molecular distillation.

Assuming that the first two components of equation (3) determine the value ν, and employing equation (2), we obtain the expression

$$\nu=\frac{2e^{-K}-e^{-2K}}{F+(1-F)\,(2e^{-K}-e^{-2K})}\,. \tag{5}$$

The, substituting the expression for ν in equation (4) we finally obtain

$$\alpha=\alpha_p\left[\left(\sqrt{\frac{M_2}{M_1}}-1\right)\times\right.$$
$$\left.\times\frac{2e^{-K}-e^{-2K}}{F+(1-F)\,(2e^{-K}-e^{-2K})}+1\right]. \tag{6}$$

From equation (6) it follows that the experimental separation factor obtained during distillation in the intermediate region depends not only on the equilibrium separation factor, the mass ratio of the separated components and the free path lengths of the vaporizing molecules but also on the geometric dimensions and the mutual location of the evaporation and condensation surfaces.

Fig. 3 gives the relation between the separation factor of lithium isotopes and the value of K, calculated by means of equation (6). When the curve was plotted it was assumed that α_s = 1.002 [9] and F = 0.2 (in accordance with the dimensions of our still). The separation factors (see Table) obtained by the authors by experiment on the assumption that $K = \frac{d}{\lambda}$ (i.e. k = 1) and α_s are independent of temperature (such an assumption may evidently be made because the absolute value of α_s is close to unity, and the temperature range examined is fairly small) are plotted on the same graph.

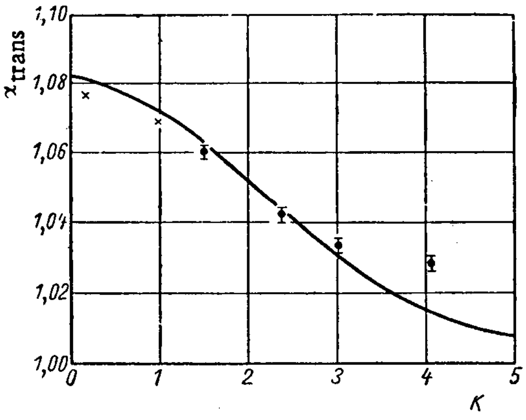


Fig. 3. Relation between the separation factor of lithium isotopes and K: ●) experimental data; ×) data of [9].

For a comparison of our values for the separation factor and those given in [9], we calculated λ_E for the conditions indicated in [9]. Assuming that d = 2.54 ohms, k = 1 (since the geometric dimensions of the still were similar to those of our still), for α values of 1.077, 1.069 and 1.055 we obtained K values of 0.168, 0.987 and 2.44 respectively. The points found were also plotted in Fig. 3, because judging by the diagram of the still given in [9], it may be assumed that the value of F was close to 0.2.

From the graph it is evident that the relation between α_{trans} and K, obtained by experiment, and the path of the curve calculated theoretically are similar.

The fairly close agreement between our experimental results and the data in [9] calculated by means of equation (6) indicates that the distillation mechanism expressed by equation (3) in [6] represents fairly correctly the processes taking place during distillation in the intermediate region. Therefore, when the separation factors of lithium isotopes obtained under different conditions are compared, in addition to the temperature and pressure of the saturated lithium vapor, it is necessary to take into account the distillation conditions (residual gas pressure, mutual location and ratio of the dimensions of the evaporation and condensation surfaces). It is precisely the effect of these factors which may explain the discrepancy between the separation factors obtained in [9] at the same temperatures in the still and in the column.

In conclusion we wish to express our thanks to G.K. Boreskov for his interest and help in this work.

LITERATURE CITED

1. M.P. Markov et al. Proc. Second International Conference on the Peaceful Uses of Atomic Energy (Geneva, 1958). Reports of Soviet Scientists [in Russian]; 6, Moscow, Atomizdat, 1959, p. 54.
2. Douglas et al. Lithium. Collection of Translations, ed. by Plyushchev. Moscow, IL, 1959, p. 36.

3. H. Hartmann and R. Sneider, Z. anorg. Chem. 180, 279 (1929).
4. K. Kelley, U.S. Bur. Mines Bulletin, 383 (1935).
5. O. Ruff and O. Johannesen, Ber. Dtsch. chem. Ges. 38, 3603 (1905).
6. G. Burrows, Trans. Instn. Chem. Engrs. 32, 23 (1954).
7. V.N. Matrozov, Molecular Distillation Apparatus [in Russian], Moscow, Mashgiz, 1954.
8. A. Bogros, Ann. Phys., X, 17, 199 (1932).
9. Trauger et al. Proceedings of the International Symposium on Isotope Separation. North Holland Publishing Co., Amsterdam, 1957, p. 350.
10. L. Perret, L. Rozand and E. Saito. Report No. 1267, given by the French delegation to the Second International Conference on the Peaceful Uses of Atomic Energy (Geneva, 1958).
11. K. Maucherat, J. Phys. et radium, VII, No. 10, 441 (1939).
12. L. Lewis, Z. Phys. 69, 802 (1931).
13. G. Kaye and T. Laby. Experimental Physicist's Handbook [Russian translation], Moscow, IL, 1949.

LETTERS TO THE EDITOR

THE ANGULAR AND ENERGY DISPERSION OF π^--MESONS IN THE SCATTERED MAGNETIC FIELD OF A SIX-METER SYNCHROCYCLOTRON

V.G. Kirillov-Ugryumov, A.A. Kropin, V.S. Roganov
and A.V. Samoilov

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 245-246, September, 1961
Original article submitted March 27, 1961

For the most efficient use of beams of charges particles from an accelerator it is essential to have detailed information on their motion in the scattered field of the electromagnet. This information can be most simply obtained by computer calculations with an analytical expression for the laws of motion of particles and a known configuration of magnetic field.

In the present work data are given on the motion of π^--mesons formed on the inner target of a six-meter synchrocyclotron at the United Institute for Nuclear Studies. For the calculations we used simple and economical formulas describing the horizontal and vertical motions of charged particles in any azimuthally symmetrical magnetic field [1]. With a small translation step h along the trajectory the coordinates of the position of the particle at the end and start of the step are connected by the relationships

$$R_{i+1}=R_i+h\cos\alpha_i-\frac{h^2}{2\varrho_i}\sin\alpha_i+\frac{h^2}{2R_i}\sin^2\alpha_i; \tag{1}$$

$$\varphi_{i+1}=\varphi_i+\frac{h}{R_{i+1}}\sin\alpha_i+\frac{h^2}{2\varrho_i R_{i+1}}\cos\alpha_i; \tag{2}$$

$$\alpha_{i+1}=\alpha_i+\frac{h}{\bar{\varrho}}-(\varphi_{i+1}-\varphi_i); \tag{3}$$

$$z_{i+1}=z_i\left(1-\frac{1}{2}\frac{h^2}{W}\frac{dH_z}{dR}\sin\bar{\alpha}_i\right)+z_i'h; \tag{4}$$

$$z'_{i+1}=z'_i\left(1-\frac{1}{2}\frac{h^2}{W}\frac{dH_z}{dR}\sin\bar{\alpha}_i\right)-z_i\frac{h}{W}\frac{dH_z}{dR}\sin\bar{\alpha}_i, \tag{5}$$

$$\frac{dH_z}{dR}=\frac{H_k-H_{k+1}}{\Delta R}>0, \tag{6}$$

where H_k and H_{k+1} are the tabular values of the magnetic field H_z closest to the considered point of the trajectory; R is the distance from the target to the center of the magnet (in centimeters); φ is the azimuthal angle (in radians); α is the angle between the radius vector R and the tangent to the trajectory in the median plane (if $\alpha = 0$ then the tangent is directed along R) φ and α being read along the direction of rotation of the protons in the accelerator; z is the distance from the trajectory to the median plane (in centimeters); z' is the angle between the trajectory and the median plane (in radians); $\bar{\rho}$ and $\bar{\alpha}$ the mean values of the radius of curvature ρ and the angle α in the range h, when $\rho = \frac{3.333P}{H_z} = \frac{W}{H_z}$ cm (P is expressed in Mev/c, H in kiloersteds). The sign for P corresponds to the sign of the charge of the particle. If $h \ll \rho$ and $h \ll R$, and the deviations from the median plane are small, then formulas (1)-(6) ensure accuracy in calculating the trajectories, sufficient for any practical purposes.

Figure 1 gives the dependence of $H_z(R)$ used in the calculations. This dependence, measured by the "Hall method" [2], agrees well with the measurements of the magnetic field of the accelerator made previously with a fluxmeter [3]. All calculations of trajectories were for a target place at a distance of 277.5 cm from the center of the magnet.

From a calculation of more than 500 trajectories with different initial conditions in the median plane it could be seen that the scattered field of the accelerator has noticeable analyzing and focusing properties. The value $d\beta(E)/$

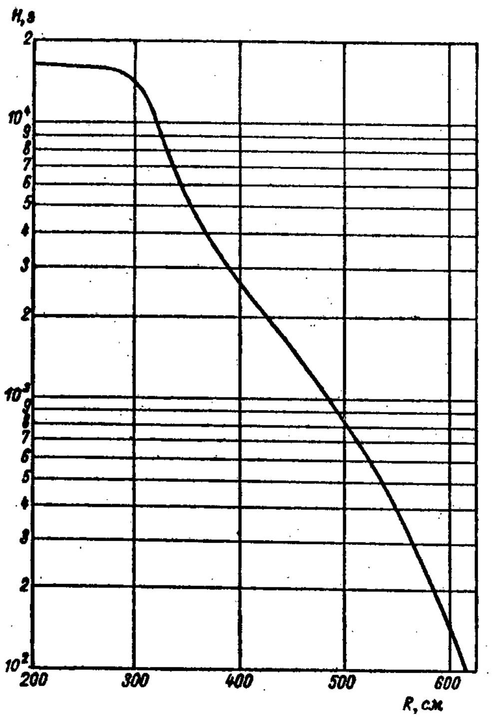


Fig. 1. Dependence of the magnetic field of a synchrocyclotron on the distance to the center of the magnet.

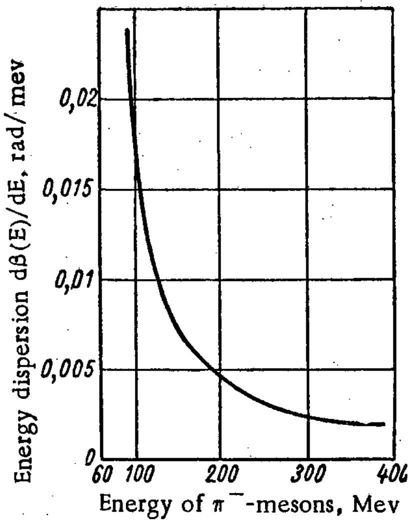


Fig. 2. Energy dispersion dβ(E)/dE of the π^--mesons emerging at an angle v = 0° to the direction of the proton beam.

dE, characterizing the analyzed properties of the field changes by more than tenfold with change in energy of the π^--mesons from 80 to 400 Mev. This can be seen from Fig. 2 which gives the energy dispersion dβ(E)/dE of the π^--mesons, emerging in the median plane at an angle v = 0 to the direction of the proton beam. Here dβ is the angle between two trajectories of the π^--mesons differing in energy by the value dE.

The angular dispersion dβ(v)/dv, characterizing the focusing properties of the magnetic field during motion of the π^--mesons in the median plane is given in Fig. 3. Here dβ is the angle beyond the limits of the magnetic field between the boundary trajectories of the beam of mesons emerging from the target in the range of angles dv. When $|d\beta/dv| < 1$ the divergence of the trajectories of the π^--mesons decreases (focusing) and when $|d\beta/dv| > 1$ it increases (defocusing). The value $d\beta/dv = 0$ corresponds to parallel trajectories. It can be seen from Fig. 3 that in a wide range of energies and angles of emergence in the median plane there is focusing of the negative π^--mesons, the greatest focusing action being observed for mesons emerging within the accelerator (positive angles).

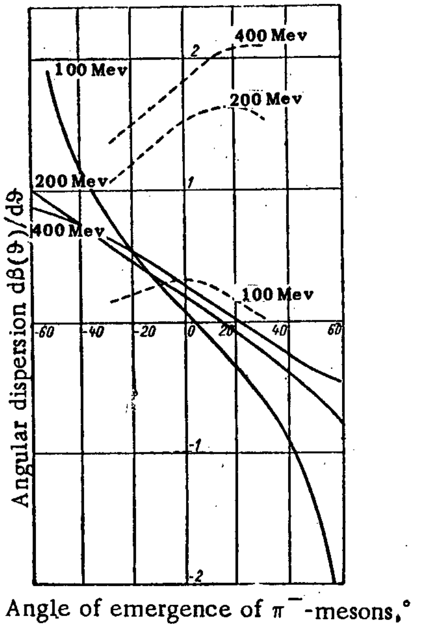


Fig. 3. Angular dispersion dβ (v)/dv π^--mesons of various energies in the horizontal (——) and vertical (---) planes.

To study the vertical motion of π^--mesons calculations were made of more than 1,000 trajectories with initial conditions $z_1(0) = 0$ cm, $z_1'(0) = 0.01$ rad and $z_2(0) = 1$ cm, $z_2'(0) = 0$ rad for various values of the energy of the π^--mesons and their angles of emergence. The indicated trajectories make it possible to obtain for paraxial rays any trajectory be means of the equations

$$\begin{pmatrix} z \\ z' \end{pmatrix} = \begin{pmatrix} z_2 & z_1 \\ z_2' & z_1' \end{pmatrix} \begin{pmatrix} z(0) \\ z'(0) \end{pmatrix}. \qquad (7)$$

An analysis of the abtained data shows that the π^--mesons with an energy greater than 100 Mev are defocused with increase in divergence of the beam approximately three-fold (see Fig. 3). Double focusing (horizontal and vertical) is observed for π^--mesons with energies greater than 100 Mev. Detailed information on these problems is contained in [4]. It should be mentioned that the data given are also applicable to the motion of positive π^--mesons emerging into the back hemisphere relative to the direction of motion of the protons.

A qualitative study of the equations of motion shows that with decrease in the distance from the target to the center of the magnet the focusing action of the scattered field of the accelerator will increase. At the present time a quantitative study is being made of this simple possibility of increasing the density of the meson beams.

In conclusion the authors would like to thank I.M. Vasilevskii for his valuable advice during the discussion of the work.

LITERATURE CITED

1. F. Farley, Report CERN, No. 59-12 (1959).
2. D.P. Vasilevskaya and Yu.N. Denisov. "Pribory i tekhnika eksperimenta", No. 3, 144 (1959).
3. V.S. Katyshev et al, Preprint of the United Institute for Nuclear Studies [in Russian] R-601 (1960).
4. V.G. Kirillov-Ugryumov et al. Preprint of the United Institute for Nuclear Studies [in Russian] R-663 and R-664 (1961).

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.**

IMPROVING THE MONOCHROMATICITY OF AN ION BEAM IN A CYCLOTRON

N.I. Venikov and N.I. Chumakov

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 247-248, September, 1961
Original article submitted March 23, 1961

One of the main faults of a cyclotron as a physical instrument is the large scatter of particle energies in the beam. In experiments needing good monchromaticity it is usual to use magnetic analysis of the emitted beam, which leads to a considerable reduction in the ion intensity.

To improve the monochromaticity of a beam of ions in the cyclotron at the I.V. Kurchatov Order of Lenin Institute for Atomic Energy [1] since 1959 successful use has been made of focusing diaphragms on dees, similar to diaphragms described in [2] with a source of ions displaced from the center of the magnet along the edges of the dees.

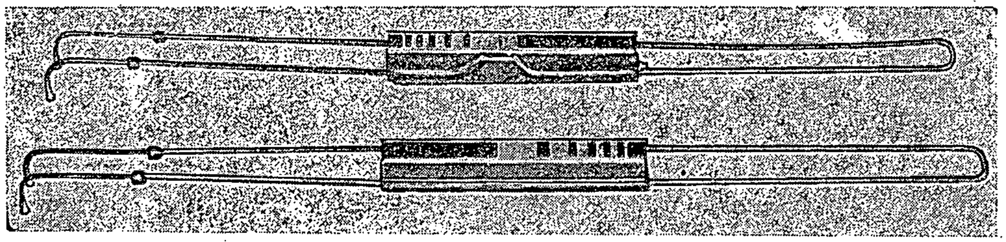


Fig. 1. Photograph of focusing slit diaphragms.

The position of the slits in the diaphragms was determined by a graphical analytical solution of differential equations of motion of ions in crossed magnetic (constant with time) and electric (changing with a frequency ω) fields. The value of the magnetic field intensity in the center of the cyclotron was chosen somewhat greater than the resonance value (~1% of H_{res}) and later was made more accurate in the calculation of ion motion up to the outlet radius by means of a method described in [3]. When calculating the dimensions and position of the slits in the diaphragms the width of the region of the starting phases of the ions was taken equal to 10°. It was determined by the requirements of good monochromaticity and small length of the bunch of ions on the one hand and sufficient intensity of the ion current at the target on the other hand. The choice of the position of the region of starting phases of the ions was also determined by compromise requirements of maximum extraction of the ions from the source (the position of the region of starting phases should be close to $\varphi = 0$) and reduction in the required high-frequency voltage at the dees (the position of the region of starting phases should be close to $\varphi = 90°$.)

Figure 1 shows a photograph of the focusing slit diaphragms used. They are made from 3-mm thick copper sheet. The heat removal is provided by distilled water passing along copper tubes soldered to the diaphragms and at the extraction dee the tube is looped to improve the heat removal from the walls at the first slit.

The slits on the dees were arranged so that during their motion the ions left the open dee and entered the diaphragmed dee. This made it possible to eliminate the defocusing section of the electric field in the slit between dees in the region of the diaphragms. With this geometry the focusing was much stronger than in the case of open dees by a factor of approximately $\frac{\cos\varphi_{in}}{\cos\varphi_{in}-\cos\varphi_{out}}$ res*, in contrast to the usual dees where there is focusing of the ions only with positive phases, in the dees with diaphragms ions with both positive and negative phases were focused.

---

* This is a reference to electric focusing due to change in the electric field between the dees during the flight of the ion through the slit. This focusing is important only for the first one or two turns.

Using this system of diaphragms ions were eliminated which had incorrect initial conditions, i.e. ions with incorrect phases and large amplitudes of radial oscillations, which would lead to large losses in intensity during acceleration, emission of the beam from the cyclotron and to an increase in the energy heterogeneity of the beam. The increase in the number of particles with the required initial conditions occurs due to strong electric focusing along the vertical and consequently reduction in losses in the region of the diaphragms. The small heterogeneity of the electric field in the radial direction due to the sagging of the field within the slits, according to rough evaluations, should not cause a noticeable increase in the energy scatter of the ions.

Strong electric focusing can lead to a considerable increase in the frequency of the vertical oscillations of the ions*, and if sufficient vertical focusing is not created in the region where the effect of the diaphragms ends, then in this region there can be considerable ion losses. In order to eliminate the ion loss the usually used form of decay of the magnetic field (Fig. 2, curve 2) was replaced by one in which in the region of termination of the effect of diaphragms,the index of decay of the magnetic field was fairly large (see Fig. 2, curve 1). Figure 3 gives the measured dependence of the ion current on the radius of acceleration, typical for all operating conditions of the cyclotron with focusing diaphragms on the dees. The least radius at which it was possible to measure the ion intensity was 25 cm and the radius of the last slit in the diaphragm was 20 cm. It can be seen from Fig. 3 that there are no ion losses at the large radii and at the radii close to the radius of the last slit there are a few losses.

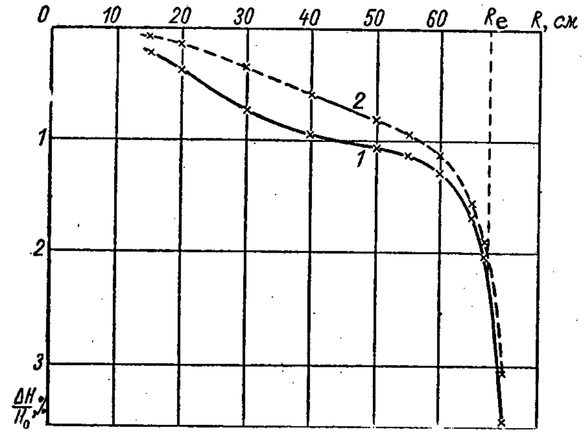


Fig. 2. Form of decay of the magnetic field (R_e is the radius of emission of the particles).

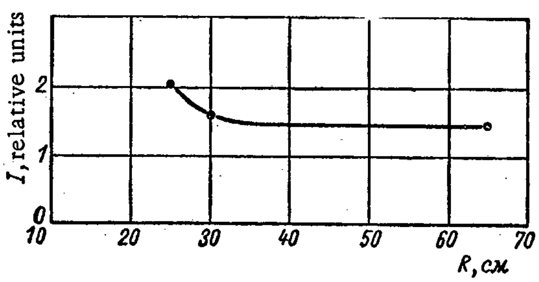


Fig. 3. Dependence of the ion current on the radius of acceleration.

The displacement of the ion source along the edges of the dees relative to the center of the magnet is found by calculating the motion of the ions at the first five to seven turns. This displacement reduces the radius of precession of the centers of the last orbits of the ions and consequently leads to a reduction in the energy heterogeneity of the beam.

The table gives the main parameters of a beam of ions for three systems of acceleration with focusing diaphragms and (for comparison) in a system of acceleration of deuterons up to an energy of 20 Mev without focusing diaphragms.

Parameters of an Ion Beam Before and After Introducing Focusing Diaphragms

Ions	Energy, Mev	Emission coefficient of a beam from the deflector, %	Maximum intensity of emitted beam, μa	Energy scatter of beam at distant target (width at half height), %
d^+ (without focusing diaphragms)	20	30–40	100	± 0.8
d^+	10	70	100	± 0.2
He_3^{+2}	35	70	30	± 0.3
d^+	20	70	100	± 0.35

The energy scatter was measured by the method of magnetic analysis of the emitted beam.

---

* Diaphragms have now been calculated and partially tested with an absence of vertical focusing on the first three half turns, which should lead to a reduction in ion losses during further acceleration.

In conclusion the authors would like to thank N.A. Vlasov, S.P. Kalinin and B.V. Rybakov for their constant interest in the work and also N.V. Starostin for his help.

LITERATURE CITED

1. L.M. Nemenov et al. "Atomnaya Énergiya", II, No. 1, 36 (1957).
2. A. Smith and W. Morton, Nucl. Instrum. and Methods 4, 37 (1959).
3. N.I. Venikov. "Atomnaya Énergiya", 11, No. 5, (1961).

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 ANGULAR ANISOTROPY OF FISSION OF EVEN-EVEN NUCLEI

V.G. Nesterov, G.N. Smirenkin and I.I. Bondarenko

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 248-250, September, 1961
Original article submitted April 25, 1961

It was shown in [1] that by studying the irregularities in the energy dependence of angular anisotropy of fragments detected in the fission of Pu^{239} by neutrons and by comparing them with the behavior of the fission width it was possible to obtain information on the structure of the spectrum of the fission channels.

In the present work a study was made of the dependence of the angular anisotropy of fission fragments $\sigma_f(0°, E_n)/\sigma_f(90°, E_n)$ during the fission of U^{233} and U^{235} by neutrons with an energy of E_n in the range 0.2-2.5 Mev. The experimental device consisted of four ionization fission chambers making it possible to carry out simultaneous recording of the fragments in the direction of the neutron beam and in a direction perpendicular to this beam for two fissionable layers: U^{233} and U^{235}. Double layers of the investigated isotopes were used in the measurements, thus making it possible to obtain simultaneously two series of experimental data. The amount of U^{233} on each side of the backing was 9 mg and the amount of U^{235} was 20 mg. The method of the measurements and the arrangement of the experiment were the same as in [1]. The measurements were carried out on the electrostatic Van de Graaf generator. The source of fast neutrons was the reaction $T(p, n)He^3$.

A solid tritium target of thickness ~75 kev was used in the experiment. The angular resolution of the detector was 9°.

Figure 1 shows the results of measurements of the angular anisotropy of fission fragments of U^{233} and U^{235} obtained in this experiment and of Pu^{239} taken from [1]. In the data given for U^{235} a small correction has been introduced ($\leq 2\%$) for the impurity ~9% U^{238}. (The values $\sigma_f(0°)/\sigma_f(90°)$ for U^{238} were taken from [2].) The errors in the angular anisotropy were determined from the scatter of separate series of measurements and coincided approximately with the statistical errors of the experiment. The obtained data agreed satisfactorily with the data of [2, 3].

The results of the present work are also given in Fig. 2. The bottom part of the figure shows the energy dependence of fissility of the investigated isotopes in the (d,p)-reaction $F = \frac{\sigma(d, pf)}{\sigma(d, p)}$, measured in [4]. It is of interest that the position of the minima in the relationship $\sigma_f(0°, E_n)/\sigma_f(90°, E_n)$ correlates with the irregularities in the dependence of the fissility on the energy of neutrons added to the nucleus-target during the (d,p)-reaction. The thresholds of new fission channels of the nuclei U^{234}, U^{236} and Pu^{240} presumably correspond to these energies of neutrons.

From the dependences of fissility of the isotopes on the energy of excitation of the fissionable nuclei given in Fig. 2 it can be seen that the channel structure of the fissility appears particularly clearly at $E_n < 0$. The thresholds of the first two channels, according to the theory of D. Hill and J. Wheeler [5], correspond to the points of inflexion of $F(E_n)$ and are −1.47 and

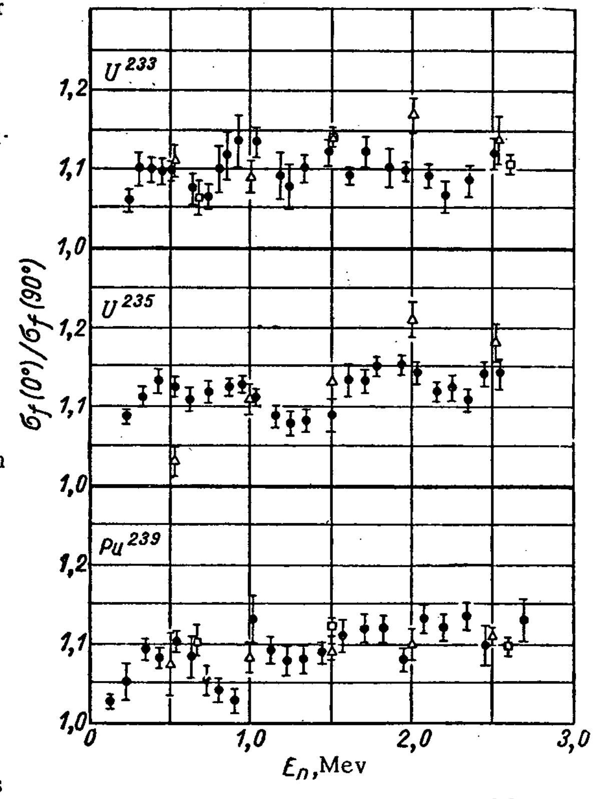
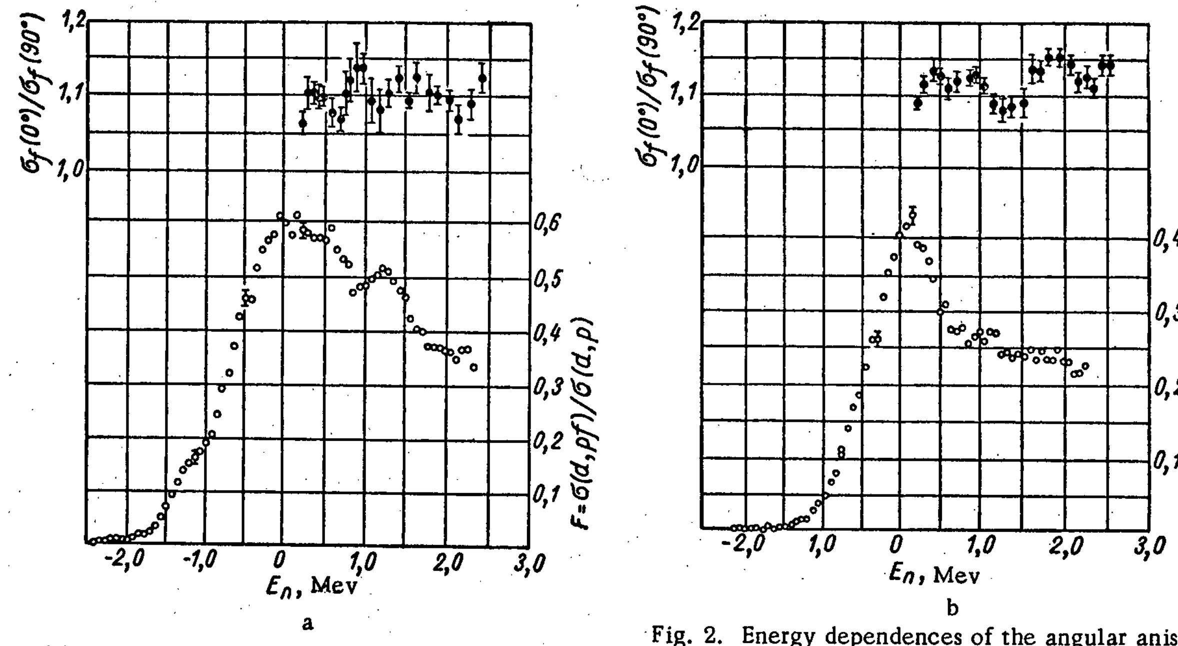
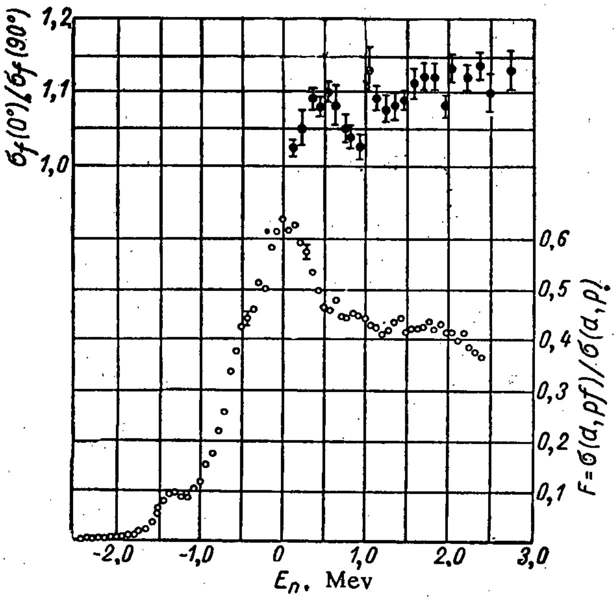


Fig. 1. Results for angular anisotropy of fission fragments of U^{233}, U^{235} and Pu^{239}. Data of work: ● – present; △ – [2]; □ – [3].



a

b



c

Fig. 2. Energy dependences of the angular anisotropy of fragments (top) and fissility (bottom) of the isotopes U^{233} (a), U^{235} (b) and Pu^{239} (c).

−0.72 Mev for U^{233}, −0.6 Mev for U^{235}, −1.61 and −0.72 Mev for Pu^{239}. The value of the threshold of the third channel is apparently close to $E_n = 0$, however it cannot be determined accurately because of the concurrence of the neutron and fission width (Γ_n and Γ_f), leading to a sharp decrease in fissility when $E_n > 0$ ($F = \frac{\Gamma_f}{\Gamma_n + \Gamma_f}$). In this region of neutron energies the appearance of new fission channels is expressed in the relationship $F(E_n)$ or in the form of weak rises or in the form of a slowing down of decay as a function of the relationship Γ_n and Γ_f. From the data given in Figs. 1 and 2 it follows that in the whole of the studied region of neutron energies the distance between neighboring clearly expressed channels is approximately the same and is 0.6-0.8 Mev. This shows that the factors causing the observed picture of the energy spectrum of fission channels for even-even compound nuclei are general.

It is possible that the structure of fission channels close to the equidistant structure indicates that the fission degrees of freedom are connected with the oscillations of a transition nucleus at a saddle point. If it is assumed that the mechanism of formation of levels of a 1^- even-even nucleus of an equilibrium shape and structure of channels of a transition nucleus is the same and has an oscillating nature, then from the position of the lowest state 1^- for nuclei with A = 230-240 ($E(1^-) = \frac{3}{2}\hbar\omega = 0.5 \div 0.6$ Mev [6]) we can obtain a value for the distance between the nearest fission thresholds $2\hbar\omega = 0.7$-0.8 Mev. This evaluation is in good agreement with the experimental data. The interpretation of the character of the spectrum of channels was proposed by V.S. Stavinskii. The authors are indebted to A.I. Leipunskii for his interest in the work, V.S. Stavinskii for discussing the experimental results, V.A. Romanov, Yu.I. Parfenov and the operating personnel of the electrostatic generator for their cooperation in the experiment, N.N. Krot for preparing the fissionable layers and M.K. Golubeva for helping with the measurements.

LITERATURE CITED

1. V.G. Nesterov, G.N. Smirenkin and I.I. Bondarenko. "Atomnaya energiya" 10, 6, 620 (1961).
2. J. Simmons and R. Henkel, Phys. Rev. 120, 198 (1960).
3. L. Blumberg and R. Leachman, Phys. Rev. 116, 102 (1959).
4. J. Northrop, R. Stokes and K. Boyer, Phys. Rev. 115, 1277 (1959).
5. D. Hill and J. Wheeler, Phys. Rev. 89, 1102 (1955).
6. B.S. Dzhelepov and L.K. Peker. Modes of Decay of Radioactive Nuclei [in Russian] Moscow, Acad. Sci. USSR Press, 1958.

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 POSSIBILITY OF THE PRACTICAL USE OF ISOMERS*

Yu.V. Petrov

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 250-251, September, 1961
Original article submitted April 25, 1961

In the reaction of slow neutrons with isomers together with radiation capture (n, γ) and elastic scatter (n, n) there is possible inelastic scatter of the second kind (n, n'), when the neutron removes all or part of the excitation energy of the isomer (in the latter case the isomer level is not the first excited)**. Rough evaluations show that for $Hf^{180\,m}$ with a half life of 5.5 hr the probability of the (n, n') reaction is comparable with the probability of radiation capture, and the cross section of the reaction in the thermal region is hundreds and thousands of barns.

The possibility of occurrence of the (n, n') reaction with a large cross section leads to the idea of its practical use. For example, this reaction can be used to throw moderated neutrons beyond the fission threshold of U^{234} and Pu^{240}, having a fairly low value of ~0.4 Mev. This would increase the multiplication factor of reactors using U^{234} and Pu^{240} as the fuel and would also facilitate their control since the moderating neutrons with an energy less than the threshold value would make a contribution to the chain reaction. Furthermore, it might be possible to use the high monochromaticity of fast neutrons arising in the (n, n') reaction. If fast neutrons are formed due to inelastic scatter of thermal neutrons by isomers, then in the system of the center of masses the relative energy of the colliding particles compared with the energy of the isomer transition E_m is very small and it can be neglected. The ratio of the beam width ΔE to the most probably energy E_0 is

$$\frac{\Delta E}{E_0} \simeq 2 \sqrt{\frac{kT}{AE_m}} .$$

When $E_m \simeq 100$ kev and $A \simeq 100$ the width of the beam is $\simeq 10$ ev. This value is less than the distance between the levels of many nuclei.

So that the fast neutrons of the (n, n') reaction should make a noticeable contribution to the multiplication factor and the spectrum of the reactor, the isomer and neutron flux of the reactor should satisfy the following rigid requirements:

1. If it is assumed that the (n, n') reaction proceeds through the formation of a compound nucleus it is essential that the condition $\Gamma_{n'} \geq \Gamma_\gamma$ should be satisfied. It is to be expected that $\Gamma_{n'}$ will be greater than in the remaining cases for magnetic and K-forbidden nuclei and also for nuclei of the mean atomic weight.

2. The product of the microscopic reaction cross section of the isomer σ_r^m by the neutron flux ϕ gives the probability of reaction in unit time. This probability should be greater than or comparable with the probability of decay, i.e. $\sigma_r^m \phi \tau \geq 1$, where τ is the lifetime of the isomer. Hence it follows that for the practical use of the (n, n') reaction very high neutron fluxes are required. Even when $\sigma_r^m \simeq 10^4$ barn for an isomer which lives for a few hours the flux required is $\sim 10^{16}$ neutrons/cm^2 · sec.

3. Although the isomers can be obtained in different ways, the most obvious is to prepare the isomers in the reactor itself by the (n, γ) reaction. For this purpose the reactor must be loaded with the isotope which forms an isomer, the activation cross section of the isomer σ_{act}^m being greater than or comparable with the activation cross section of the main state $-\sigma_{act}^0$. This requirement means that the K-forbidden nuclei must be neglected since they have a large spin and the probability of obtaining a nucleus with a large value of spin due to the (n, γ) reaction is usually small.

---

* This work was presented to the Symposium on Neutron Studies of Nuclear Reactors in Vienna, October, 1960.
** Yu.V. Petrov. "Zh. eksperim. i teor. fiz.", 37, 1170 (1959).

In conclusion it should be mentioned that the (n, n') reaction has not yet been observed experimentally and the reaction cross sections are unknown. Further experimental studies are needed to decide on the possibility of developing a research reactor with a monoenergetic beam of neutrons and on the use of isomers for the chain reaction.

I would like to thank B.P. Konstantinov, A.D. Piliya and G.V. Skornyakov for discussing this work.

THE SPACE DISTRIBUTION OF FAST FISSION NEUTRONS IN IRON

V. P. Mashkovich and S. G. Tsypin

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 251-255, September, 1961
Original article submitted January 30, 1961

Iron is one of the most convenient, cheap and widely used shield materials (it is used for reactor vessels, thermal shielding, as a building material, in iron-water mixtures, etc.). However, there is not much data in the literature on the distribution of neutrons in iron [1-4].

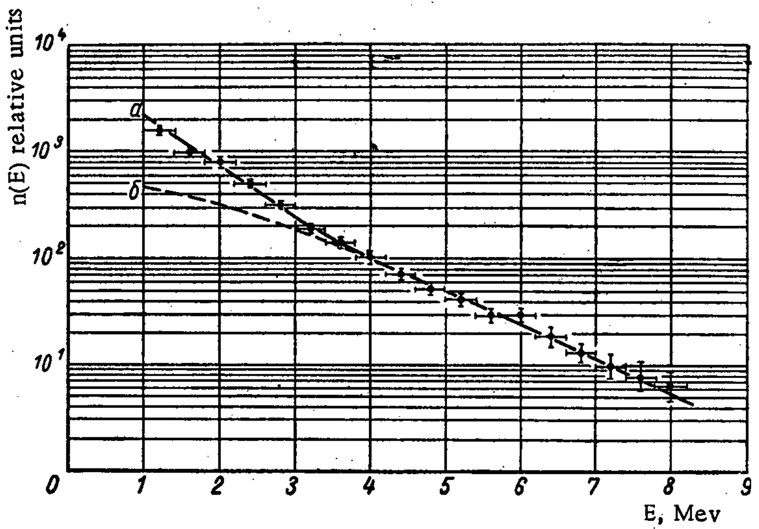


Fig. 1. Spectrum of neutrons incident on the investigated shield (curve a). The spectrum of fission neutrons is shown for comparison (curve b).

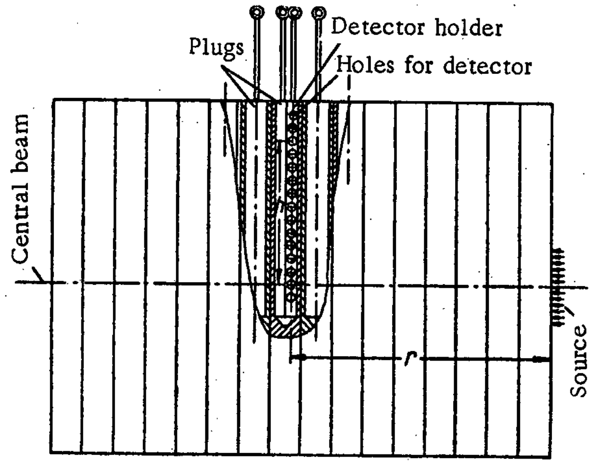


Fig. 2. Arrangement of iron prism.

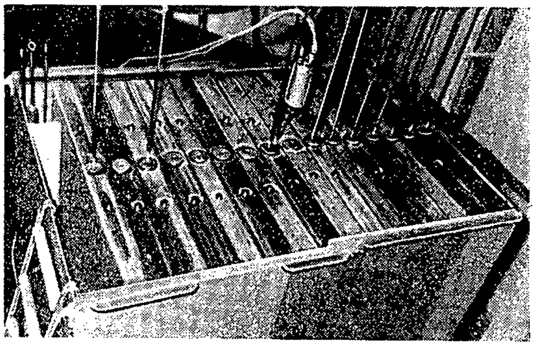


Fig. 3. Overall view of prism.

In the present work an experimental study was made of the space distribution of neutrons of the BR-5 reactors in iron [5-7].

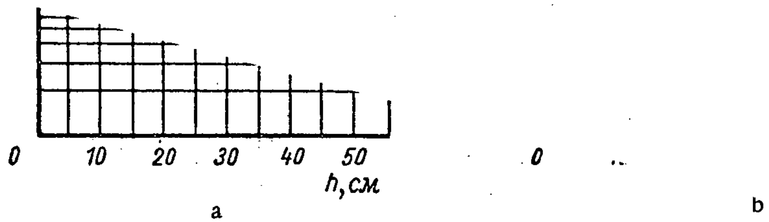


Fig. 4. Activity of threshold indicators (a — sulfur, b — aluminum) versus h for various values of r, cm: 1) 3.7; 2) 15.4; 3) 27.1; 4) 38.8; 5) 50.5; 6) 62.2.

The spectrum of neutrons incident on an iron prism is shown in Fig. 1. The spectrum was determined by means of photographic plates with a 200 μ thick emulsion. The photographic plate was placed in the beam of neutrons as they left the channel of the biological shield. The spectrum was plotted on the basis of an analysis of more than 2,500 tracks of recoil protons emitted forward at an angle of ± 15°. In the obtained spectrum allowances were made for the dependence of the cross section of scatter of neutrons by hydrogen on the energy, the background and final thickness of the emulsion layer. From a comparison of the obtained spectrum with the fission spectrum it can be seen that at energies less than 3 Mev there is a certain softening of the spectrum.

The neutrons passed into the reactor shield through a ~250-mm diameter channel and entered a tank in which there was a prism measuring 1320* x 1360 x 1880 mm made up of iron piles. The neutron beam with a total divergence of ~ 5° entered the tank through the middle of the side wall of a prism measuring 1320 x 1360 mm. The prism was made up of nine piles measuring 1320 x 1360 x 117 mm and following these piles there were seven iron piles measuring 1390 x 1360 x 117 mm. The iron pile was made up of six sheets measuring 1320*(1390) x 1360 x 19.5 mm.

---

* Beginning with the tenth pile this dimension was increased to 1,390 mm.

In each pile there was a 90-mm diameter vertical hole to a depth of 830 mm for an iron plug. In the plug in which the measurements were made there was a detector holder in the form of an iron strip. The strip had holes to locate the detectors. The empty holes and the places not occupied by detectors were filled with iron cylinders.

The plugs with the dector holders made it possible to place the detectors at various points of the iron prism, locating the position of the detector with an accuracy of 1 mm in the horizontal and vertical directions. The detectors were placed at different distances r from the source and at different distances h from the central ray (Fig. 2).

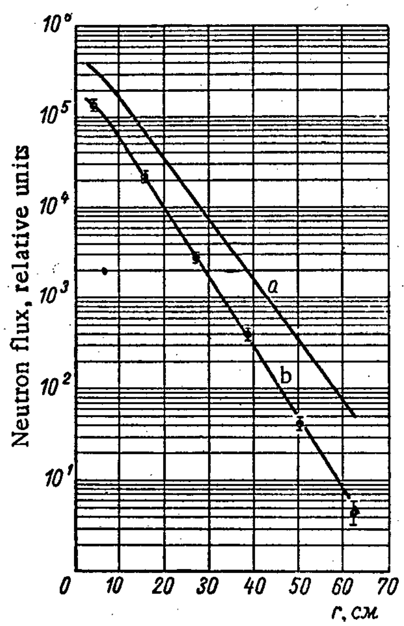


Fig. 5. Function of neutron attenuation of a plane monodirectional source (a) and curve of attenuation in the direction of the central ray (b) from measurements with sulfur indicators.

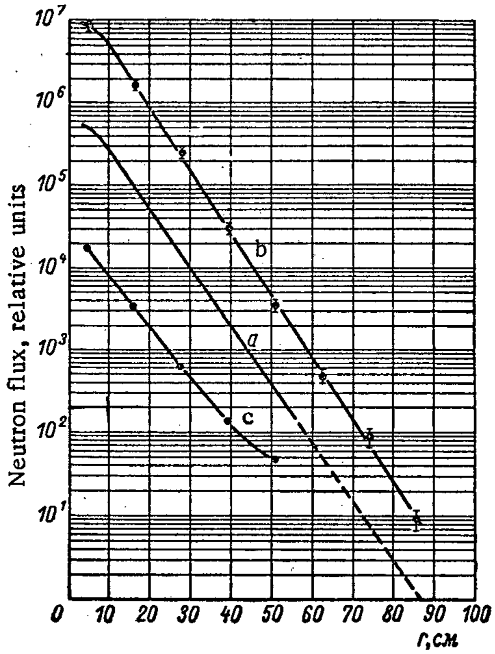


Fig. 6. Function of neutron attenuation of a plane monodirectional source (a) and curves of attenuation in the direction of the central ray (b) measurements on a gamma-spectrometer; (c) measurements on an end counter, for aluminum indicators.

The iron used was St-0 (γ = 7.86 g/cm^3, impurities of carbon, manganese, sulfur and phosphorus totaled 0.6%).

Figure 3 shows an overall view of the iron prism.

The detectors of the fast neutrons were threshold indicators S^{32} (n,p) P^{32} and Al^{27} (n, α) Na^{24} with effective thresholds with respect to the spectrum incident on the shield of ~ 3 and ~ 7 Mev respectively. The detectors were 35-mm diameter discs. The height of the sulfur indicators (fused chemically pure sulfur) was 6 mm, that of the aluminum discs (chemically pure AV-000 Aluminum) was 20 mm. The indicators were placed in cadmium cans of 0.6 mm thickness.

The induced activity of the sulfur indicators were determined by plotting decay curves, thus eliminating the effect of foreign impurities. It was not possible to determine the induced activity of the aluminum indicators in this way since it was difficult to distinguish between the main activity and the activity of the impurities which begin to have an especially important effect with increased distance from the source due to the large difference in the penetrating capacity of the streams of fast and intermediate neutrons. The activity of the aluminum indicators was therefore determined from the peak of the photoelectrons formed in the crystal by γ-rays of Na^{24} with an energy of 2.76 Mev. The measurements were made on a scintillation γ-spectrometer with a NaI(Tl) crystal measuring 80 x 80 mm [8]. The aluminum detectors were placed in a fixed position near the crystal-scintillator. The energy scale was checked from the γ-radiation of a Co^{60} isotope. A correction was made for the activation of the impurity Na^{23} $(2 \pm 1) \cdot 10^{-4}$% by the stream of intermediate neutrons.

TABLE 1. Results of Relaxation Length Measurements

Indicator	Effective threshold with respect to the spectrum incident on the shield, Mev	Measured range of iron thicknesses, cm	Relaxation length in the direction of the central ray, cm	Relaxation length for a plane monodirectional source, cm
$Th^{232}(n,f)$	~2	50	6.5	7.5
$S^{32}(n,p)\,P^{32}$	~3	65	5.6	6.5
$Mg^{24}(n,p)\,Na^{24}$	~5	40	5.6	6.3
$Al^{27}(n,\alpha)\,Na^{24}$	~7	85	5.8	6.3

Figure 4 gives the activities of the sulfur (a) and aluminum (b) indicators versus h for various values of r.

Figures 5 and 6 show the functions of neutron attenuation of a plane monodirectional source, determined from measurements by sulfur and aluminum indicators according to the formula of [9].

$$G_{\text{pl}}(r) = C \int_0^\infty N(r,\ h)\, h\, dh, \qquad (1)$$

where N(r,h) are the distributions given in Fig. 4a, b; C is a constant.

TABLE 2. Asymptotic Cross Sections in a Transport Approximation, Barn

Cross sections of reaction	Energy group, Mev				
	1.4-∞	1.4-2.5	2.5-4	4-6	6-8
σ tr	2.2	2.2	2.3	2.2	2.0
σ removal calc.	0.7	0.8	1.0	1.2	1.33
σ tr	1.5	1.4	1.3	1.0	0.7
σ asumpt.	1.9	1.9	2.1	2.1	2.0

Figures 5 and 6 also show the curves for neutron attenuation in the direction of the central ray.

For aluminum indicators Fig. 6 shows the curve for neutron attenuation in the direction of the central ray measured on an end counter, i.e., without eliminating the effect of foreign impurities. These measurements were made after soaking the indicators for 15-20 hr; of the foreign activity there remained only the activity of the Cu^{64}, having a half life close to that of Na^{24} and the activity of Na^{24} formed according to the reaction $Na^{23}(n,\gamma)\,Na^{24}$.

Measurements were also made with a fission chamber with Th^{232} and threshold indicators $Mg^{24}(n,p)\,Na^{24}$ with effective thresholds with respect to the spectrum incident on the shield of ~2 and ~5 Mev respectively. The obtained data were corrected for the count due to the impurity of U^{235} for the chamber with Th^{232} and the extra activation of impurities for the magnesium indicators.

Table 1 gives the results of the measurements by various indicators. The obtained relaxation length for measurements with a fission chamber with Th^{232} agrees well with the data of [1,2]. The difference in the relaxation lengths measured by the threshold detectors according to the reactions $S^{32}(n,p)P^{32}$; $Mg^{24}(n,p)\,Na^{24}$ and $Al^{27}(n,\alpha)\,Na^{24}$ and a fission chamber with Th^{232} can be explained by the reduction in cross section of iron at an energy of ~1-2 Mev.

In constrast to sources used in the work given above on the measurement of fast neutron transmission of the reactor spectrum in iron [1-3], the source used in the present work has the advantage that it does not require corrections for the geometry of the experiment. The relaxation lengths obtained experimentally from measurements with sulfur, magnesium and aluminum indicators are in good agreement with the relaxation lengths calculated from the removal cross section [10], differing from the latter by 10%.

Table 2 gives the calculated values of asymptotic cross sections in a transport approximation for some energy groups. These cross sections were obtained on the basis of accepted group cross sections and a formula for determining the asymptotic diffusion length [11]. They are in good agreement with the cross sections calculated from measured relaxation lengths ($\sigma_{S^{32}} \sim 1.81$ barn; $\sigma_{Mg^{21}} \sim 1.87$ barn and $\sigma_{Al^{27}} \sim 1.87$ barn).

The authors would like to thank A. I. Leipunskii, I. I. Bondarenko and V. V. Orlov for their valuable comments during the discussion of the work and graduate of the MIFI Yu. K. Emakov who took an active part in the measurements. The authors are also indebted to A. V. Larichev and A. N. Nikolaev for helping in the work.

LITERATURE CITED

1. D. L. Broder et al. "Atomnaya énergiya", 7, No. 4, 313 (1959).
2. D. L. Broder et al. Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Reports of Soviet Scientists, Vol. 2 [in Russian] Moscow, Atomic Energy Press, 1959, p. 674.
3. D. Wood. Nucl. Sci. and Engng, 5, 45 (1959).
4. E. Blizard. Annual Rev. Nucl. Sci., 5, 91 (1955).
5. A. I. Leipunskii et al. Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Reports of Soviet Scientists, Vol. 2 [in Russian] Moscow, Atomic Energy Press, 1959, p. 215.
6. A. I. Leipunskii et al. "Atomnaya énergiya", 5, No. 3, 277 (1958).
7. "Atomnaya énergiya", 7, No. 2, 192 (1959).
8. A. V. Larichev and G. A. Cherevatenko. Collection: "Instruments and methods for analyzing radiations" [in Russian] No. 3, Moscow, State Atomic Energy Press (in the press).
9. V. A. Dulin et al. "Atomnaya énergiya", 9, No. 4, 315 (1960).
10. H. Coldstein. The Attenuation of Gamma-Rays and Neutrons in Reactor Shields, US AEC, Washington, 1957.
11. B. Price, K. Horton and K Spinney. Nuclear Shielding [Russian translation] Moscow, Foreign Literature Press, 1959.

THE PROBLEM OF THERMAL CONTACT RESISTANCE DURING HEAT TRANSFER TO LIQUID METALS

O. P. Astakhov, V. I. Petrov and O. S. Fedynskii

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 255-257, September, 1961
Original article submitted March 28, 1961

A comparison of the experimental data on the heat transfer of liquid metals with the theoretical data of Martinelly-Lyon [1,2] shows that most experiments [3-9] do not agree with theory or agree poorly. The theory has only been confirmed experimentally in [10-13]. The following feature is of interest. The theory is best confirmed by those experiments in which the heat exchangers were tubes of diameter 25, 30 and 40 mm and it is not confirmed by experiments using tubes with diameters less than 10 mm.

In the derivation of theoretical heat-exchange equations the temperature of the interface region between the liquid metal and the wall of the tube is assumed equal to the temperature of the outer surface of the liquid metal stream, which can obviously only be the case with an absolutely pure surface of heating. The difference between the experimental data and the theory is therefore usually explained by the contact thermal resistance at the boundary between the solid wall and the molten metal, which is not allowed for by the theory. Various hypotheses have been put forward on the nature of this resistance but as yet there has been no decided point of view.

If we assume that the Martinelly-Lyon theory is true with all its assumptions and the only reason for the discrepancies in the experimental data both among themselves and with the theoretical equation is the contact thermal resistance then, without making assumptions as to the nature of this additional resistance and without going more deeply into the problem as to whether the oxides are the only reason for its appearance, it should be mentioned that the fact of existence of a contact resistance leads to consequences which are interesting from a practical point of view although as yet little attention has been paid to these consequences. In fact, in such a case it should be assumed that the coefficient of heat transfer measured in the experiments is essentially a coefficient of heat transfer from the wall to the stream of coolant through a contact layer.

We will analyze the possible effect of the contact thermal resistance R' (in m^2 hr · °C/kcal) on the relationship of the coefficient of heat transfer α measured in the experiments and the coefficient of heat transfer α_0 calculated from theoretical formulas.

From the relationship

$$\frac{1}{\alpha}=\frac{1}{\alpha_0}+R' \qquad (1)$$

we obtain

$$\frac{\alpha}{\alpha_0}=\frac{Nu}{Nu_0}=\frac{1}{1+R'\frac{\lambda_l}{d}Nu_0}, \qquad (2)$$

where α_0, Nu_0 are the coefficient of heat transfer and the Nusseldt criterion, calculated according to the theoretical Martinelly-Lyon equation; λ_l is the coefficient of thermal conductivity of the liquid metal; d is the internal diameter of the tube. If follows from relationship (2) that the results of experiments obtained on a tube of one diameter using a coolant of a certain degree of purity and represented in the form of the dependence Nu(Pe) cannot be recommended for calculating heat transfer in tubes of another diameter without knowing how R' depends on the diameter of the tube and the flow rate of the liquid metal.

In fact, writing the relationship (2) for tubes of a different diameter with a fixed value of the Pe number, we obtain

$$\frac{Nu_1}{Nu_2}=\frac{1+R_2'\,\frac{\lambda_{l\ 2}}{d^2}\,Nu_0}{1+R_1'\,\frac{\lambda_{l\ 2}}{d_1}\,Nu_0}\,.$$

Hence it can be seen that only in the case where the ratio of the Nu numbers is equal to unity can the experimentally obtained Nu_1 be used in the calculation for another diameter and this in its turn is only possible when the contact thermal resistance is absent or changes so that the value $R'\ \lambda_l/d$ remains constant for a constant value of Pe, i.e., R' changes in proportion to the diameter of the tube when Pe = const. However, as already mentioned, due to the lack of information on the nature of the contact resistance there is not yet any basis for assuming the same character of dependence of R' on the tube diameter.

If the contact resistance is only due to physical properties of the actual interface region, i.e., if for a certain degree of contamination of the coolant by oxides for a given all-liquid metal pair the value R' remains constant at different flow rates and is independent of the radius of curvature of the surface, then from the relationships (1) and (2) it follows that the best coincidence of the experimental data with the theory should occur when using tubes of a larger diameter. This feature is noticed when analyzing the results of the experiments.

Since the values of α measured in experiments with the presence of thermal contact resistance in accordance with relationship (1) depend on the two values α_0 and R', each of which obey different laws of similarity, then for a reliable comparison of the experimental data obtained under various conditions with one another and with the results of theoretical solutions the criterial equation of heat exchange should contain a complex of determining values $(R'\ \lambda_l/d)$, considering the degree of the effect of contact resistance on the process of heat transfer (the contact criterion).

We will explain these ideas with an example. We will assume that in the turbulent flow of sodium in a 24-mm diameter tube ($Re > 10^4$) an experimental curve of Nu(Pe) is obtained, 5% lower than the theoretical Martinelly-Lyon curve, i.e., $Nu/Nu_0 \simeq 0.95$. It is assumed that this accuracy points to good agreement with the theory since usually the error of the experiment is ±10%.

We will evaluate the thermal contact resistance. For example, for Pe = 200 the value Nu = 8.73 and for τ_l = 240 °C the value λ_l = 68 kcal/m·hr °C. Substituting the values of Nu_0 and λ_l in relationship (2) we obtain $R' = 2.13 \cdot 10^{-6}$ m^2·hr °C/kcal, which agrees well with the data of [10].

We will assume that the value R' is only determined by the physical properties of the interface region and is independent of the tube diameter and the conditions of motion of the coolant. Then for the same conditions and the same purity of the liquid sodium, but for a tube of diameter not 24 mm but 3 mm in accordance with relationship (2) we obtain Nu/Nu_0 i.e., the lack of agreement with theory will be not 5 but 30%.*

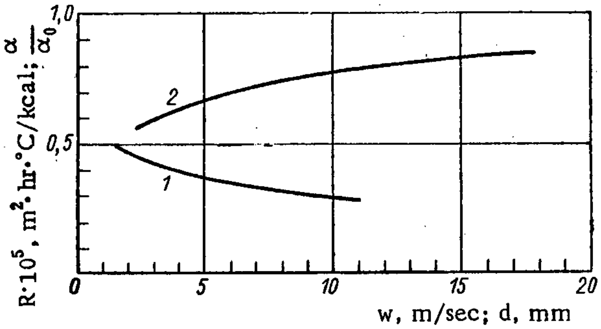
In the literature there are not experimental studies in which the purity of the liquid metal was kept constant and only the diameter of the tube was varied. It was therefore not possible to follow the dependence of R' on the diameter at constant rates and medium temperature of the coolant.

We will try to establish the character of the dependence of R' on the flow rate for a constant tube diameter, assuming that the Martinelly-Lyon theory is true and the difference between the experimental data and the theoretical data is only due to the presence of contact thermal resistance at the wall-liquid metal boundary.

For this purpose we will use the experimental data of [4] on the heat transfer of liquid sodium in a copper tube of 8.6 mm diameter at t_l = 240°C. These data are satisfactorily approximated by the formula $Nu = 5.9 + 0.015 \cdot Pe^{0.8}$, according to which in the range of numbers Pe = 200–1400 the ratio $Nu/Nu_0 = 0.75$. Then for d = 8.6 mm and λ_l–68 kcal/m·hr°C, $R' = 4.22 \cdot 10^{-5}/Nu_0$ (Pe). Since the experiments were carried out using a tube of one diameter, for the mean temperature of the coolant of 240°C and the same purity of liquid metal as in the experiment, it was possible to find the character of the dependence R'(w) (figure). With change in the flow rate of the coolant in

---

*The possibility of a larger effect of the contact resistance in small diameter tubes was first mentioned by Poppendick [14].



Effect of tube diameter on the coefficient of heat transfer in the presence of thermal contact resistance: 1) R'(w) when d = const; 2) α/α_0 (d) with an allowance for R'(w).

the experiments from 1.58 to 11 m/sec the thermal contact resistance changed from $0.4 \cdot 10^{-5}$ to 0.28×10^{-5} m^2 hr. °C/kcal. Consequently, in the range of flow rates, studied in the experiments R' depends weakly on w.

We will calculate further with an allowance for the dependence R'(w), the effect of the tube diameter on the ratio $\alpha/\alpha_0 = Nu/Nu_0$ for a sodium-copper system with the same purity of metal as in the experiments of [4] and fixed values of Pe and t_l (for example, Pe = 400 t_l = 240°C). The results of these calculations carried out according to formula (2) with an allowance for the dependence R'(w) are also represented in the figure.

It should be mentioned that the dependence $\alpha/\alpha_0(d)$ holds in the range of numbers Pe = 200–1400 since the value of the product R' Nu_0 is then practically constant.

A study of curve (2) of the figure shows that when studying heat transfer to sodium under conditions close to those obtaining in [4] the experiment will be in satisfactory agreement with the Martinelly-Lyon theory for an internal diameter of the experimental tube somewhat greater than 20 mm.

The presence of additional thermal resistance at the interface between the liquid metal and the wall points to another important practical fact. The authors of most experimental studies only deal with the representation of the results in the coordinates Nu-Pe and state whether there is a larger or smaller correspondence between the experimental data and the theoretical solution. The value of the contact thermal resistance is not calculated and its dependence on the various factors is not analyzed. The results of the experiments are therefore best represented in the form of the dependence $Nu^{-1}(Pe)$. In these coordinates by means of a simple comparison of the experimental data with the theoretical data the value of the thermal contact resistance and its dependence on Pe is readily determined since, bringing relationship (1) to a dimensionless form, we obtain

$$R' \frac{\lambda_l}{d} = \frac{1}{Nu} - \frac{1}{Nu_0}.$$

Although it does not introduce anything new, this treatment of the data makes it possible to readily follow the dependence of the thermal resistance on the conditions. The established tradition of seeking a value characterizing the intensity of heat transfer (α, Nu) and not the resistance to heat transfer (1/α, 1/Nu) distracts from the fact of existence of an additional thermal resistance and hinders the rapid solution of the problem.

LITERATURE CITED

1. R. Martinelly, Trans. ASME, 69, No. 8, 947 (1947).
2. R. Lyon. Chem. Engng. Progr., 47, No. 2, 75 (1951).
3. M. A. Mikheev, O. S. Fedynskii, V. M. Deryugin and V. I. Petrov. Collection: "Heat transfer and thermal modeling" [in Russian], Moscow, Acad. Sci. USSR Press, 1951, p. 69.
4. I. I. Novikov et al. " Atomnaya énergiya", No. 4, 92 (1956).
5. V. M. Borishanskii and S. S. Kutateladze. "Zh. tekhn. fiz.", 28, No. 4, 836 (1958).
6. V. I. Ibragimov, V. I. Subbotin and P. A. Ushakov. "Atomnaya énergiya", 8, No. 1, 54 (1960).
7. M. N. Ivanovskii. Collection: "Problems of Heat Exchange". [in Russian] Moscow, Acad. Sci. USSR Press, 1959, p 100.
8. S. S. Kutateladze et al. "Liquid metal coolants". Appendix No. 2 to "Atomnaya energiya", Moscow, Atomic Energy Press, 1958, p. 81.
9. B. Lubarsky, S. Kaufmann. Reivew of Experimental Investigations of Liquid Metal Heat Transfer. NACA, Report 1270, 1956.
10. P. L. Kirillov et al, "Atomnaya énergiya", 6, No. 4, 382 (1959).
11. M. S. Pirogev. "Atomnaya énergiya" 8, No. 4, 367 (1960).

12. H. Brown, B. Amstead, B. Short. Trans. ASME, 79, No. 2 (1957).
13. S. Isakoff, T. Drew. General Discussion on Heat Transfer. London Conference, 1951, p. 405.
14. M. Jacob. Heat Transfer, v. 11, N.-Y., John Wiley a. Sons, Inc. 1957, p. 504.

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 THERMODYNAMICS OF THE REDUCTION OF URANIUM TETRAFLUORIDE BY CALCIUM

N. P. Galkin, U. D. Veryatin and Yu. V. Smirnov

Translated from Atomnaya Energiya, Vol. 11, No. 3.
pp. 257-260,September, 1961
Original article submitted April 27, 1960

At the present time the main method for the production of metallic uranium is the reduction of uranium tetrafluoride by calcium or magnesium. The processes of reduction are established according to the reaction

$$UF_4 + 2Me = U + 2MeF_2 + Q$$

Because of the distinctive features of these processes it is interesting to compare the results of the thermodynamic calculation of the calcium-thermal reduction of UF_4 with those of the magnesium-thermal reduction published previously [1-6]. The initial physicochemical data of the thermodynamic calculation are given in Table 1.

The equilibrium constant of the reaction $UF_4 + 2Ca = U + 2CaF_2 + Q$ at different temperatures was determined from the isotherm equation of the reaction

$$\Delta Z_T^0 = -4{,}576T \lg K, \text{ where } \lg K = -\frac{\Delta Z_T^0}{4{,}576T}.$$

Changes in the free energy of the reaction ΔZ_T^0 for various temperature ranges were determined from the Gibbs-Helmholtz equation

$$\Delta Z_T^0 = \left(\Delta H_{298}^0 - \int_0^{298} \Delta C_p\, dT\right) + \int_0^T \Delta C_p\, dT -$$
$$-T\left(\Delta S_{298}^0 - \int_0^{298} \frac{\Delta C_p}{T} dT\right) - T\int_0^T \frac{\Delta C_p}{T} dT.$$

Assuming

$$\Delta H_0 = \Delta H_{298}^0 - \int_0^{298} \Delta C_p\, dT$$

$$\text{and } \Delta S_0 = \Delta S_{298}^0 - \int_0^{298} \frac{\Delta C_p}{T} dT,$$

we obtain

$$\Delta Z_T^0 = \Delta H_0 + \int_0^T \Delta C_p\, dT - T\Delta S_0 - T\int_0^T \frac{\Delta C_p}{T} dT.$$

TABLE 1. Initial Physicochemical Data of the Thermodynamic Calculation

Substances	Specific heat, cal/degree · mole	Recommended temperature range, °K	Heat of formation at 298°K, cal/mole	Absolute value of entropy at 298°K, cal/°mol.	Transformations				Literature cited
					form	Temperature, °K	heat, cal/mole	change in entropy, cal/°mol.	
UF_{4_s}	$25,52 + 8,7 \cdot 10^{-3} T$*	298—1309	—443000	36,1	$UF_{4_l} \rightarrow UF_{4_l}$	1309	12350	9,43	[7,9)
UF_{4_l}	$32,0 + 9,0 \cdot 10^{-3} T$	1309—1690	—	—	$UF_{4_l} \rightarrow UF_{4_g}$	1690	57500	34,02	[9]
UF_{4_g}	44,0	—	—	—	—	—	—	—	[9]
$U_{\alpha-s}$	$3,25 + 8,15 \cdot 10^{-3} T + 0,8 \cdot 10^{5} T^{-2}$	298—938	—	12,03	$U_{\alpha-s} \rightarrow U_{\beta-s}$	938	665	0,709	[7,9]
$U_{\beta-s}$	10,28	938—1049	—	—	$U_{\beta-s} \rightarrow U_{\gamma-s}$	1049	1165	1,111	[7,9]
$U_{\gamma-s}$	9,12	1049—1405	—	—	$U_{\gamma-s} \rightarrow U_l$	1405	2950	2,10	[7,9]
U_l	8,99	1405—3800	—	—	—	—	—	—	[9]
$CaF_{2_{\alpha-s}}$	$14,3 + 7,28 \cdot 10^{-3} T + 0,47 \cdot 10^{5} T^{-2}$	298—1424	—290300	16,46	$CaF_{2_{\alpha-s}} \rightarrow CaF_{2_{\beta-s}}$	1424	1140	0,801	[7,9]
$CaF_{2_{\beta-s}}$	$25,81 + 2,50 \cdot 10^{-3} T$	1424—1691	—	—	$CaF_{2_{\beta-s}} \rightarrow CaF_{2_l}$	1691	7100	4,2	[7,9]
CaF_{2_l}	23,90	1691—2780	—	—	—	—	—	—	[7,9]
$Ca_{\alpha-s}$	$5,24 + 3,50 \cdot 10^{-3} T$	298—723	—	9,95	$Ca_{\alpha-s} \rightarrow Ca_{\beta-s}$	723	240	0,33	[7,9]
$Ca_{\beta-s}$	$6,29 + 1,40 \cdot 10^{-3} T$	723—1123	—	—	$Ca_{\beta-s} \rightarrow Ca_l$	1123	2200	1,96	[9]
Ca_l	7,4	1123—1963	—	—	$Ca_l \rightarrow Ca_g$	1963	38600	19,66	[7]
Ca_g	4,97	>1963	—	—	—	—	—	—	[9]

---

* Calculated according to the data of [7,8].

TABLE 2. Thermal Effect and Free Energy of the Reaction $UF_4 + 2Ca = U + 2CaF_2$ for Various Temperature Ranges

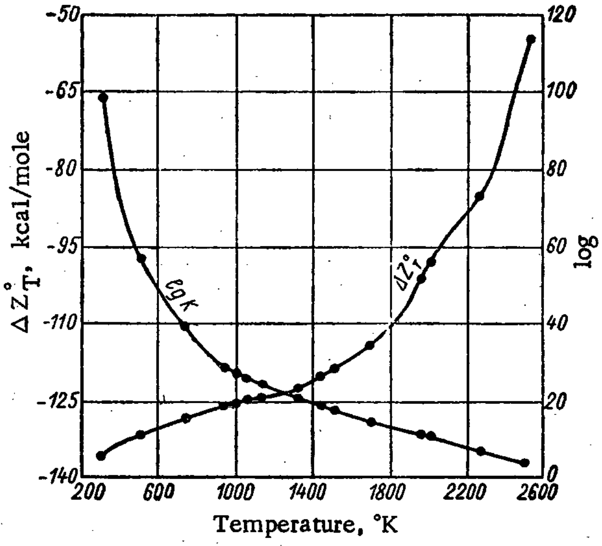
Temperature range, °K	ΔH°_T, kcal/mole	ΔZ°_T, kcal/mole
298—723	$-136090-4,15T+3,5\cdot10^{-3}T^2-1,74\cdot10^5T^{-1}$	$-136090-15,64T-3,5\cdot10^{-3}T^2-0,87\cdot10^5T^{-1}+4,15T\log T$
723—938	$-136151-6,25T+5,605\cdot10^{-3}T^2-1,74\cdot10^5T^{-1}$	$-136151-27,87T-5,605\cdot10^{-3}T^2-0,87\cdot10^5T^{-6}+6,25\log T$
938—1049	$-137678+0,78T+1,53\cdot10^{-3}T^2-0,94\cdot10^5T^{-1}$	$-137678+18,98T-1,53\cdot10^{-3}T^2-0,47\cdot10^5T^{-1}-0,78\log T$
1049—1123	$-135296-0,38T+1,53\cdot10^{-3}T^2-0,94\cdot10^5T^{-1}$	$-135296+8,51T-1,53\cdot10^{-3}T^2-0,47\cdot10^5T^{-1}+0,38\log T$
1123—1309	$-138968-2,60T+2,93\cdot10^{-3}T^2-0,94\cdot10^5T^{-1}$	$-138968-2,32T-2,93\cdot10^{-3}T^2-0,47\cdot10^5T^{-1}+2,60\log T$
1309—1405	$-142578-9,08T+2,78\cdot10^{-3}T^2-0,94\cdot10^5T^{-1}$	$-142578-46,28T-2,78\cdot10^{-3}T^2-0,47\cdot10^5T^{-1}+9,08\log T$
1405—1424	$-139445-9,21T+2,78\cdot10^{-3}T^2-0,94\cdot10^2T^{-1}$	$-139445-49,45T-2,78\cdot10^{-3}T^2-0,47\cdot10^5T^{-1}+9,21\log T$
1424—1690	$-102485-25,23T-3,1\cdot10^{-3}T^2$	$-102485-200,14T+3,1\cdot10^{-3}T^2+25,23\lg T$
1690—1963	$-193881-2,01T$	$-193881+31,81T+2,01\log T$
>1963	$-280622+2,85T$	$-280622+112,84T-2,85\log T$

TABLE 3. The Thermal Effect, Free Energy and Equilibrium Constant for the Reduction of UF_4 by Calcium

Temperature, °K	ΔH^0_T, kcal/mole	ΔZ^0_T. kcal/mole	log K
298	—137,6	—134,3 (—80,1)*	98,49
500	—137,64	—132,1 (—77,8)	57,72
723	—138,0	—129,6 (—74,1)	39,17
938	—135,7	—126,3 (—70,7)	29,42
1000	—135,5	—125,7 (—69,4)	27,46
1049	—134,1	—125,3 (—68,7)	26,11
1123	—138,3	—124,8 (—67,4)	24,29
1309	—149,8	—122,6 (—64,0)	20,47
1405	—147,0	—120,6 (—60,0)	18,76
1424	—144,7	—120,3 (—59,2)	18,46
1500	—147,3	—118,9 (—54,0)	17,32
1690	—197,3	—114,9 (—44,8)	14,85
1963	—275,0	—101,5	11,30
2000	—274,9	—98,3	10,74
2273	—274,1	—74,2	7,13
2500	—273,5	—54,3	4,74

---

*For comparison the parentheses contain values of ΔZ^0_T for the reduction of UF_4 by magnesium, calculated according to the data of [6].



Dependence of ΔZ_T and log K on the temperature for the calcium-thermal reduction of UF_4.

Table 2 gives the equations for the changes in the thermal effect ΔH^0_T and free energy of the calcium-thermal reduction of UF_4 for different temperature ranges obtained as a result of the thermodynamic calculation. The figure shows graphically the dependence of the free energy and the logarithm of the equilibrium constant on the temperature for the same reaction. Table 3 gives numerical values of the thermal effect, free energy and the logarithm of the equilibrium constant for characteristic temperatures of the process. Analyzing the date of Table 3 we see that, starting with the boiling point of uranium tetrafluoride (1,417°C) and calcium (1,690°C), the thermal effect of the reaction increases sharply.

A thermodynamic calculation gives a theoretical temperature for the reduction of UF_4 by calcium of 2,100°C. The actual temperature of the process measured with a tungsten-molybdenum thermocouple was found to be 2,000°C, which considerably exceeds the melting point of the slag (1,418°C). The liberated heat is therefore sufficient both for fusion and for overheating the products of smelting and consequently the calcium-thermal process, in constrast to the magnesium-thermal process, does not need preliminary heating of the charge.

The reduction of UF_4 is carried out in open apparatuses since the vapor pressure of calcium at high temperatures is less than that of magnesium.

In constrast to the thermal effect, the free energy and hence the equilibrium constant for the reduction of UF_4 by calcium decrease with increase in temperature. However, their values (see Table 3) indicate the almost complete displacement of the equilibrium of the reaction toward the formation of metallic uranium and calcium fluoride.

The results of the thermodynamic calculation therefore point to the superiority of the calcium-thermal process of reduction of UF_4 over the magnesium-thermal process. In other countries, however, as the reducing metal they use both calcium and magnesium, mainly because the latter is much cheaper.

LITERATURE CITED

1. Gelin, Mogad and Nelson. Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Selected reports of non-Soviet scientists [Russian translation] vol. 7, Moscow, Atomic Energy Press 1959, p 417.
2. Melvanin. Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Selected reports of non-Soviet scientists [Russian Translation] vol. 7. Moscow, Atomic Energy Press 1959. p. 436.
3. Teier. Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Selected reports of non-Soviet scientists [Russian translation] Vol. 6, Moscow, Atomic Energy Press 1959, p. 5.
4. Decrault et al, Transactions of the Second International Conference on the Peaceful Use of Atomic Energy (Geneva, 1958). Selected reports of non-Soviet scientists [Russian translation] Vol. 7, Moscow, Atomic Energy Press 1959, p. 485.
5. Metal Ind., 94, No. 7, 127 (1959).
6. I. M. Dubrovin and A. K. Evseev. "Atomnaya énergiya", 7, No. 4, 379 (1959).
7. O. Kubaschewski, E. Evans, Metallurgical Thermochemistry. London—New York, Pergamon Press, 1958.
8. N. A. Landiya. "Zh. tekhn. fiz", 25, 927 (1951).
9. A. Glassner. The Thermochemical Properties of the Oxides, Fluorides and Chlorides to 2500°K. New York, ANL-5750, 1958.

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.**

NEWS OF SCIENCE AND TECHNOLOGY

TENTH SESSION OF THE LEARNED COUNCIL OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

V. Birgukov

Translated from Atomnaya Énergiya, Vol. 11, No. 3.
pp. 261, September, 1961

The tenth session of the Learned Council of the Joint Institute for Nuclear Research met May 24-27. The scientists who converged on Dubna to participate in the deliverations of the Council were the following outstanding physicists of member nations of the Institute: L. Jánosy (Hungary), S. Titeika (Rumania), V. Votruba (Czechoslovakia), H. Niewodniczański (Poland), A. Konya (Hungary), H. Pose (East Germany), Chang Wen-Yu (China), M. Danysz (Poland), P. Pilika (Albania), N. Sodnom (Mongolia), and many others. The sessions of the Council proceeded under the chairmanship of D. I. Blokhintsev, Director of the Institute, and G. Barwich and E. Dzhakov, Vice-Presidents. The various directors of the laboratories of the Joint Institute, including V. I. Veksler, V. P. Dzhelepov, I. M. Frank, and G. N. Flerov, took part in the deliberations. The members of the Learned Council heard and discussed about twenty reports reflecting the achievements of recent months reported by the laboratories of the Institute.

I. M. Frank, Director of the Neutron Physics Laboratory, told of experimental research underway on the pulsed reactor of the laboratory*, on investigations of the reactor itself, and a detailed study of its characteristics, and also on physical experiments investigating neutron beams. The fundamental trends in physical research are neutron spectrometry and slow-neutron scattering studies of solids and liquids. Frank also rendered an account of some interesting developments in experimental apparatus. In its resolution, the Learned Council took note of the extensive work accomplished by the staff of the Laboratory during the time elapsed since the startup of the reactor, and recommended an expansion of the scope of research work on the reactor, with plans for attracting additional Institutes and guest scientists from member nations, interested in research in the field of solid state physics, semiconductors, and nuclear physics, into the work.

The scientists sitting on the Learned Council heard with deep interest a communication delivered by V. P. Alfimenkov of the Neutron Physics Laboratory on the work of a team of physicists studying the Mossbauer effect in zinc-67.

A review of the problem of the synthesis of transuranium elements with the aid of heavy ions was given by G. N. Flerov, Director of the Nuclear Reactions Laboratory.

Some interesting research work is in progress at the Nuclear Problems Laboratory on design of polarized hydrogen targets. B. S. Neganov of the laboratory staff delivered a communication on the design of a stationary cryogenic machine developed for the purpose, and capable of reaching a temperature of 0.01°K.

M. I. Podgoretskii of the High Energy Laboratory delivered an extensive summary report making available final results on inelastic interactions between 7 Bev pions and 9 Bev protons on the one hand, and neutrons on the other, based on work by an Institute team using the synchrophasotron accelerator at Dubna. The reporter presented data obtained with photographic emulsions and bubble chambers. These results are the most exact ones presently available. An analysis of the data enable physicists of the Institute and other bodies to extract interesting conclusions on π-N- and N-N-interactions and on nucleon structure.

As already reported, a model of an annular synchrocyclotron (phasotron) has been commissioned at the High Energy Laboratory. E. Myaz of the laboratory staff told the members of the Learned Council of experiments conducted on this model.

Two reports were presented to the Learned Council by Institute theoretical physicists Ya. A. Smorodinskii: "The neutrino and astrophysics," and S. S. Gershtein: "Problems in the experimental verification of the universality of weak interactions."

---

*Cf. JAE May 1961, Vol. 10, No. 5, Russian page 437.

The Learned Council confirmed the decision of a panel awarding prizes sponsored by the Joint Institute for 1961 for the best scientific research projects completed at the Joint Institute:

for the discovery of the new particle, the $\tilde{\Sigma}^-$-hyperon, and a series of projects on the study of the properties of strange particles;

for a series of projects on development and design of a cyclotron with a spatially varied magnetic field intensity pattern;

for a cycle of research projects devoted to the physics of weak interactions at high energies.

During the tenth session, panel sessions were also held on the topic of low energies, with reports delivered on scientific research efforts at the Neutron Physics Laboratory and Nuclear Reactions Laboratory. This panel, whose work stimulated much interest among member-nations of the Joint Institute, concurred with the plans for further collaboration in research in the field of low-energy physics.

INTERNATIONAL CONFERENCE ON THEORETICAL ASPECTS OF PHENOMENA OCCURRING AT VERY HIGH ENERGIES

V. S. Barashenkov

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 262-264, September, 1961

About seventy theoretical physicists from various countries, as well as CERN experimental and theoretical physicists, took part in a conference on this topic in June 1961, at Geneva. The basic problem faced by the conference was a review of the present status of the physics of weak interactions, electromagnetic interactions, and strong interactions at high energies, and a discussion of the most promising avenues for future research. Particular attention was given to a discussion of possible experiments that might be run on large electron and proton accelerators. Several other questions relating to the design of new accelerators were also taken up at the conference.

S. Berman and Y. Nilson delivered a review report on weak interactions. Although no basically new findings have been reported in this area since the 1960 Rochester Conference, their report contained many interesting details. Discussion of various interactions involving the neutrino occupied a prominent place in their report, covering the points: neutrino scattering and absorption by electrons, and neutrino absorption by neutrons. A significant portion of the report concerned a discussion of second-order processes in the weak-interaction constant G. In order to obtain finite values for the cross sections of these processes, the Λ-parameter cutoff must be introduced. For example

$$\sigma_{\mu\to e+\gamma} \sim \frac{\alpha G^4 \Lambda^4}{(2\pi)^6} M_\mu .$$

According to some considerations, particularly the fact that no decay of this type has been observed to date, an estimate was obtained:

$$50 \text{ Bev} < \Lambda < 100 \text{ Bev}$$

However, as D. I. Blokhintsev noted in the discussion from the floor, this decay will be a forbidden mode, in general, if B. M. Pontecorvo's hypothesis on the existence of the neutrino in two modes is valid; the estimate adduced for Λ is therefore not entirely convincing.

A report by T. Lee was devoted to a study of effects associated with the possible existence of a vector boson meson W. A meson fitting the description might be detected in an inelastic scattering event of a neutrino on a nucleus of charge Z:

$$\nu + Z \rightarrow W^{+} + \mu^{-} + \begin{cases} Z \text{ (coherent scattering)} \\ Z^{*} \text{ (incoherent scattering).} \end{cases}$$

The coherent scattering cross section is proportional to Z^2, and the cross section for incoherent scattering to $\sim Z$; the proportionality constant is $\sim 10^{-37}$ cm^2 in both cases.

G. Bernardini reported on the status of the neutrino experiment at CERN. At the present time, it is becoming increasingly clear that this daring experiment is bogged down in enormous technical difficulties; some of them remain quite obscure. At the beginning of the conference hundreds of thousands of photographic plates taken in a freon bubble chamber were available; several tens of thousands have already been provided for determining background and developing methods and procedures. So far not one single event has been observed which might be interpreted as a neutrino interaction.

A review report on the present status of electrodynamics was presented by A. Peterman. Splendid agreement between experimental and theoretical data is typical of this branch of physics. At the present time, there is literally not one single experimental fact which has not been reconciled with theory. The further development of theory requires first of all extensive improvement in experimental precision. As Van Hoff noted in his concluding report, deviations from the established laws of quantum electrodynamics due to variations in the photon propagators brought about by strong interactions may be anticipated when sufficient precision is attained in measurements. D. I. Blokhintsev noted that electromagnetic interactions in the region of very high energies will be greatly modified by "weak interactions," which may become "strong" at very high energies ("strong" in the sense of cross-section values).

B. Richter told of some work scheduled for the electron beam-stacking accelerator at Stanford, which will be ready for operation in the very near future. Plans call for detailed investigation of the generation of positrons, μ-and π-mesons; special attention will be given to elastic scattering of electrons on electrons. Theoretical calculations have shown that radiation corrections to the familiar Moller formula may run as high as 10% under certain conditions.

A paper by R. Gatto (Frascati, Italy) dealt with plans for studying electromagnetic phenomena in beams of colliding electrons and positrons. The suggested aim of these experiments is to press the study of processes involving vectorial mesons and peripheral interactions between gamma quanta and photons, in addition to annihilation of electrons and positrons with the formation of gamma photon pairs and various species of mesons and baryons.

Investigations of nucleon-nucleon and nucleon-nucleus interactions occurring at energies > 100 Bev in cosmic rays point to an approximate constancy of total cross sections of strong interactions, in any case in the energy range up to 10^6 Bev. However, it should be noted that errors in the measurements reach very high proportions, and that experimental data do not exclude a very slow increase or decrease in cross sections. Over the entire energy range stretching from several Bev to 10^6 Bev, 80% of all the particles generated are π-mesons; the mean transverse momentum and optimum energy value of particles being generated in the center-of-mass system also remain constant and independent of the energy of the primary particle. The mean number of particles generated varies approximately as the fourth root of the energy of the primary particle. The coefficient of inelasticity for very high energies is about 0.2-0.3. These problems were the subject of a review report presented by D. Perkins.

The results found in cosmic rays were also discussed in reports by Polish physicists M. Miezowics and J. Herjul. The investigations of multiple particle production at very high energies, carried out in Poland, and especially the investigation of open angular distributions with two maxima (the so-called two-humped stars) performed by the Polish physicists led to the conclusion that the principal features of inelastic interactions at very high energies may be accounted for by assuming a dual-center generation of secondary particles.

The attention of the conference was also attracted to a paper by B. M. Pontecorvo and Ya. A. Smorodinskii on the relation between the neutrino and astrophysics. Calculations have demonstrated that available experimental data are not in contradiction with the hypothesis holding that the energy density associated with neutrino and antineutrino fluxes is larger by many orders of magnitudes than the energy density associated with apparent matter throughout the universe.

G. Cocconi and G. von Dardel reported experimental results obtained with the new large CERN accelerator. Data on total cross sections had been published earlier. New results referred primarily to π-p-interactions at 16 Bev and p-p-interactions at 24 Bev. These findings do not differ qualitatively from those obtained at Dubna for π-p-interactions at 7 Bev and p-p-interactions at 9 Bev. In particular, secondary particles in the center-of-mass system have sharply anisotropic angular distributions. It was stressed that the mean transverse momenta of generated particles of different species remain more or less constant independently of the species and energy of the colliding particles. This constancy of transverse momenta is observed over the entire presently accessible range of high energies.

In his report, G. Cocconi also discussed some interesting data on quasielastic p-p-scattering at 24 Bev. During measurements of momentum distributions of protons scattered at very small angles, a maximum which might be interpreted as due to resonance interaction between an intermediate π-meson and a target proton in the 3,3-state was detected, in addition to the usual maximum corresponding to elastic scattering. Some experimental indications point to the existence of two additional maxima corresponding to two successive resonances in π-N-interactions.

A review of statistical theories of inelastic interactions at energies ≤ 30 Bev formed the subject matter of papers by R. Hagedorn and E. Sudershan. It was noted in both reports that the various variants of statistical theories usually employed for calculation of multiple production of particles are suitable for explaining only averaged, global characteristics of inelastic interactions. For example, distributions of stars by multiplicity, probabilities of various channels of inelastic reactions, and mean momenta of particles generated are close to their experimental values. However, everything pertaining to angular distributions is in sharp contradiction to experimental evidence. This is apparently precisely what is invoked, in particular, to explain the pronounced divergence, noted by R. Hagedorn, between theoretical and experimental probabilities of antinucleon formation at various angles in p-p-collisions at 24 Bev. At the limits of applicability in each case, several variants of the statistical theories yield close results and prove to be highly useful for calculating beams and planning experiments.

A special session was devoted to a discussion of diffraction phenomena in strong interactions. The results of calculations of elastic -N-interactions observed at Dubna were reported on in a paper presented by D. I. Blokhintsev. It was shown that the real part of the amplitude of elastic π-N-scattering at high energies (>1 Bev) is much smaller than its imaginary part; the distribution of nuclear matter in the nucleon and the nucleon radius were computed; a new method for analysis of diffraction scattering, which is in some cases preferable to the more familiar optical model, was proposed.

The phenomena of diffractive particle production were discussed in a detailed and exhaustive report by M. Good. It is generally known that the theory of such phenomena was first developed by the Soviet physicists A. I. Akhiezer, I. Ya. Pomeranchuk, and E. L. Feinberg. At the present time, this theory has gained utmost urgency because of the possibility of verifying it experimentally on the large accelerators now available.

G. Solzman delivered a review paper on single-boson peripheral interactions; the results of numerical calculations run on electronic computers at Dubna were reported in the paper by D. I. Blokhintsev. Experimental data now available are not in contradiction to the assumption that the cross section of peripheral π-N- and N-N-collisions is many times in excess of the cross section for central collisions, for which a purely statistical description is applicable. The average numbers of particles produced, their angular and momentum distributions calculated under the assumption of a purely single-meson process, are in excellent agreement with empirical experience, within the limits of experimental error.

The theory of peripheral interactions, which is a natural outgrowth of statistical theory, nevertheless remains a very coarse theory. In particular, the virtuality of a peripheral meson is neglected in the calculations even at high momentum transfers (~ 0.5 Bev). But the theory still fits satisfactorily with experiment in many cases, even when its conditions of applicability are rather poor. It was noted in the discussion that the further progress of this theory depends crucially on amassing fairly accurate experimental data to establish the points at which divergences between theory and experiment occur.

The use of single-meson peripheral interactions to account for quasielastic p-p-scattering detected in 24 Bev experiments was the subject of reports by F. Celleri and E. Ferreri, M. Baker, and B. Feld. Dispersion relations techniques were invoked by the first two authors in calculating the pion-nucleon vertex.

The use of Mandelstam binary dispersion relations to calculate high-energy phenomena was discussed in papers presented by S. Fraucci, S. Fubini and D. Amati, C. Goebel. This trend is one which has come into prominence only recently, and most of the results here are of solely methodological interest; however some very encouraging numerical results have also come to light. For example, angular distributions of π^--mesons scattered elastically on protons at energies of 1.7 and 5 Bev, calculated by Fubini and Amati, are in excellent harmony with experimentally derived values. Despite the crudity of the approximations used in the calculations, this undoubtably represents considerable progress, since all calculations in this field have up to now been carried out solely on the basis of the phenomonological optical model.

A report delivered by H. Leman was devoted to an investigation of the asymptotic properties of the amplitude of elastic scattering. It was shown that the real part of the amplitude is always considerably less at high energies than its imaginary part, although the form of the energy dependence of the real part is dependent on concrete assumptions as to the manner in which the total cross sections tend to their constant limiting values as energy increases. These conclusions are in good agreement with results of computations carried out at Dubna. A considerable portion of Leman's report was given over to an account of the work of V. A. Gribov and I. Ya. Pomeranchuk, who examined the asymptotic behavior of the amplitude of processes involving particles and antiparticles in the ground state. It was particularly emphasized in this paper that no exponential variation in the cross section such as predicted by statistically theory was ever encountered. One should note, however, that all these conclusions are based on a replacement of a virtual meson by a real one. The results of Gribov and Pomeranchuk may conceivably indicate that such a replacement must be resorted to with great caution.

A report by A. Schock presented the parameters of now familiar proton accelerators extrapolated to energy regions of the order of several hundred billion electron volts, and carried out a comparison of possibilities seen in accelerators of the usual type and accelerating systems based on colliding proton beams. The conventional accelerators will serve a broader range of purposes, apparently, from the standpoint of versatile experimentation.

Interesting data on electron accelerators with colliding beams were contained in papers presented by B. Tuszek and B. Richter. Construction of an electron and positron colliding beam accelerator with particle energies of 250 Mev in each beam is nearing completion at Frascati. The presence of one and only one storage ring is a feature of this accelerator. Electrons and positrons are obtained via pair formation of gammas, which are in turn generated by an electron synchrotron.

The expected beam lifetime is ~250 hrs under 10^{-10} mm Hg pressure. At the present time, the storage system has been completely assembled, and the first experiments on injection and storage of particles have been carried out. At Stanford, construction is nearing completion on an electron beam stacking system at 500 Mev. It is expected that the first experiments on elastic scattering of electrons by electrons will be successfully engineered in about one half year.

Stress was laid time and again in the discussions and reports on the enormous importance of improved accuracy of experimental data. This task is one of the most important and most urgent ones in contemporary high-energy physics.

USE OF TRITIUM IN PHYSICAL AND BIOLOGICAL RESEARCH

Ya. M. Varshavskii and A. A. Ogloblin

Translated from Atomnaya Énergiya, Vol. 11, No. 3,
pp. 264-267, September, 1961

A symposium devoted to the use of the radioactive isotop of hydrogen – tritium – in physics, chemistry, and biology, was held in Vienna during May 1961. The symposium was organized by the International Atomic Energy Agency in collaboration with the Joint Commission on Applied Radioactivity of the International Union of Scientific Societies. About 300 delegates from 28 countries and from four international organizations were in attendance. The calling of this symposium on an international scale was completely justified by the already large and consistently expanding interest in tritium. Tritium is the only radioactive isotope of hydrogen – the element which enters into the composition of water and a large variety of other widely distributed and abundant chemical compounds, and also into the composition of almost all substances forming living organisms. This has led to the recent extensive use of tritium as a labeled atom in chemical and biological investigations. It is important to bear in mind that, of the remaining elements of vital importantce to chemistry and biology (i.e., oxygen, nitrogen, and carbon), only carbon has a long-lived isotope, C^{14}, suitable for research ends. However, in contrast to tritium, pure C^{14} is virtually inaccessible and the specific activity of C^{14} preparations is quite low (0.001 curie/mole), while tritium preparations have an activity of several curies per mole. This fact, added to the relatively low cost of tritium and tritiated compounds, lends particular importance to tritium applications.

Since tritium readily displaces ordinary hydrogen in water, it has been possible to us tritium in various branches of geophysics related to flow and movement of water, such as meteorology, oceanology, and hydrology. The study of the problem of the origin of tritium on earth has revealed data of interest on cosmic phenomena.

Research related to the tritium nucleus, known as the triton, has assumed intense interest and led to applications of practical importance. Triton is, following the deuteron, the simplest nuclear system, and the study of its interactions with other nuclei has yielded a series of valuable information on the structure of nuclei and the mechanism of nuclear reactions. The large cross sections of some reactions involving tritons at low energies and the large energy yields of those reactions have made tritium one of the most important thermonuclear fuels.

All aspects of the use of tritium in various fields of natural science reveal many features in common, related to the procedure for introducing tritium into the system being studied, detection of tritium, and consideration of isotope effects due to the considerable difference in the masses of tritium and its light hydrogen counterpart, protium.

The papers delivered at the symposium may be arbitrarily broken down into two groupings, as follows: 1) methods for detecting and recording tritium responses; 2) distribution of tritium in nature and its use in meteorology, oceanology, and hydrology; 3) isotope effects of tritium; 4) techniques for introducing tritium into molecules of chemical compounds; 5) use of tritium for the study of the mechanism underlying chemical reactions and radiation-chemical processes; 6) the use of tritium as a tracer atom in the study of biological processes and the effect of intrinsic radiation emitted by tritium on biological systems.

Methods for Detecting and Recording Tritium

The most precise technique for determining the amount of tritium present consists of measuring tritium activity. Since the beta particles formed as tritium decays are very soft (β-spectrum cutoff at 18 kev, corresponding to a range of 0.5 mg/cm^2), the tritium has to be introduced into the operational volume of the counter in order for activity to be measured. At the present time, two techniques for recording tritium emissions have been employed with success: 1) using a Geiger counter (less frequently a proportional counter) with tritium introduced in the gaseous phase into the counter interior; 2) using a scintillation counter with a tritium-containing liquid scintillator.

The primary advantage of Geiger counters in this application is their high efficiency (close to 100%), although they can be used to measure the activity of only a few specimens (since the entire specimen must be converted to the gaseous phase). In most cases, preliminary enrichment of the specimen with tritium is necessary, introducing some additional error into the measurements. The most important problem in the design of facilities based on Geiger counters is therefore reduction of counter background and finding means of increasing the amount of tritium which might gain access to the counter.

To reduce background, recourse is had to shielding against external radiation and to anticoincidence counters. To reduce background attributable to radioactive contaminations of the counter material proper, the volume of the counter used to record tritium emissions is sometimes separated from the volume of anticoincidence counters in which it nests by a single thin foil. In the best counters reported on at the symposium, the background was 2-3.5 cpm for an effective volume of 1.5-3 liters.

The amount of tritiated gas which can be accommodated in the counter is limited by a deterioration in counter characteristics. An investigation of the quenching properties of various gases has shown that ethylamine yields the best results. When the counter is filled with ethylamine to 3-7 cm Hg and with hydrogen to 40 cm Hg, very few spurious counts are observed; the length of the plateau goes to 500 volts. Good results are also had with ethyl ether, isopropylamine, and isoprene. All of these gases yield excellent counter characterisitics superior to those of ethylene, the standard gas used till now. Another very effective approach has been to supplement internal quenching by means of a quenching gas medium with external quenching with the aid of an electronic circuit, which lengthens the counter dead time to 10^{-3} sec.

Until recently, no success had been met in attempts to obtain satisfactory counter characteristics when a counter was filled with water vapor to a pressure above 20 mm Hg. A paper by R. Ealey and L. Ballard (USA) described a counter having a plateau over 200 volts in length when the counter was filled with water vapor to 350-400 mm Hg, and with a mixture of butane and helium to 350-400 mm Hg.

In contrast to Geiger counters, scintillation counters can be used with many specimens. However, the efficiency in recording tritium radiation is not high for scintillation counters, in fact usually only several percent, attributed to the low energy of decay. This efficiency has been successfully enchanced by the use of special multiplier tubes (J. Sharpe, W. Stanley, Britain).

The composition of the scintillator has an important effect on tritium counting conditions. In working with tritiated water, as D. Beal and J. Whitehead (Britain) have shown, the best mixture is dioxane – naphthalene – water with a water content of 18.6%. Difficulties often arise in work with organic compounds, because these compounds either will not dissolve in the scintillator or because they quench the light flash. This explains why choice of the proper solvent is one of the first problems to be tackled.

On the whole, the symposium evinced a certain tendency to give primacy to the role of Geiger counters over that of scintillation counters. The best facilities using Geiger counters are capable of measuring a tritium concentration of the order of 1 atom of tritium per 10^{16} hydrogen atoms. Scintillation counters remain most convenient for rapid and not particularly precise determination of tritium content.

Problems related to recording of tritium nuclei formed in nuclear reactions were discussed in a paper presented by A. A. Ogloblin (USSR). The technique developed in this case allows for measuring the energy and angular distributions of tritons under conditions practically free from background contributed by other charged particles. The tritons emerging from the target are trapped in stacks of foils situated around the target, and after an exposure tritium content is measured in each foil. The use of this technique has made it possible to investigate the fundamental features of nuclear reactions involving triton formation.

Geophysical Research

Tritium is being widely employed in current geophysical research. Since the half-life of tritium is negligibly small compared to geological time, some constant source of tritium on the earth is required for its continued presence. Until 1954, the primary source for the formation of tritium on the earth was constituted by cosmic rays. During the past 7 years, the amount of tritium has increased some 10-15 times, which is due to tests of thermonuclear weapons. Tritium content in atmospheric precipitation, in air samples, and in surface waters is now decisively dependent on the place, time, and nature of the explosions carried out. This has been very convincingly demonstrated by W. Libby (USA) in a long report read to the symposium. Tritium content in precipitates and water samples is observed to be a linear function of the amount of thermonuclear material exploded.

The thermonuclear origin of atmospheric tritium is strikingly confirmed by the clearly defined correlation between tritium content and Sr^{90} content in precipitates and fallout. Measurements carried out during the years 1958-1960 show that the content of both isotopes in fallout varies with time in an identical manner. In the spring of 1959 a sharp maximum in the content of both isotopes was observed; this is related, in Libby's view, to tests performed during the autumn of 1958. Since the summer of 1959, following the cessation of nuclear weapons testing, tritium and Sr^{90} content in atmospheric precipitation has fallen off sharply.

On the papers devoted to tritium formation in nature unrelated to thermonuclear explosions, one worthy of particular attention, presented by E. Feierman (USA), reported a variation in tritium content in meteorites and in the outer casings of artificial satellites brought back from circumterrestrial orbits. The quantity of tritium measured in meteorites (seven stony meteorites and eight iron meteorites were studied) agrees in general terms with what one would predict from the effect of primary cosmic particles. However, the tritium content found in the material of satellites turned out to be many times higher than that formed in response to bombardment by cosmic rays. The satellite Discoverer-XVII was launched on November 12, 1960 and was in orbit for 50 hours with apogee at 995 km and perigee at 185 km. An intense solar flare appeared on the sun several hours prior to the launching. Tritium content in the satellite material proved to be several thousand times higher than in meteorites. Tritium content in the material of the Discoverer-XVIII satellite, launched on December 7, 1960 into an orbit with similar orbit parameters, proved to 10-20 times less than in the preceding satellite, but still many times larger than in meteorites. One plausible explanation to account for the results obtained is that tritium was formed as a result of nuclear reactions on the surface of the sun during the period of increased solar activity. Some of this tritium reached the earth and was trapped in its vicinity for some time following the flare. Pursuance of these investigations should be of great interest in the study of solar processes.

The hydrological investigations reported on at the symposium refer predominantly to the study of ground water flow in different localities and terrains. The study was carried out by concurrent measurement of natural tritium and introduction of tritium into water reservoirs, in some cases. Experimentation showed that the use of tritium in this type of investigation yielded results in no wise inferior, with respect to precision and accuracy, to those attained by other methods. Investigations in the area of oceanology pertain primarily to the study of the mixing rate of waters.

Isotope Effects of Tritium

Great differences in the masses and zero energies of hydrogen isotopes lead to very noticeable isotope effects in the case of tritium which cannot be ignored when evaluating the results of experiments involving isotope exchange. The more generalized theoretical problems involved in isotope effects were considered by Ya. M. Varshavskii (USSR) and Y. Biegeleisen (USA).

Varshavskii's paper described a method of statistical-thermodynamical calculation of equilibrium isotope effects for various types of hydrogen isotope exchange reactions. Calculated values of tritium distribution coefficients (α) for protium-tritium exchange between different components at 20°C were presented. It was shown that the value of α may reach very high values (above 20) for some systems (e.g., hydride of an alkali metal – hydrocarbon system). The physical fundamentals of the general approach which had made it possible to predict the values of α for isotope exchange in any systems of hydrogen-containg substances were formulated in this paper.

The problem of the relationship between isotope effects for deuterium and tritium was considered in Biegeleisen's paper. The predominant role is attributed to what is known as the primary isotope effect, corresponding to processes accompanying the scission of chemical bonds or major effects due to bond disruption. The secondary effect, much smaller in scope, is due to a change in intermolecular forces. A method for tentative calculation of tritium isotope effects based on data dealing with deuterium isotope effects was laid bare in this paper.

Methods for Introducing Tritium into Molecules

The very simple and convenient method for introducing tritium into molecules of complex organic compounds suggested by K. Wilzbach in 1957 has opened up broad perspectives for the use of tritium as a tracer atom in organic chemistry, biochemistry, and biology. The gist of the Wilzbach method is that the substance to be investigated is placed in an atmosphere of gaseous tritium, the isotope exchange process sets in and protium atoms are replaced by tritium atoms. One essential feature is that in the case of tritium exposure, in contrast to deuterium labeling, exchange takes place not only at the O-H- and N-H-bonds, but also at the C-H- linages. The Wilzbach method has been extended at present to promote tritiation of gaseous, liquid, and even solid compounds. The mechanism of the corresponding isotope exchange reactions is still somewhat obscure, but available data support the view that hydrogen exchange is a radiation-chemical process initiated by tritium-emitted betas.

In his report to the symposium, K. Wilzbach (USA) presented new data on the method which he discovered and which bears his name. The paper laid special emphasis on radiation-chemical side reactions taking place in the system. One typical trait of the method is the nonuniform distribution of tracer throughout the molecule. For example, in the case of toluene, the content of tritium in the ortho position is 16 times the tritium content in the CH_3– group, while the tritium content at the meta- and para- positions is 7 times as great as in the CH_3– group. And in the mandelic acid molecule, tritium concentration in the aromatic ring is 75% of tritium content in the CH(OH)COOH functional group.

Other techniques for tritium-labeling of molecules were also discussed at the symposium, (e.g., exchange in an electrical discharge, exposure to ultraviolet light, etc.). As a rule, the different techniques are distinguished mainly by a preferential labeling of different sites in a molecule. For example, the Wilzbach labeling technique leads to a preparation labeled predominantly in the ring in the case of toluene, whereas toluene labeling under an electric discharge chiefly affects the CH_3– group (H. Ache, West Germany).

Problems involving preferential tritium labeling of iodine-containing compounds were dealt with in a paper by P. Feng (USA). Interacting with tritium gas, iodine is easily replaced by tritium with the formation of selectively tagged compounds.

Labeling of complex organic compounds without the use of tritium gas was the topic treated by two reports. D. Garnett (Australia) told of experimental findings on isotope exchange between T_2O and aromatic hydrocarbons and their derivatives in the presence of platinum catalyst. A typical feature of the isotope exchange reaction with T_2O was the pronounced difference in rate of exchange for various hydrogen atoms on the aromatic ring. The catalytic exchange method has some advantages over the Wilzbach method, since more selectively tagged products can be arrived at through the former method. R. Falter (USA) devoted his paper to isotope exchange between vapors of organic substances and heated uranium tritide.

Several reports touched on the biosynthesis of tritium-labeled biologically active compounds.

Investigations of Mechanisms in Chemical Reactions

D. Barre (USA), in a review paper, took up questions associated with the use of tritium in the radiation chemistry of organic compounds. The origin of hydrogen atoms liberated in radiolysis can be determined in some cases by introduction of tritium as tracer atom, as can the mechanism of interaction between hydrogen gas and organic matter, etc. The data obtained were correlated with data available for deuterium. This comparison resulted in a successful evaluation of the dependence of isotope effects on the mechanism behind the process, and in drawing of inferences on the effect of the intrinsic radiation of tritium on radiolytic and isotope exchange processes in the systems studied.

A. Powell (USA) told of results of an investigation of the Cannizzaro reaction using tritium tracer in the para-positions of benzaldehyde and phenyl benzoate. The principal inference drawn from the research is that the first stage of the Cannizzaro reaction is an intermolecular shift of the hydride ion, rather than an intermolecular displacement of hydrogen. The isotope effect discovered for this reaction is an indication that the stage of proton transfer follows the first stage, rather than running concurrently with the shift of the hydride ion.

D. Beal (Britain) reported on applications for a highly promising double-labeling (H^3 and C^{14}) technique. This method makes it possible to study the amino acid composition of proteins in trace quantities (of the order of micrograms), opening up new opportunities in protein chemistry.

Biological Investigations

Roughly half of all the papers submitted to the symposium dealt with tritium applications in biological research. These may be subdivided under two headings: 1) papers in which radiation effects of tritium on biological systems are investigated; 2) papers dealing with the study of various biological processes with tritium used as tracer atom.

The radiation effects of tritium may have the effect of accelerating hydrogen isotope exchange, with some loss of tracer as a result, and may lead in some instances to appreciable changes in the characteristics of the biological system. Results of a study of tritium beta effects on the growth and activity of ricketsial bodies, influenza virus, intestinal bacilli, the bacterial flora of the cud of large horned cattle, etc. were presented in some papers. A paper by E. Cronkite (USA) dealt with a study of the toxicity of tritiated thymine.

The possibility of employing the beta radiation of tritiated drugs to cure cancer was examined in a paper by D. Marian (Britain). A high-activity (28 curies/mole) preparation was synthesized, and this preparation readily gained access into living cells. The intake of malignant cells was found to be more rapid than that of healthy cells. It is important that assimilation of the preparation by bone marrow cells proceed at a rate of at most only one fifth that of tumor cells. Positive results were indicated from use of this preparation on patients.

Papers devoted to the use of tritium tracer touched on research into the broadest variety of biochemical processes: most of the reports dealt with particular problems. At the same time, several methodological novelties of some interest were reported on. A paper by J. Hampton (USA) demonstrated new opportunities for the simultaneous use of autoradiography and electron microscopy for the study of cell processes in vivo. The method suggested was successfully employed for detailed monitoring of the process of incorporation of tritiated thymine into the nucleus of a DNA cell.

W. Siri (USA) presented his findings from an investigation of isotope exchange in animal organisms. The analysis showed that approximately 98% of the tritium introduced into the organism was incorporated into the body water, and 2% into the tissues.

Many papers were devoted to a study of cell metabolisms using tritiated thymine and cytidine preparations. In particular metabolic studies were made of bone marrow cells (F. Gavosto, Italy; W. Bond, USA), tissue metabolism of thyroid hormones (J. Roche, France), etc.

SEMINAR ON THE USE OF ISOTOPES AND NUCLEAR RADIATIONS IN BLAST FURNACE PRODUCTION

P. L. Gruzin

Translated fromAtomnaya Énergiya, Vol. 11, No. 3,
pp. 268-269, September, 1961

A broad research and development plan for applications of radioactive isotopes and nuclear reactions in the metallurgical industry was started in the USSR in 1948-1949. At the present time, many research projects on the possible applications of isotopes and nuclear radiations are being completed at factories and in Institutes. This has pointed up a need for topical seminars on special problems in metallurgical production.

A seminar on the use of isotopes and nuclear radiations in blast furnace production was held during March 1961 at Dneprodzerzhinsk, under the sponsorship of the Commission of the State Scientific and Engineering Committee of the Russian Soviet Federated Socialist Republic on the integration of isotopes and nuclear radiations into industry, and of the Dzershinskii metallurgical plant. Over 50 scientists and engineers engaged in the development and production engineering of various isotope and radiometric techniques and instruments in blast furnace production took part in the seminar. The most important metallurgical enterprises of the nation (the Dzerzhinskii plants, the Il'ich "Azovstal' " plant, the Stalino (Donets), Krivoi Rog, Novaya Tula, Cherepovets, KMK, YuGOK, etc, plants) were represented at the seminar, along with leading scientific and research Institutes engaged in metallurgical studies (TsNIIChM ferrous metallurgy research institute, the Ukrainian Institute of Metals, the Dneprodzerzhinsk metallurgical institute, the Moscow Engineering and Physics Institute (MIFI), and other). 19 papers and communications on the use of radiation and isotope methods and instrumentation for monitoring, control, and investigation of blast furnace production processes were read to the seminar. The participants benefited from trips to the Dzerzhinskii plant, the Krivoi Rog metallurgical enterprise, and the YuGOK enterprise, where they became acquainted directly at shop level with the substance of the advances based on isotopes and nuclear radiations, and with the process instrumentation of these major plants. All of this was an enormous aid to the seminar participants in carrying out a detailed discussion of the contents of the papers, and singling out the perspectives of further work.

Let us spend some brief time on typical reports made to the seminar, and outstanding remarks by participants.

P. L. Gruzin (Moscow) and A. D. Kutsenko (Dneprodzerzhinsk) gave, in their papers, a general evaluation of the status of work on applications of instruments and nuclear radiations in various branches of metallurgical production, and shed light on the perspectives of further production-line exploitation of the achievements of nuclear physics in metallurgical practice. Attention was drawn to the extensive opportunities for the use of radiation sensors whose functioning is based on the use of β- and γ- and neutron radiation, and various process control systems of metallurgical interest. The applications of neutron sources of radiation for continuous monitoring of high temperatures and moisture of raw materials was discussed in particular. Possibilities for the use of radiometric techniques to monitor the dimensions of hot-rolled product of complex configuration were discussed, as well as the activation analysis method in application to blast-furnace burden, and the method of gamma-neutron probing of the tuyere zone and the shaft of the blast furnace. In the discussions on the papers, it came out that all of these questions are of vital significance to the plans for starting up the world's largest blast furnaces in our country.

A report by I. G. Polovchenko and V. N. Uzlyuk was devoted to a review of research involving tracer and radioisotope studies carried out at the Dzerzhinsk plant in cooperation with the TsNIIChM institute. The reporters limited their treatment in the main to a generalization of data from their own investigations, partially known to the participants of the seminar from published materials. Data on the economic effectiveness of the use of various radiometric techniques and instruments in blast furnace process control were heard with intense interest. It was pointed out in their report that isotopes have been successfully employed to extract valuable data on problems involving control of the blast furnace melting furnace, for improving furnace design, atutomation and correction of operations during a heat, with a resulting increase of 2.5-3% in pig iron melts, a 3-3.5% reduction in fuel costs, and a 5-8% increase in furnace operating life.

Several reports and statements from the floor were devoted to peculiarities in the design of on-off and servoed radiometric level gages for monitoring the level of blast furnace burden, and the results of industrial production tests at the Dzerzhinskii plant. All of the reporters and commenters introduced many valuable suggestions on improving individual components in the existing prototypes. V. I. Afanas'ev and V. G. Smirnov gave a brief characterization of the design of a new model of servoed radiometric burden level gage (URMS-2), developed by TsNIIChM on the basis of industrial tests of the device under production conditions at the Dzerzhinskii plant. The participants at the seminar acknowledged the feasibility and timeliness of the installation of URMS-2 devices at 15 blast furnaces of the NTMZ, Krivoi Rog, KMK, Il'ich, and other metallurgical plants during the 1961-1962 period.

Several reports and comments were devoted to a discussion of radiometric techniques for control of hot spots in the well of blast furnaces (at the Dzerzhinskii, KMK, "Azovstal' ", Il'ich, and NTMZ plants). These techniques have been in use at over 30 furnaces. The method was first tried out in 1950 at the NTMZ plant, and data extracted from the experiment provided a basis for suggestions toward enhancing well durability (increased cooling facilities, use of improved refractories, etc.). Subsequent research work at those plants confirmed the correctness of those suggestions, which have been incorporated in good measure into blast furnace construction practice, with excellent economic returns of a qualitative nature. The method developed for checking hot spots in the blast furnace well has been adopted by other countries.

A. V. Pugachev (Tula) devoted his paper to a discussion of results of industrial testing of a radiometric facility designed to monitor the degree of sintering of sinter cake. V. M. Ivanov pointed out several difficulties standing in the way of adapting this device to production conditions at KMK. N. S. Gogin (NTMZ) noted that the use of the radiometric method for monitoring the degree of sintering of sinter cake under high-temperature operating conditions is of enormous significance.

The seminar also took up the results of a study of the rate of flow of burden materials in blast furnaces (of the Dzerzhinsk "Avozstal' " plants), the perspectives for the use of radiometric methods in quality control of burden (TsNIIChM), and some questions relating to blast furnace production theory where isotope applications are concerned (Dneprodzerzhinsk metallurgical institute). A paper presented by A. S. Golovan' dealt with the perspectives for the development of research on radioisotope applications in enterprises of the Dnepropetrovsk Council of the National Economy.

At the concluding session of the seminar, a resolution was adopted in which the most efficient approaches for implementation of isotope and nuclear radiation techniques in blast furnace production were indicated. The participants of the seminar pointed up the need for a systematic program of topical seminars on applications of radioactive isotopes and nuclear radiations in particular branches of metallurgical industry. We may accordingly rest assured that this first experience in carrying out topical seminars of this nature has been a positive one.

ISOLATION OF TECHNETIUM

A sophisticated process [1] for obtaining kilogram quantities of technetium Te^{99} (weak beta-emitter with a half-life of $2.12 \cdot 10^5$ yrs) from spent nuclear fuel has been developed at ORNL. To date, most of the technetium was extracted, along with uranium in UF_6 obtained by fluorination of uranium trioxide, from spent uranium. Anion exchange techniques have been successfully employed to extract technetium more efficiently. The technetium from a concentrate containing negligible amounts of fission fragments and ions of aluminum, calcium, sodium, uranium, and fluorine, was extracted with 2,4-dimethylpyridine. The organic phase was distilled off and Tc^{99} was collected in the residue with some amounts of impurities from the concentrate and with the dimethylpyridine. This product was extracted to remove organic impurities, using an extractant mixture of tri-n-octylamine in benzene. Pure technetium was isolated in the form of ammonium pertechnate by repeated crystallizations from a solution of ammonium nitrate. This salt was reduced by contacting with hydrogen at 400-500°C, and a metallic powder containing over 99.9% Tc^{99} was obtained. This improvement in technology brought the cost of technetium down from 1600-2800 dollars/gram to 100 dollars/gram. At the present time, the monthly output at a pilot plant has increased a thousandfold and amounts to about 400 g of metal, but may be increased further to meet mounting demands. The pertechnate ion—a powerful inhibitor of corrosive attack by water on iron and steel—is being eyed as a potential anticorrosion medium for boiling water reactors. Tc^{99} has the added distinction of being an excellent superconductor (the transition temperature of 11.2°K is the lowest [2] for the elements). Its melting point is ~2200°C [3]. Most of the fundamental properties of this element have yet to be studied, although some considerations on its possible alloys are discussed in the literature[4].

LITERATURE CITED

1. Chem. Engng. News, 39, No. 9, 52 (1961).
2. A. N. Murin et al. Uspekhi khimii. 30, 249 (1961).
3. E. Anderson et al. Nature, No. 1883, 48 (1960).
4. N. V. Ageev et al. Doklady akad. nauk SSSR, 129, 555 (1959).

REFLECTING BETA THICKNESS GAGE MONITORS SETTLED COAL DUST IN MINES (ROTOP-3A GAGE)

The use of the principle of the reflecting thickness gage [1] has aided in the development of a device for sensing the amount of dust precipitated on the surfaces of mine workings, an advance of no mean significance for miners' safety conditions.

The radiation -actuated reflecting thickness gage for monitoring coal dust, the ROTOP-3 [2,3], developed by the State Makeev Scientific Research Institute of Work Safety in the Mining Industy jointly with the Khar'kov Mine Surveying Instruments Manufacturing Plant (KhZMI), has passed industrial tests with flying colors and has been recommended for routine use.

In 1960, KhZMI engineered industrial production of a modernized version of the ROTOP-3A thickness gage. The functioning of this instrument is based on changes in the intensity of reflected beta radiation by the isotope Tl^{204} as a function of the thickness of a layer of monitored coal dust lying on tope of a rock substrate. The presence of an appreciable difference in atomic numbers (of the order of 7-8 units) between the coal, which is the exposed material in the given case, and the host rock which is the bulk material forming the substrate, provides the necessary conditions for successful functioning of the radiation thickness gage.

The gage (Fig. 1,2) consists of a planar ionization chamber with a stretched aluminum foil and polyethylene film covering the entrance window a compartment for an annular radiation source surrounding the ion chamber, a d-c electrical amplifier, and a microammeter calibrated in units of surface concentration of dust.

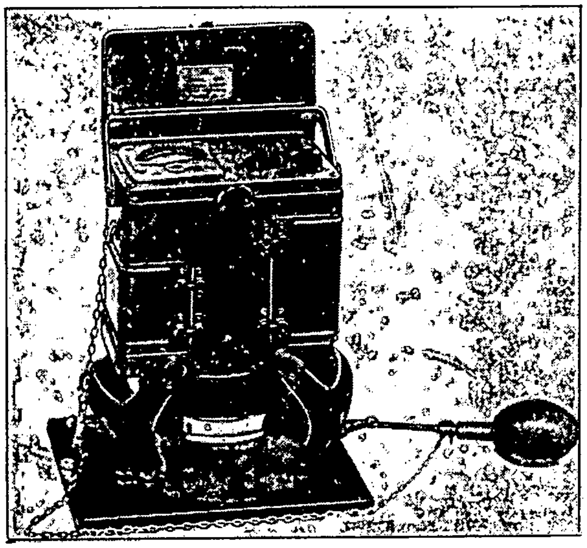


Fig. 1. General view of the ROTOP-3A

The annular emitter is made up of 29 point sources of Tl^{204} built up on the base of a standard BI source. The total activity over the emitter surface is 5 microcuries. The d-c amplifier is based on a 2E2P electrometer tube included in a balanced bridge circuit. The electrical compensation of the initial current provided for in the circuit makes it possible to amplify and measure only that part of the ionization current which is due to reflection from a coal-dust layer.

The redesigning of the instrument for transient measurements under the natural conditions prevailing in coal pits, with a rather uneven and rough contouring of the rock substrate, necessitated considerable changes from the more familiar coating-layer thickness gages, and added to the difficulties hampering measurements. The principal difficulty is due to the impossibility of constantly compensating initial current, since the contouring of the surface to be monitored is different for any run of measurements.

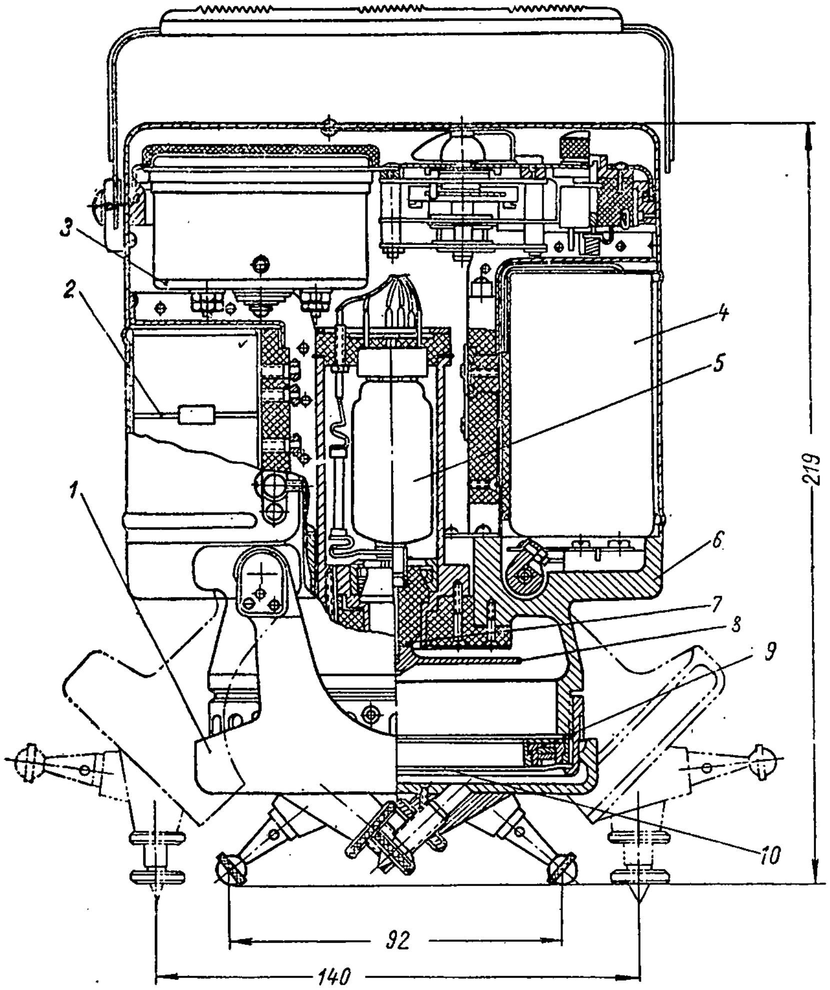


Fig. 2. Cross-sectional view of the ROTOP-3A thickness gage: 1) shielding screen; 2,4) supply compartments; 3) micorammeter; 5) electrometer tube; 6) ion chamber housing; 7) amber insulator; 8) grid electrode; 9) radiation source; 10) diaphragm for entrance window.

The redesigning of the instrument for transient measurements under the natural conditions prevailing in coal pits, with a rather uneven and rough contouring of the rock substrate, necessitated considerable changes from the more familiar coating-layer thickness gages, and added to the difficulties hampering measurements. The principal difficulty is due to the impossibility of constantly compensating initial current, since the contouring of the surface to be monitored is different for any run of measurements.

A procedure of measurements was developed to eliminate any effects of mine topography on the results, and functions as follows. The gage is placed on a rock substrate covered with coal dust. All of the current due to reflection of radiation is compensated by feeding in compensating voltage, and the gage is reset to zero. A rubber bulb is then squeezed to blow away an area of dust from underneath the instrument, and the compensation voltage proves insufficient in view of the increased reflection. The circuit then balances out at a level proportional to the amount of dust removed, and this is recorded by the output device. When compensating voltage is used in this manner, some constant contribution from the voltage is always placed across the control grid of the measuring part of a 2E2P double tetrode to drive the grid bias to a value equal to the bias voltage across a second control grid, i.e., actually to reset the amplifier. The remaining portion of the voltage, whose function is to directly compensate ionization current, varies in different measurements and is higher or lower depending on the surface topography of the section of mine being monitored. The effect of surface topography on instrument readings is thereby virtually eliminated, enhancing the use of the gage as a portable instrument.

The measurement range of the instrument runs from 0 to 70 g/m^2 with a sensitivity of 1 g/m^2. Within these limits, the thickness of a coal-dust coating is far removed from what is known as infinite thickness, so that the instrument scale is linear. For the same reason, any unevenness in dust distribution is without effect on instrument readings within an effective surface area range of $\sim$150 cm^2. The error in the measurements does not exceed 10 % of measured value over the range 10-70 g/m^2. The instrument weighs 3.2 kg. Mercuric oxide batteries and wafer cells are used as power supplies. The instrument is operated by a single operator. The leaktightness of the radiation sources and the comparatively high hardness of the radiation from the isotope selected for the job (E_{max} = 0.765 Mev), as well as the presence of shielding "jaw" hinges shutting off the emitter when in "off" position, fully guarantee radiation safety of the instrument in conformity with the latest public health rules.

Experience in the use of the gage has demonstrated the efficiency of ROTOP-3A gages in rendering serious assistance while safeguarding mine safety conditions for the benefit of miners.

LITERATURE CITED

1. E. Clarke, S. Carlin, W. Barbour. Electr. Engng., 70, No. 1, 35 (1951).
2. F. E. Krigman et al. Patent No. 113576, 1958.
3. Ya. N. Fortel'meister et al. Ugol', No. 1, 48 (1959).

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.**

Brief Communications

Poland. In line with the decision adopted by the X session of the Learned Council of the Joint Institute for Nuclear Research, a conference on cyclotron-based scientific research was held June 5 to 10, 1961, at the Institute of Nuclear Physics at Krakow. Reports from physics institutes of member nations of the Joint Institute for Nuclear Research were presented to the conference. The agenda of the conference included an exchange of experiences on the performance and further improvement of the U-120 model cyclotron, specimens of which are being used in many institutes of member nations of the Joint Institute, and time was set aside for a discussion of the results of physics experiments carried out on accelerators, and trends in future research.

Participants learned from the papers presented that a stable mode of acceleration had been achieved by the time of the conference on all U-120 cyclotrons in use, and that experimental researches are being undertaken on a broad scale. Possibilities for expanding the range of accelerated particles, increasing the limiting energy, and monochromatizing beams of accelerated ions were also discussed.

It should be noted that despite individual technological flaws which came to light in the process of testing and adjustment, the U-120-1 cyclotrons developed and fabricated by the Institute of Electrophysical Equipment (USSR) have come in for high praise at the conference.

A wealth of experimental material dealing with scattering on the nuclei of various particles has been amassed in recent years. Papers were read to the conference on measurements of spectra and angular distributions of neutrons and charged particles in reactions of types (d,n); (d,t); (α,n); (α,t), etc. The discussion demonstrated the need for further research efforts in these areas, and the urgency of obtaining intense beams of polarized protons on the cyclotron.

In experiments on investigation of gamma radiation appearing in response to bombardment of some nuclei by protons, deuterons, and heavy ions, a certain amount of interest has centered on the study of cascade gamma transitions in (α,γ) reactions, and on experiments probing into coulombic excitation of levels in nuclei.

Much attention focused on problems of technique, particularly semiconductor detectors for charged particles.

The silicon detectors developed and manufactured at the Nuclear Research Institute (of Czechoslovakia) have excellent linearity into the 12 Mev proton energy range, and an energy resolution not inferior to 0.6%. Laboratories equipped with these silicon detectors could simplify their experimental methods appreciably and effect an increase in the accuracy of their measurements.

The last session also discussed the problem of improving avenues of scientific information exchange between the institutes of the various member-nations of the Joint Institute.

BIBLIOGRAPHY

NEW LITERATURE

Books and Symposia

Translated from Atomnaya Energiya, Vol. 11, No. 3,
pp. 287-294, September, 1961

J. Bowen, E. Neisters. Upravlenie yadernymi reaktorami: a translation of Nuclear Reactor Control published in Britain. Moscow, Gosatomizdat, 1961. 96 pages, 30 kopeks.

The book reviews the basic parameters of the control system of gas-cooled uranium-graphite reactors. The effect of changes in reactivity and speed of coolant flow on reactor performance in different operating modes is described, and a method for studying transients by analog simulation is presented. Specifications for control components and loops are given.

The concluding chapter contains a concise description of instruments for measuring neutron flux.

The book is written for scientific and engineering personnel and technicians engaged in the design and operation of nuclear reactors, and for students majoring in nuclear engineering.

P. Margen. Vybor optimal'nykh variantov v reaktorostroenii Abridged translation from the English. [Optimization of reactor design] Moscow, Gosatomizdat, 1961. 100 pages, 40 kopeks.

This book is devoted to the timely question of the economics of nuclear electric power generating stations, to the optimization of power station parameters on the basis of an engineering economics analysis. The objects of analysis in this book are the reactor core, heat transfer and friction, and the thermodynamic cycle, which are approached in the context of a power station built around a gas-cooled reactor using heavy water moderator. The book contains six chapters. The first chapter outlines in popular style the procedure for the engineering costs analysis of the conductor carrying the current. Subsequent chapters provide the fundamental relationships for physical and thermal core calculations and for calculating the thermodynamic cycle of the station.

A procedure is considered for optimizing core parameters and heat transfer parameters in a physical analysis, and some considerations on the proper choice of thermodynamic cycle for a nuclear power station are outlined in brief.

The appendices present formulae and tables needed for calculating optimum parameters for a nuclear power station.

The book is written for nuclear power specialists engaged both in reactor core calculations and in the design of power engineering equipment, and for graduate students specializing in nuclear power engineering.

V. L. Shashkin. Metody analiza estestvennykh radioaktivnykh elementov. Moscow, Gosatomizdat, 1961. 152 pages, 47 kopeks. [Methods of analysis of natural radioelements].

This book provides a review of radiometric and nucleonic methods in the analysis of elements in the uranium, radium, and actinium-uranium series in natural formations and in products of uraniferous and thoriferous ore processing. Characteristics of the radioactive properties of natural radioactive elements are given. Methods for the measurement of radioactive radiations are described, and techniques of analysis based solely on measurements of radioactive radiations are outlined.

Methods for determination of uranium, thorium, protactinium, actinium, and polonium are presented, in addition to the emanation methods of such vital importance in the determination of radium and radon isotopes. The principles of complex radiochemical analysis are elucidated. The list of useful literature references appended includes 126 titles.

The book is written for radiochemists and physicists working in the field of analysis of natural radioactive elements. It may also prove useful to students majoring in those topics.

I. NUCLEAR POWER PHYSICS

NEUTRON AND REACTOR PHYSICS. PHYSICS OF HOT PLASMAS AND CONTROLLED FUSION. PHYSICS OF ACCELERATION OF CHARGE PARTICLES

Doklady akad. nauk SSSR, 137, No. 4 (1961)

B. N. Gershman 822-25. On some features of transverse propagation of microwaves in a magnetoactive plasma.

Zhur. tekhn. fiz., XXXI, No. 6 (1961)

Ya. B. Fainberg et al., 633-39. Note on the nature of instabilities in interactions between charged-particle beams and a plasma.

V. S. Imshennik, Yu. I. Morozov, 640-49. Analysis of instability of a beam of charged particles in an electron plasma.

M. D. Gabovich, I. M. Mitropan, 676-79. Observation of hydromagnetic oscillations in the plasma of a pulsed electrodeless discharge.

Zhur. eksptl. i. teoret. fiz., 40, No. 5 (1961)

A. I. Morozov, L. Solov'ev, 1316-24. Kinetic examination of some plasma equilibrium configurations.

P. S. Zyryanov, 1358-56. Quantum theory of acoustic oscillations of an electron-ion plasma in a magnetic field.

Yu. N. Dnestrovskii, D. P. Kostomarov, 1404-10. On the dispersion equation for an ordinary wave propagating in a plasma at right angles to the externally applied magnetic field.

M. T. Zhumartbaer, 1434-39. On the stability of magnetic tangential discontinuities in relativistic hydrodynamics.

Izvestiya akad. nauk SSSR, seriya fiz., 25, No. 4 (1961)

A. K. Trofimov, 460-61 Luminescence of lanthanides in thorium oxide.

B. S. Grebenskii et al., 500-503. On enhancing the efficiency of slow-neutron scintillation detectors.

G. V. Gorshkov et al., 504-505. A disperse-phase fast-neutron detector.

Pribory i tekhnika eksp., No. 2 (1961)

S. Ya. Nikitin, 5-13. Modem techniques in processing bubble chamber plates.

Yu. M. Khirnyi, L. N. Kochemasov, 14-19. Injector for negative hydrogen ions.

O. D. Kovrigin et al., 19-25. A double-focusing large beta-ray spectrometer.

V. N. Lukashev, 26-34. Analysis of electron trajectories in an axial beta-ray spectrometer with centrally placed source.

V. F. Litvin, 33-34. Double focusing over a broad energy range with the aid of sectored homogeneous magnetic fields.

A. I. Veretennikov et al., 42-46. Gamma-ray spectrometer uses organic scintillator with time sampling of gamma radiation.

M. I. Daion et al., 47-52. Spark-counter telescope in a magnetic field measures pulses of fast charged particles.

A. M. Ratner, I. A. Rom-Krichevskaya, 53-62. Note on the theory of energy resolution in scintillation counters.

A. E. Voronkov et al., 63-68. New instrument automatically scans nuclear emulsions by the TV raster method. I. Servo system.

E. Fenyes et al., 68-72. Semiautomatic measuring instrument for processing bubble chamber plates and Wilson chamber plates.

V. I. Strizhak, N. S. Nazarov, 72-75. Neutron generators.

V. N. Bochkarev, V. V. Nefedov, 80-81. Scintillation detector for separately recording heavy and light ionized particles.

N. A. Vitovskii et al., 82-83. Silicon n-p-counters for heavy charged particles operate without supply sources.

Amer. J. Phys., 29, No. 4 (1961)

J. Solbrig, 257-61. Doppler effect in neutron resonance absorption.

Amer. J. Phys., 29, No. 5 (1961)

C. Ananiades, J. Dewdney, 329. Alpha-particle semiconductor detector.

Energia Nucleare, 8, No. 4 (1961)

C. Galotto et al., 243-46. Design of photoneutron source and its calibration.

Nucl. Energy, No. 156 (1961)

- -, 199-200. Methods and equipment for training courses in nuclear physics.

Nucl. Instrum. and Methods, 10, No. 4 (1961)

D. Caro, J. Rouse, 249-58. The variable-energy cyclotron at Melbourne University.
G. Wilson, 259-62. Phase variations near the center of a cyclotron.
G. Kelley et al., 163-71. Source of high constant ion currents.
I. Myers, H. Larson, 281-88. Precision instruments for monitoring beams in electron accelerators.
R. Glover et al., 343-47. Telescopic counter system for fast-neutron experiments.
H. Grassler, K. Tesch, 353-55. Detection efficiency of a plastic scintillator for neutrons in the 1-14 Mev energy range.

Nuovo Cimento, XIX, No. 6 (1961)

H. Carvalho et al., 1131-41. Angular distribution of uranium photofission fragments.

Techn, Digest, III, No. 6 (1961)

- -, 48-50. Microscope for measuring nuclear particle tracks.

II. NUCLEAR POWER ENGINEERING

NUCLEAR REACTOR THEORY AND CALCULATIONS. REACTOR DESIGN. PERFORMANCE OF NUCLEAR REACTORS AND POWER STATIONS

Atompraxis, 7, No.4 (1961)

H. Bildstein, P. Koss, 126-28. The ASTRA reactor fuel elements.
W. Cawley, 131-35. Problems in load transfer of fuel elements.
H. Benzler, 135-41. Power engineering problems in a gas-cooled reactor.
H. Schudi, 142-46. Approximate calculation of optimal pitch in uranium lattices.

Atompraxis, 7, No. 5 (1961)

J. Stohr, 189-93. Fuel elements for graphite-moderated reactors using pressurized-CO_2 coolant.

Energia Nucleare, 8, No. 4 (1961)

G. Zorzoli, 255-60. Theoretical investigations and experimental results obtained for critical assemblies with moderator of organic fluid and water.
F. Castelli, 161-69. The Enrico Fermi nuclear power station.

I. Bachmann, 270-75. Experience of the first stages of operation of the Yankee Atomic reactor.

M. Covino, R. Lepore, 176-87. Details of the planning and development of the Garigliano nuclear power station.

Jaderná Energie, 7, No. 5 (1961)

- -, 158-66. Physics of heavy-water reactor lattices.

Kernenergie, 4, No. 4 (1961)

W. Fratzscher, R. Nitsch, 269-75. Evaluation of heterogeneous reactors from the standpoint of thermodynamic potential.

A. Sydow, 276-84. The UNIMAR analog computer in nucleonics programs.

Kernenergie, 4, No. 5 (1961)

H. Hessel, 384-90. Note on the problem of constant burnup in pressurized-water reactors.

Nucl. Energy, No. 156 (1961)

- -, 201 The NESTOR neutron source reactor

- -, 202-204. The Sizewell nuclear power station.

B. Link,R. Clark, 205-209. Model of an experimental reactor for studying heat transfer.

- -, 209. Reloading mechanism of the AGR reactor.

Ncul. Engn., 6 No. 61 (1961)

- - , 239-52. Maritime heavy water reactor with steam cooling system.

Nucl. Power, 6, No. 62 (1961)

J. Collier, 61-66. Fuel burnup in liquid-cooled reactors. 1.

- -, 70. Thermocuples for elevated temperatures.

S. Hollands, 78-79. The export policy of the USA in the nuclear power field.

Nucl. Sci. and Engng., 9, No. 4 (1961)

C. Orth, 417-20. Diffusion of lanthanides and actinides from graphite at high temperatures.

G. Smith et al., 421-29. Experimental investigation of resonance capture of neutrons by U^{238} in UO_2 fuel elements.

D. Parks, 430-41. Effect of motion of atoms on thermalization of neutrons.

G. Boyd, et al., 442-54. Flow transients in a multiloop reactor system.

E. Hellstrand, J. Weitman, 507-18. The resonance integral for thorium in the form of metallic rods.

Nucleonics, 19, No. 6 (1961)

D. Keller, 45-48. Calculating fuel burnup for stainless-clad UO_2.

F. Boni, P. Otten, 58-61. Steam generators for the Enrico Fermi power station and the Hallam nuclear power station.

A. DeStordeur, 74 ff. Drag coefficients for remote-controlled components between fuel elements.

Nucleonik, 3, No. 2 (1961)

P. Weissglas, 54-57. Theoretical calculation of effect of lattice parameters on destruction of coolant channels in a natural-uranium burner with heavy water moderator and coolant.

E. Kern, A. Schatz, 61-76. Diffusion of radioactive substances in solids of grainy structure.

W. Hage, L. Cameron, 76-80. Iterative solution of a system of kinetic reactor equations for a rod drop experiment.

E. Eberth, W. Oldekop, 80-83. Two-group diffusion theory for a finite heterogeneous pebble-bed reactor.

P. Ahlstrom, P. Weissglas, 83-85. Spatial variations in concentration of isotopes in a fuel element rod.

Reactor Sci. and Tech., 14, No. 1 (1961)

W. Blackburn, 1-8. Deflection of fuel elements in assembly due to creep.

M. Reier, J. De Juren, 18-24. Diffusion length of thermal neutrons in water over the 23-244°C temperature range.

L. Blake, 31-48. Extensive fuel burnup in fast reactors.

R. Bertrand, 49-50. Determination of Pu^{239} content in a specimen of spent natural uranium, with the aid of an alpha spectrometer.

D. Popplewell, 50-51. Specific α-activity and half-life of U^{233}.

J. Adam, M. Rogers, 51-52. Use of x-ray diffraction in the study of fission-fragment damage to uranium carbide and uranium nitride.

III. NUCLEAR FUEL AND MATERIALS

NUCLEAR GEOLOGY AND PRIMARY ORE TECHNOLOGY. NUCLEAR METALLURGY AND SECONDARY ORE TECHNOLOGY. CHEMISTRY OF NUCLEAR MATERIALS.

Doklady akad. nauk SSSR, 137, No. 3 (1961)

Yu. B. Paderno, G. V. Samsonov, 646-47. Electrical properties of hexaborides of alkali and rare-earth metals and thorium.

Zhur. neorgan. khim., 6, No. 4 (1961)

O. L. Kabanova, 786-89. Complexing of plutonium (V) and EDTA.

I. I. Chernyaev et al., 790-98. On the complex nature of uranyl peroxide compounds.

A. V. Nikolaev, S. M. Shubina, 799-803. Nature of the linkage in complexes of uranyl nitrate and butylphosphate compounds, from IR absorption spectra.

O. E. Zvyagintsev, L. G. Khromenkov, 874-82. On complexes between thorium and tartaric acid.

Chung Huang-Bang, P. I. Fedorov, 971-76. The ternary system thorium sulfate—sodium sulfate—water.

G. A. Polonnikova, L. V. Utkina, 1001-1003. On ammonium uranyl sesquicarbonate.

Zhur. fiz. khim., 35, No. 3 (1961)

L. M. Kovba et al., 563-68. Study of the crystalline structure of uranates. I. Uranates containing tetragonal layers of $(UO_2)O_2$.

D. A. Knyazev, 612-19. Calculating separation coefficients of isotopes in ion exchange.

Zavod. lab., 27, No. 5 (1961)

V. B. Spivakovskii et al., 390-91. Determination of traces of uranium in rocks and natural waters.

Radiokhimiya, 3, No. 2 (1961)

V. B. Shevchenko, V. S. Shmidt, 121-28. Extraction of ruthenium and several other fission products by tri-n-octylamine from nitrate solutions.

V. B. Shevchenko et al., 129-36. Extraction of uranium (VI) and (IV) from chloride solutions by the diisoamyl ether of methylphosphonic acid.

S. Mints, A. Ugnevskaya, 137-43. Effect of salting-out agents on extraction of uranyl nitrate by cyclohexane.

I. E. Starik et al., 151-54. Study of the state of protactinium in aqueous solution. IV. Ion exchange method.

V. I. Grebenshchikova, Yu. P. Davydov, 155-64. Study of the state of Pu(IV) in dilute solutions of nitric acid.

V. I. Grebenshchikova, Yu. P. Davydov, 165-72. Adsorption of Pu(IV) on a glass surface.

V. M. Vdovenko et al., 174-80. Vapor pressure above ether solutions of uranyl nitrate.

P. N. Palei et al., 181-86. Express extraction-photometric determination of uranium using arsenazo III reagent.

V. M. Solntsev, Yu. M. Tolmachev, 187-94. Dissolution reaction of U_3O_8 in sulfuric acid. I. On the kinetics of some reactions with powders.

J. Maly et al., 195-98. Reaction of plutonium dioxide with ammonium hydrogen fluoride in the absence of water.

K. K. Aglintsev, 237-39. Determination of effective age of fission fragments.

V. F. Luk'yanov et al., 239-40. Analytic chemistry of thorium, III. Photometric determination of thorium using arsenazo III in natural materials.

Fizika metallov i metallovedenie, 11, No. 3 (1961)

V. N. Strekalovskii et al., 400-403. Phase transformations in reduction and oxidation processes of uranium oxides.

Atompraxis, 7, No. 4 (1961)

J. Robertson, 121-26. UO_2 fuel elements.

B. Baines, 128-31. High-density graphite.

Canad. Mining and Metallurg. Bull., 53, No. 583 (1960) (1961)

W. Evans, 893-900. Metallurgy of highly reactive materials.

Kernenergie, 4, No. 5 (1961)

K. Helbig, 291-92. Determination of error in absolute activity measurements of specimens by the coincidence method.

Kernenergie, 4, No. 5 (1961)

J. Fialkowski, R. Plejewski, 391-94. Spectrographic analysis of radioactive slurries.

Mining and Chem. Engn. Rev., 53, No. 6 (1961)

- -, 57-59, Processing of uranium ores.

Nucl. Energy, No. 156 (1961)

M. McQuillan, T. Farthing, 195-97. Beryllium.

O. Joklik, 211-20. Radiation polymerization of methylmethacrylate.

Nucl. Power, 6, No. 62 (1961)

G. Llewelyn, R. Allardice, 71-76. Experience in processing enriched fueld elements.

O. Plail, 81-82. Methods of irradiating fissile materials. 6.

Nucl. Sci. and Engng., 9, No. 4 (1961)

F. Sicilio et al., 455-61. Decontamination of irradiated tributyl phosphate by distillation in a kerosene-type solvent.

J. Keyes, A. Krakoviak, 462-74. Niconel fatigue at 768° C due to high-frequency temperature oscillations.

G. Seaborg, 475-87. The transuranium elements.

T. Gens, 488-94. What's new in the processing of uranium-zirconium alloy fuel.

J. Williams, C. Huffine, 500-506. Electrolysis of yttrium metal in the solid state.

Nucleonics, 19, No. 6 (1961)

D. Worlton, 80-82. Ultrasonic testing of uranium slugs.

J. Bates, 83-85. Improving high-temperature thermal conductivity.

IV. NUCLEAR RADIATION SHIELDING

RADIOBIOLOGY AND RADIATION HYGIENE. SHIELDING THEORY AND TECHNIQUES. INSTRUMENTATION

Agrobiologiya, No. 2 (1961)

I. M. Vasil'ev, 259-69. Effect of ionizing radiations on plants.

Byul. Kirgiz. nauchno-issled. inst. zemledeliya, No. 5 (1960)

Ta. A. Ivanov, B. N. Kulikov, 43-46. Effect of irradiation of seeds by radioactive cobalt on the growth, development, and crop yield of wheat and barley.

Zhur. Vsesoyuz. khim. ob-va im. Mendelleeva, 6, No. 2 (1961)

A. A. Kastal'skii, 193-99. Decontamination of sewage waters containing radioactive materials.

Izvestiya vyssn. ucheb. zaved. Lesnoi zhur., No. 1 (1961)

A. D. Tarabarin, 37-39. Uptake of P^{32} by mycorrhizic and nonmycorrhizic oaklets in relation to preliminary phosphate treatment.

Izmerit. tekhnika, No. 4 (1961)

M. R. Yudin, O. A. Filippov, 37-42. Tissue-equivalent fast-neutron dosimeter.
V. S. Merkulov, 61-63. Soviet radioisotope-based instrumentation.

Pribory i tekhnika eksper., No. 2 (1961)

M. Ya. Balats et al., 171. Fabrication of plastic scintillators by the press method.

Radiobiologiya, 1, No. 1 (1961)

L. P. Breslavets et al., 128-34. Changes in pollen grains in rye plants exposed to continuous gamma bombardment.
N. M. Berezina, V. A. Yazykova, 135-38. Significance of disturbance to metabolic reactions in radiation damage to seeds (of the corn plant).
G. V. Radzievskii, 141-48. Dosimetry for external alpha radiation.

Radiokhimiya, 3, No. 2 (1961)

Yu. A. Kototov et al., 199-206. Sorption of long-lived fission products by soils and clayey minerals.

Atompraxis, 7, No. 5 (1961)

J. Baarli, K. Madshus, 167-70. Analysis of background radiation in the 0.08-1.7 Mev range measured by a scintillation counter.
R. Tzschaschel, 170-72. Gamma-spectrometric investigation of fallout specimens by the gray wedge method.
H. Munzel, M. Hollstein, 177-78. Effect of shape of loop on the counting characteristics of a methane flow-type counter.
H. Scharpenseel, 178-81. Effect of several material parameters on measuring efficiency in liquid scintillation spectrometry.

Energia Nucl., 8, No. 4 (1961)

A. Persano et al., 287-94. Calculating safety factors and radiological shielding for nuclear power stations.

Health Phys. 5, Nos. 1-2 (1961)

- -, 1-19, Suggested rules for radiation shielding.

E. Wagner, G. Hurst, 20-26. GM gamma dosimeter with low neutron sensitivity.

G. Brownell et al., 27-36. Large plastic scintillators for radioactivity measurements.

P. Harris, 37-44. Irradiation dose determination in an accident due to criticality at the Los Alamos laboratories in 1958.

M. Randloph et al., 24-29. Decay of polonium-beryllium fast-neutron sources.

E. Ray, S. Hammond, 50-56. Use of alpha-pulse amplitude analyzer in dosimetric monitoring of surroundings.

E. Gupton et al., 57-62. Use of flat film badge at ORNL in criticality accidents.

A. Broido, J. Teresi, 63-69. Study of hazard associated with radioactive fallout. I. Determination of gamma and beta dosage.

D. Gardiner, K. Cowser, 70-78. Removal of radioisotopes from low-activity industrial wastes.

P. Zigman, J. Mackin, 79-84. Premature decay of fission product mixtures. II. Rates of liberation of gamma-energy and ionization in response to fissioning of U^{235} by thermal neutrons.

Health Phys., Nos. 3-4 (1961)

W. Lacy, 228-32. Some problems in deep-pit disposal of radioactive wastes.

H. Larson, 233-35. Pocket dosimeter counter.

C. Bernard et al., 236-43. Silver metaphosphate glass for x-ray measurements in fields of neutron and gamma radiation.

E. Tochilin, R. Golden, 244-249. Investigation of relative sensitivity of photographic emulsions to beta and gamma radiation.

L. Stephens et al., 267-74. Radioactive fallout and natural background radiation in the Sna Francisco Bay area.

J. Teresi, C. Newcombe, 275-88. Calculation of maximum tolerance concentrations of radiactive fallout in water and air.

D. Summers, M. Gaske, 289-92. Maximum tolerable activity of fission products in air and water.

M. Rankin, 293-98. Air alpha activity badge.

F. Bradley, 298-301. Use of electrometer with vibrating-reed sensor as alpha counter.

B. Wheatley, 301-302. Integrating dosimeter with ionization chamber.

E. Geiger et al., 302-304. Simplified method for alpha-emitter autoradiography.

H. Wyker, 309-11. Maximum tolerable concentration of nonidentified radioisotopes in water.

R. Rosen, 311. Method for evaporating water fallout samples.

Jaderná Energie, 7, No. 5 (1961)

V. Stach, 146-50. Safety factors for overheating in fuel elements.

Kernenergie, 4, No. 4 (1961)

R. Reichel, 285-90. Study of de-excitation time in liquid organic scintillators.

Nucl. Power, 6, No. 62 (1961)

D. Brocardo, 67-69. Safety and reliability of scram circuits. 1.

Nucleonics, 19, No. 6 (1961)

P. Berry 62. Attenuation coefficients for gamma radiation.

P. Wickersham, L. Ostwald, 66 ff. Microwave detector for measuring thermal neutron flux.

Nukleonik, 3, No. 2 (1961)

M. Bormann et al., 85-92. Particle discrimination with the aid of scintillation detectors.

Radiation Res., 14, No. 3 (1961)

L. Skargard, H. Johns, 231-60. Spectral flux density of scattered and primary radiation at 250 kv.

L. Skarsgard et al., 261-80. Correction for iterative characteristics of a scintillation spectrometer.

N. Barr et al., 291-95. Use of Fricke dosimeter for measuring photoelectric absorption.

Radiation Res., 14, No. 4 (1961)

A. Boni, 374-80. Polyacrylamide gamma dosimeter.

V. RADIOACTIVE AND STABLE ISOTOPES

TRACER TECHNIQUES. USES OF RADIOACTIVE RADIATIONS. DIRECT CONVERSION

Avtomob. dorogi, No. 4 (1961)

V. G. Firstov, 22-23. Radiometric sensing of compacting of roadbed.

Vestnik akad. nauk Kazakh. SSR, No. 3 (1961)

V. I. Ryakhovskii, 107-108. Nuclear radiations for disinfection of fur and leather raw materials.

Gazovaya prom., No. 4 (1961) [Gas industry]

V. A. Astakhov et al., 10-14. Automatic radioactive condensate bleed, type AKO-1.

Doklady akad. nauk SSSR, 137, No. 4 (1961)

I. N. Plaksin et al., 880-81. Neutron activation analysis applied to determination of tungsten content in minerals and beneficiation products.

Doklayd akad. nauk Uzbek. SSR, No. 3 (1961)

V. P. Vasil'ev. Study of intermediate layer of an oxide cathode, with the aid of radioactive tracers.

Zavod. lab., 27, No. 4 (1961)

V. N. Fainberg, 411-13. Gamma-ray flaw detection of thick-walled parts by means of a scintillation counter.

Izvestiya akad. nauk Eston. SSR. Seriya fiz.-matem. i tekhn. nauk, 10, no. 1 (1961)

A. I. Karpov. 75-81. Experimental investigation of speed of particles and resistances in pneumatic conveying by the tracer method.

Kozhev.-obuvnaya prom., No. 2 (1961) [Shoe and leather industry]

I. A. Mad, E. P. Mediis, 12-13. Radioactive instrumentation in extractive industry.

Razvedka i okhrana nedr, No. 3 (1961)

A. A. Ya. Doronin, 44-45. Experience in the use of radioactive techniques for delineating tectonic zones.

Sb. nauchno-issled. inst. osnovanii i podzemnykh sooruzh. akad. stroit. i arkhitek. SSSR, No. 43 (1961)

D. E. Pol'shin, Hsi Chung-Han, 5-12 Gamma-ray method for investigating a planar field of soil density.

Trudy Vsesoyuz. nauchno-issled. inst. veterar. sanitarii, 17 (1960)

V. I. Rogachev et al., 171-76. Ionizing radiations applied to the preservation of meats and meat products.

Trudy Moskv. energet. inst., No. 34 (1961)

N. N. Yakimov, L. G. Sherstnev, 315-22. Tracer studies of diffusion processes in an oxide cathode.

Trudy nauchno-issled. inst. asbesta, slyudy, asbestotsementnykh izdelii i proektr. stroit. predpriyatii slyudyanoi prom., No. 11 (1961) [mica and asbestos research]

M. G. Egorov, L. A. Sukhova, 114-18. Determination of B_2O_3 in synthetic boron micas, by the neutron absorption method.

Appl. Radiation and Isotopes, 10, Nos. 2-3 (1961)

J. Dale et al., 65-71. Ion chamber for measuring β- and γ-radiation of standard radioactive preparations. I. Possible applications and calibration.

J. Dale, 72-78. Ion chamber for measuring β- and γ-radiation of standard radioactive preparations. II. Instrument response to gamma radiation.

F. Carleton, H. Roberts, 79-85. Determination of specific activity of tritium-labeled compounds on paper chromatograms with a servomechanism.

J. Puig, J. Dobo, 112-15. Radiochemical grafting by irradiation at low temperatures.

R. Platzman, 116-27. Total ionization of gases by high-energy particles.

H. Otto, M. Winand, 128-31. Sampling system for high-intensity gamma sources.

Atompraxis, 7, No. 6 (1961)

W. kolb, 146-50. Gamma radiography in boiler construction.

Jaderna Energie, 7, No. 5 (1961)

B. Dolezel, 151-58. Effect of ionizing radiations on polymers.

Nucl. Engn., 6, No. 61 (1961)

P. Barrett et al., 230-32. Pulsed neutron sources.

Nucleonics, 19, No. 6 (1961)

B. Scott, W. Driscell, 48-52. Radiometric chemical analysis in automatic process control.

J. Cameron, J. Rhodes, 53-57. Radioactive sources in x-ray spectrometry.

- -, 88-89. A vessel with a seed irradiation facility.

T. Gregson et al., 90-93. Measurement of age of industrial components by the radioactive dating technique.

ENGINEERING AND PHYSICS JOURNAL INZHENERNO-FIZICHESKII ZHURNAL

THE JOURNAL COMES OUT MONTHLY IN TWELVE PRINTED FOLIOS.

The burden of the Journal's contents concerns scientific problems of deep significance for modern engineering. In particular, the Journal publishes the results of theoretical and experimental physical research in the area of heat and thermodynamics (heat exchange and mass balance, thermal conductivity theory, thermodynamics, physics of combustion, theory of dessication), physics of structural materials (soil mechanics, structural-mechanical and rheological characteristics of disperse media, heat transport in structural materials and enclosing structures), the thermodynamics of irreversible processes and its applications to transport phenomena in the presence of phase transformations, chemical transformations, and nuclear transmutations, as relates to technological processes. The Journal will also publicize engineering and technical methods for the solution of scientific and engineering problems.

The basic task of the Journal is to aid to the maximum the assimilation of the results of scientific physics research into actual engineering practice, to contribute to closer coordination of the efforts of physicists and engineers alike, as well as designers, in industrial enterprises and in-plant laboratories.

The Journal publishes articles and short notes, and contains the features: book review and current bibliography, chronicle of outstanding events in the scientific life and activities of the USSR and other nations, a section of review articles on the timeliest aspects of modern science and engineering.

The readership of the Journal embraces broad circles of scientific workers, professorial and educational institute staffs, graduate students, undergraduates, engineers and technicians, workers in designing, drafting, and planning units, and in-plant laboratories.

Subscriptions to the Engineering and Physics Journal will be processed by all municipal and district subsections of Soyuzpechat', by communications offices and sections, and by all persons authorized for subscription processing in industrial enterprises, scientific institutions, and schools.

The subscription price is set at 8 rubles, 40 kopeks annually, 4 rubles 20 kopeks per half-year.

Soviet Journals Available in Cover-to-Cover Translation

ABBREVIATION	RUSSIAN TITLE	TITLE OF TRANSLATION	PUBLISHER	TRANSLATION BEGAN Vol.	Issue	Year
AÉ	Atomnaya énergiya	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)		1	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. éksp(erim). biol. i med.	Byulleten' éksperimental'noi biologii i meditsiny	Bulletin of Experimental Biology and Medicine	Consultants Bureau	41	1	1959
DAN (SSSR) Dokl(ady) AN SSSR	Doklady Akademii Nauk SSSR	The translation of this journal is published in sections, as follows:				
	Life Sciences	Doklady Biochemistry Section	American Institute of Biological Sciences	106	1	1956
		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
		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
	Chemical Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology	Consultants Bureau	106	1	1956
		Proceedings of the Academy of Sciences of the USSR, Section: Chemistry	Consultants Bureau	106	1	1956
		Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry	Consultants Bureau	112	1	1957
	Earth Sciences	Doklady Earth Sciences Sections (Includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections)	American Geological Institute	124	1	1959
		Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry	Consultants Bureau	106-123	1 6	1957-1958
		Proceedings of the Academy of Sciences of the USSR, Sections: Geology	Consultants Bureau	106-123	1 6	1957-1958
	Mathematics	Doklady Soviet Mathematics	The American Mathematics Society	131	1	1961
	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	106	1	1956
		Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections)	Consultants Bureau	106-117	1	1956-1957
Derevoobrabat. prom-st'.	Derevoobrabatyvayushchaya promyshlennost'	Wood Processing Industry	Timber Development Association (London)		9	1959
	Élecktrosvyaz	Telecommunications	Massachusetts Institute of Technology*		1	1957
Éntom(ol). oboz(renie)	Éntomologicheskoe obozrenie	Entomological Review	American Institute of Biological Sciences	38	1	1959
Farmakol. (i) toksikol(ogiya)	Farmakologiya i toksikologiya	Pharmacology and Toxicology	Consultants Bureau	20	1	1957
FMM	Fizika metallov i metallovedenie	Physics of Metals and Metallography	Acta Metallurgica*	5	1	1957
Fiziol. zhurn. SSSR (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
	Geokhimiya	Geochemistry	The Geochemical Society		1	1958
FTT	Fizika tverdogo tela	Soviet Physics—Solid State	American Institute of Physics	1	1	1959
Izmerit. tekh(nika)	Izmeritel'naya tekhnika	Measurement Techniques	Instrument Society of America		1	1959
Izv. AN SSSR, 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(all). 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
Izv. AN SSSR Ser. geol.	Izvestiya Akademii Nauk SSSR: Seriya geologicheskaya	Izvestiya of the Academy of Sciences of the USSR: Geologic Series	American Geological Institute		1	1958
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
Kolloidn. zh(urn).	Kolloidnyi zhurnal	Colloid Journal	Consultants Bureau	14	1	1952
	Kristallografiya	Soviet Physics – Crystallography	American Institute of Physics	2	1	1957
Metalov. i term. obrabot. metal.	Metallovedenie i termicheskaya obrabotka metallov	Metal Science and Heat Treatment of Metals	Acta Metallurgica	6	1	1958
	Metallurg	Metallurgist	Acta Metallurgica		1	1957
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
	Priborostroenie	Instrument Construction	British Scientific Instrument Research Association		1	1959
Pribory i tekhn. éks(perimenta)	Pribory i tekhnika éksperimenta	Instruments and Experimental Techniques	Instrument Society of America		1	1957
Prikl. matem. i mekh.	Prikladnaya matematika i mekhanika	Applied Mathematics and Mechanics	American Society of Mechanical Engineers		1	1958
PTÉ	(see Pribory i tekhn. éks.)					
	Problemy Severa	Problems of the North	National Research Council of Canada			
Radiotekh.	Radiotekhnika	Radio Engineering	Massachusetts Institute of Technology*	12	1	1957
Radiotekh. i élektronika	Radiotekhnika i élektronika	Radio Engineering and Electronics	Massachusetts Institute of Technology*	2	1	1957
	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 veroyatnostei i ee primenenie	Theory of Probability and Its Applications	Society for Industrial and Applied Mathematics		1	1956
Tsvet. Metally	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
UMN	Uspekhi matematicheskikh nauk	Russian Mathematical Surveys	London Mathematical Society	15	1	1960
Usp. fiz. nauk	(see UFN)					
Usp. khim(ii)	(see UKh)					
Usp. matem. nauk	(see UMN)					
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
Vop. virusol.	Voprosy virusologii	Problems of Virology	National Institutes of Health*		1	1957
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 Zh. éksperim. i teor. fiz.	Zhurnal éksperimental'noi i theoreticheskoi fiziki	Soviet Physics–JETP	American Institute of Physics	28	1	1955
ZhFKh Zh. fiz. khimii	Zhurnal fizicheskoi khimii	Russian Journal of Physical Chemistry	The Chemical Society (London)		7	1959
ZhMÉI Zh(urn). mikrobiol. épidemiol. i immunobiol.	Zhurnal mikrobiologii, épidemiologii i immunobiologii	Journal of Microbiology, Epidemiology and Immunobiology	National Institutes of Health*		1	1957
ZhNKh Zh(urn). neorgan(ich). khim(ii)	Zhurnal neorganicheskoi khimii	The Russian Journal of Inorganic Chemistry	The Chemical Society (London)		1	1959
ZhOKh 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 khimli	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 teknicheskoi 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

*Sponsoring organization. Translation through 1960 issues is a publication of Pergamon Press.

SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET PERIODICALS

FIAN	Phys. Inst. Acad. Sci. USSR
GDI	Water Power Inst.
GITI	State Sci.-Tech. Press
GITTL	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.
MKhTI	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
VNIIM	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.

RESEARCH BY SOVIET EXPERTS

Translated by Western Scientists

RADIATION CHEMISTRY PROCEEDINGS OF THE FIRST ALL-UNION CONFERENCE MOSCOW 1957

More than 700 of the Soviet Union's outstanding research scientists participated in this conference sponsored by the Academy of Sciences and the Ministry of the Chemical Industry. Each of the 56 reports read in the various sessions covers either the theoretical or practical aspects of radiation chemistry, and special attention is given to radiation sources used in radiation-chemical investigations. The general discussions which followed each report and reflected various points of view on the problem under analysis are also included.

PRIMARY ACTS IN RADIATION CHEMICAL PROCESSES	**$25.00**
RADIATION CHEMISTRY OF AQUEOUS SOLUTIONS (Inorganic and Organic Systems)	**$50.00**
RADIATION ELECTROCHEMICAL PROCESSES	**$15.00**
THE EFFECT OF RADIATION ON MATERIALS INVOLVED IN BIOCHEMICAL PROCESSES	**$12.00**
RADIATION CHEMISTRY OF SIMPLE ORGANIC SYSTEMS	**$30.00**
THE EFFECT OF RADIATION ON POLYMERS	**$25.00**
RADIATION SOURCES	**$10.00**

Individual volumes may be purchased separately

Special price for the 7-volume set **$125.00**

Tables of contents upon request.

CONTEMPORARY EQUIPMENT FOR WORK WITH RADIOACTIVE ISOTOPES

Of the 110 isotopes produced in the USSR during 1958, 92 were obtained by neutron irradiation. The methods and technological procedures used in the production of isotopes and the preparation of labeled compounds from them are reviewed in detail. Shielding and manipulative devices for work with radioactive isotopes are illustrated as well as described fully. These collected reports are of interest to all scientits and technologists concerned with radioactive isotopes.

Tables of contents upon request.

Durable paper covers 66 pp. illus. $15.00

PRODUCTION OF ISOTOPES

The eighteen papers which comprise this volume were originally read at the All-Union Scientific and Technical Conference on the Application of Radioactive Isotopes, Moscow, 1957. The reports consider the problems and achievements of Soviet scientists in the production of radioactive isotopes by irradiation of targets in Soviet reactors and cyclotrons. Not only is this work of significance to producers of isotopes, but many of the papers will prove useful to isotope users as well.

Tables of contents upon request.

Durable paper covers 136 pp. illus. $50.00

Payment in sterling may be made to Barclay's Bank in London, England.

CONSULTANTS BUREAU
227 West 17th Street • New York 11, N.Y. • U.S.A.

Now available . . . an insight into the Soviet problems and achievements in . . .

PRODUCTION of ISOTOPES

The eighteen papers which comprise this volume were originally read at the All-Union Scientific and Technical Conference on the Application of Radioactive Isotopes, Moscow, 1957. The reports consider the problems and achievements of Soviet scientists in the production of radioactive isotopes by irradiation of targets in Soviet reactors and cyclotrons. Not only is this work of significance to producers of isotopes, but many of the papers will prove useful to isotope users as well.

The Development of Isotope Production in the USSR.
Certain Aspects of the Production of Radioactive Isotopes in a Nuclear Reactor.
Production of Radioactive Isotopes in a 10-Mev Deuteron Cyclotron.
Determination of Product Yields in Nuclear Reactions.
Spectrochemical Methods of Analyzing High-Purity Materials Used in Reactor Construction and for the Production of Radioisotopes.
Quantitative Spectral Determination of Impurities in Radioactive Preparations.
The Production of Alpha-, Beta-, and Gamma-Sources Using Oxide Films on Aluminum and Its Alloys.
Stable Isotopes Enriched by the Electromagnetic Method.
Ultrahigh-Temperature Ion Source for Electromagnetic Separation of Isotopes of Elements in the Platinum Group.
Inhomogeneous-Field Mass-Spectrometer for Analysis of Light-Element Isotopes.
The Relative Abundance of Palladium and Germanium Isotopes.
Some Problems in the Theory of Isotope Separation.
Separation of Isotopes of Light Elements by Diffusion in Vapors.
A Diffusion Column for the Separation of Isotopes.
A Fractionating Column for Preparing BF_3 Enriched in the Isotope B^{10}.
An Investigation of the Separation of the Stable Isotopes of Light Elements.
The Separation of Carbon Isotopes.
Low-Temperature Methods for Separating Helium Isotopes ($He^3 - He^4$).

1959 durable paper covers 136 pp. $50.00

c/b CONSULTANTS BUREAU
227 WEST 17TH STREET, NEW YORK 11, N. Y.