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CALCULATION OF THE OUTPUT AND PARAMETER OPTIMIZATION FOR CHEMONUCLEAR INSTALLATIONS

B. G. Dzantiev, A. K. Krasin, G. V. Nichipor, V. T. Kazazyan, and I. A. Savushkin

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The output of a radiochemical installation is a very important specification, determining, in many respects, the installation's efficiency. It is directly related to the energy which is absorbed by the chemical reactant. Usually, the output O for any radiochemical apparatus is determined by the equation [1]

$$O = kM \int_{V_{r.v.}} G(I, t, \tau, p) I(\varkappa_i, \omega_i) dV, \quad (1)$$

where M is the molecular weight of the irradiated medium; I is the dose rate absorbed, eV/cm^3·sec; $\varkappa_i$ are the space coordinates; ω_i is a generalized symbol for the properties of the medium and the nature of the radiation spectrum; k is a dimensional constant; $V_{r.v.}$ is the apparatus' reaction volume; G is the radiochemical yield, mole/100 eV; t, τ, and p are the temperature, contact time, and reactant pressure.

Calculation of the integral in Eq. (1), as a rule, is quite difficult. In the majority of cases, one cannot obtain an exact, analytic determination of the integral because of the complicated nature of the dependence of G(I, t, τ, p) and I($\varkappa_i$, ω_i) on numerous factors. Therefore, various means are utilized for approximating the solution.

It is advisable to determine the output of chemonuclear installations through the kinetic energy of the fission fragments, which comprises ~84% of the fission energy. In this case, reduction of the problem to a numerical integration of the outputs for the individual chemonuclear channels is an effective way to approximate the solution of Eq. (1). The output for the different kinds of chemonuclear channels can be determined more precisely, taking account of many factors, if the mechanism for the formation of a useful product is known. At the same time, the solution of the system of kinetic equations, describing the elementary reactions, permits one to determine the distribution of the end product concentrations at every moment of time along the length of the channel.

Let us consider such an approach for the calculation of the output of experimental and industrial chemonuclear installations, as illustrated by the synthesis of hydrazine.

The influence of the temperature conditions of a channel of a chemonuclear reactor on the final concentrations of the products of the radiolysis of ammonia under conditions of a nonisothermal gas flow and a variable dose rate was investigated in [2], based on the equations of chemical kinetics. However, the results obtained cannot yet be directly applied to the specific design of a channel, since variations in the effectiveness of the utilization of the energy of the fragments and the rate of flow of the reactant as a result of an increase in the temperature along the length of the channel, as well as other effects, were not taken into consideration for the simplification of the calculations.

In the present paper, a more general model for the calculation of the output of a chemonuclear channel is proposed. Calculation of the output and optimization of parameters for a channel in a chemonuclear loop installation was carried out on the basis of the proposed model. The possibility for realizing hydrazine synthesis on the basis of a chemonuclear reactor on an industrial scale is considered.

Calculation Procedure

From the results of the kinetic analysis carried out in [3, 4], taking into consideration the mass-transport equation, let us describe the distribution for the concentrations of the components of the irradiated

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TABLE 1. Values of the Coefficients m and n for a Channel with Diameter b = 0.2 cm

Fuel thickness, μ	$\frac{z}{H_к} \leq 0,5$		$\frac{z}{H_к} > 0,5$	
	m	n	m	n
1	0,272	−0,0447	0,237	−0,029
3	0,174	−0,0227	0,1607	−0,0187
5	0,116	−0,0113	0,112	−0,0133

gas mixture along the length of the channel z for the process involving the formation of hydrazine from gaseous ammonia, on the assumption that one can neglect the diffusion of matter in the direction of the flow, in the form of the following time-independent system of equations [5]:

$$\frac{d[(H)/\gamma(z)]}{dz} = [W - 2k_3M(H)^2 - k_2M(H)(R) - k_4(H)(\Gamma) - k_6(H)(A)]\frac{S}{g}; \quad (2)$$

$$\frac{d[(R)/\gamma(z)]}{dz} = [W - 2k_1M(R)^2 - k_2M(H)(R) - k_5(R)(\Gamma) + k_6(H)(A)]\frac{S}{g}; \quad (3)$$

$$\frac{d[(\Gamma)/\gamma(z)]}{dz} = [k_1M(R)^2 - k_4(H)(\Gamma) - k_5(R)(\Gamma)]\frac{S}{g}; \quad (4)$$

$$\frac{d[(H_2)/\gamma(z)]}{dz} \approx [k_6(H)(A) + k_3M(H)^2 + k_4(H)(\Gamma)]\frac{S}{g}. \quad (5)$$

Here (H), (R) = (NH_2), (Γ) = (N_2H_4), (A) = (NH_3), (H_2) are the instantaneous concentrations of the radical and molecular components; M = (A) + (H_2) + (Γ) + (R) + (H) ≈ (A); k_1, k_2, k_3, ..., k_i are the rate constants for the respective elementary reactions entering into the system of equations (2)-(5); g is the mass flow of the reactant, kg/sec; S is the transfer cross section for the reactant in the channel, m^2; $\gamma(z)$ is the instantaneous density of the reactant along the length of the channel, kg/m^3.

Considering that the total pressure of the mixture is the sum of the partial pressures of all the components, let us define the change in the concentration of ammonia along the length of the channel by an algebraic equation of the form

$$(A) = \frac{p}{RT(z)} - [(H) + (R) + (\Gamma) + (H_2)]. \quad (6)$$

Then for the output of the end product, one can write the following equation:

$$O_i = M_i g_i \sum_{n=1}^{n} \frac{\Delta C_{in}}{\gamma_{in}}, \quad (7)$$

where ΔC_{in} is the change in the instantaneous concentration of the i-th product in the n-th section of the channel's length; M_i is the molecular weight of the i-th product.

For the determination of the rate of initial decomposition of the ammonia W, one can utilize the formula

$$W = G_{(-NH_3)} \cdot 10^{-2} I(z), \quad (8)$$

where $G_{(-NH_3)}$ is the amount of the initial radiative discharge from the decomposition of the ammonia; I(z) is the value of the absorbed dosage along the length of the channel, $eV/cm^3 \cdot sec$.

In order to complete the system of equations (2)-(6), one should provide a law for the variation in the temperature T(z), the dose rate I(z), and the reactant's density $\gamma(z)$ with the coordinate z.

Assuming that the variation in the dose rate along the length of the channel is expressed by the product of the neutron flux, varying sinusoidally along the length of the channel, and the efficiency for utilizing the fission fragments' energy, let us write

$$I(z) = I_{max} \sin \frac{\pi(z + 2\delta)}{H_{eff}} \varepsilon(z), \quad (9)$$

where δ is an effective correction. In the case of chemonuclear fuel in the form of a stack of parallel slabs, one can utilize the formulae from [1, 6] to calculate $\varepsilon(z)$.

For chemonuclear fuel with cylindrical channels, the value of the efficiency is not expressible in elementary functions. In this case, the calculations for the efficiency can be accomplished by the Monte Carlo method [7]; one can approximate the results of the calculations with good accuracy (not worse than ±6%) by a linear law:

$$\varepsilon\left(\frac{z}{H_к}\right) = n\frac{z}{H_к} + m.$$

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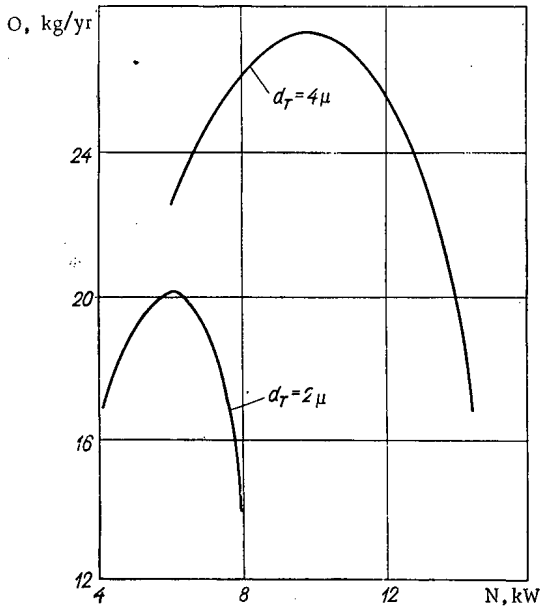

Fig. 1

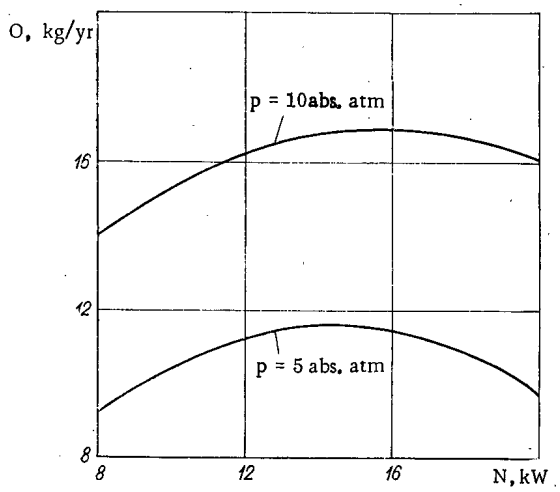

Fig. 2

Fig. 1. Dependence of the output for a channel of the CNI-5 on the installation's thermal output, for a change in the latter due to the distance between the fuel layers.

Fig. 2. Dependence of the output of a CNI-5 channel on the installation's thermal output with variation in the latter due to variation in the fuel thickness.

The values of the coefficients n and m, for example, for the case of thin layers (1-5 μ) of UO_2, applied to the inner surface of a cylinder with diameter b = 2 mm, and gaseous ammonia as reactant at a pressure p = 10 abs. atm are presented in Table 1.

For the calculation of the dependence of the range of the fission fragments on the reactant's density along the length of the channel $R_B(z)$, one utilizes the relationship

$$R_B(z) = R_{f.e}\frac{\gamma_0}{\gamma(z)}.$$

For the dependence of T(z), in the case of a sinusoidal law for the distribution of the heat release, on the length of the channel, one can utilize the expression

$$T(z) = T_0 + \frac{\Delta T}{2}\left[1 - \cos\frac{\pi z}{H_{eff}}\right].$$

Here T_0, γ_0, and $R_{f.e}$ are the temperature, reactant density, and range of the fragments at the channel's entrance; ΔT is the temperature increment for the reactant along the length of the channel.

The variation in the density $\gamma(z)$ was found from the ideal gas equation and was taken into consideration when calculating the efficiency and the exposure time of the reactant in the irradiation zone at the given dose rate I(z).

Solving the system of equations (2)-(7) with the initial conditions:

$$(NH_3)\Big|_{z=0} = \frac{p}{RT_0};\ (R) = (H) = (\Gamma) = (H_2)\Big|_{z=0} = 0,$$

we find the distribution of the concentrations of the products and the size of the output along the length of the channel for selected values of the reaction rates and the prescribed laws governing the behavior of the parameters. The values of the constant k_i, needed in the calculation, are cited in [3, 4].

The given algorithm was programed on a "Minsk-22" electronic computer. The fourth order Runge-Kutta method was utilized for the solution of the system of nonlinear, kinetic equations.

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TABLE 2. The Essential Radiochemical Characteristics of the CNI-5 when p = 10 abs. atm

Distance between layers, cm	$\frac{d_f}{R}$	Total thermal output of channel, kW	Average contact time, sec	Efficiency*, $\varepsilon_1/\varepsilon_2$	Output of N_2H_4, kg/yr	Specific output of N_2H_4, kg/cm^3·yr	Average realizable amount G, mole/100 eV	Concentration of N_2H_4 at channel exit·10^{-5}, mole/liter	Maximum dose rate in reactant ·10^{19}, eV/cm^3·sec
0,1	0,25	8,0	0,312	0,206/0,161	14,0	0,0140	0,107	0,43	1,2
	0,50	14,4	0,177	0,132/0,107	16,8	0,0168	0,112	0,29	1,38
	0,75	19,8	0,126	0,092/0,073	16,2	0,0162	0,104	0,20	1,34
0,2	0,25	6,0	0,58	0,250/0,220	20,0	0,0146	0,165	0,84	0,84
	0,50	12,0	0,29	0,158/0,143	25,6	0,0157	0,165	0,61	1,04
0,35	0,25	4,0	0,98	0,254/0,251	16,4	0,0087	0,190	1,01	0,52
	0,50	6,0	0,66	0,160/0,159	22,4	0,0118	0,270	0,93	0,50

*ε_1 and ε_2 are the values of the efficiency at the entrance and the exit, respectively, of the channel when R=8μ.

In this way, the method considered in conjunction with the neutron-physical calculations permits one to determine the output for a different type of chemonuclear installation and the assignment, including behavior, of such factors as dose rate, temperature, reactant density, and so forth, which is a significant approximation to the actual conditions occurring in experimental and industrial chemonuclear installations.

Calculation of the Output and Parameter Optimization for a Channel of a Chemonuclear Loop Installation

The method considered was utilized for the calculation of the output and optimization of the parameters for a channel of a chemonuclear loop installation (CNI-5). The fundamental design and basic technical characteristics of a channel in a CNI-5 are cited in [8, 9]. As a basic criterion for determining the best channel design, it is advisable that one choose the dependence of the output on the thermal output of the channel. Such a choice is determined by the fact that, first of all, the total thermal output of the channel, as a rule, limits the possibilities for the experimental equipment and the conditions for radiation safety at the assembly site of the loop installation (for the CNI-5, the maximum thermal output is ~10 kW) [8, 9]; second, the thermal output is directly connected with the thermophysical, hydraulic, and radiation conditions for conducting the procedure. At the same time, if one expresses the change in the thermal output via the change in such parameters as the fuel thickness and the distance between the layers of fuel, one can carry out a complete optimization for construction of the channel.

The calculation was carried out a pressures of 5 and 10 abs. atm for the gaseous ammonia with temperature T_0 = 323°K at the entrance to the channel and temperature T_{exit} = 473°K at its exit. Thus, the channel was warmed up along its length at a constant temperature of 150°C. The original data for the calculation (dose rate, consumption, etc.) and the values of the thermal output as a function of the distance between the fuel layers and their thickness are taken from [9].

The dependence of the output on the installation's thermal output, for a change in the latter due to a change in the distance between the plane fuel layers, arranged perpendicular to the axis of a channel with given length H, is shown in Fig. 1. The curves represent two fuel thicknesses df, equal to 2 and 4 μ. It is seen that this dependence has a sharply defined maximum; while with an increase in the fuel thickness, the absolute value of the maximum increases and is shifted in the direction of a larger thermal output. Thus, if for d_f = 2 μ, the maximum of the output occurs at a thermal output N = 6 kW and results in 20.2 kg/yr of hydrazine; then, for d_f = 4 μ, the maximum corresponds to an output N = 10 kW and equals 27 kg/yr in magnitude.

The analogous dependence of the output on the fuel thickness for a fixed distance b = 0.1 cm between the layers and pressures of 5 and 10 abs. atm is presented in Fig. 2. This dependence has a smoother character, and one is able to conclude that the maximum is attained in the 14-15 kW interval of the thermal output, i.e., for 4-5 μ fuel layer thicknesses.

As is seen from Table 2, an increase in the channel's thermal output is due to an increase in the density of the loaded fuel layers which results, as was to be expected, in an increase in the maximum dose

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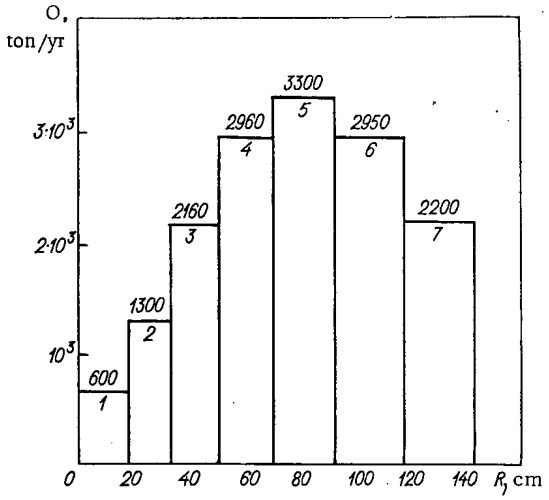

Fig. 3

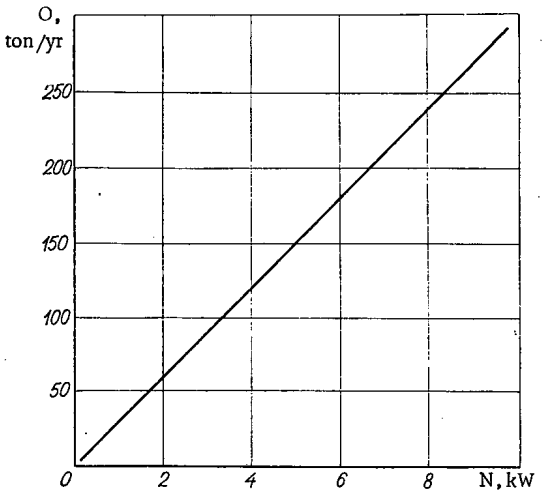

Fig. 4

Fig. 3. Diagram of the output of the active zone for an industrial chemonuclear reactor (N = 500 MW, d_f = 4 μ).

Fig. 4. Output of the channel of an industrial reactor as a function of its thermal output (d_f = 4 μ).

rate and, which at first glance is strange, a decrease in the concentration of hydrazine at the channel's exit. This effect is associated with a decrease in the density and an increase in the flow rate of the radiolyzed gas, i.e., with a decrease in the average time of contact.

From Table 2, it is seen that the contact time changes more rapidly than the dose rate increases. Thus, for the case where p = 10 abs. atm and d_f = 2 μ, the average time of contact decreases from τ = 0.98 sec, when b = 0.35 cm, to τ = 0.312 sec, when b = 0.1 cm, i.e., 3.1 times; whereas the dose rate increases correspondingly from $0.52 \cdot 10^{19}$ to $1.2 \cdot 10^{19}$ eV/cm^3·sec, i.e., only 2.3 times. According to [3, 4], for the conditions under consideration, one can assume that on the average the variation in the hydrazine concentration along the length of the channel is determined by the square root of the dose rate and the contact time τ. The simultaneous effect of these factors results in, regardless of the increase in the dose rate, a concentration of the hydrazine in the exit leading from the channel. Insofar as the installation's output is proportional to the concentration of the end product in the mass flow weight rate of the reactant, then this results in an optimum.

The more extreme character of the extremal dependence of the output on the thermal output, with a change in the latter due to the density of the fuel layer charge, than on the fuel thickness is associated with an additional increase of the reactant rate as a result of a decrease in the unoccupied volume of the channel.

On the basis of the optimization of the parameters attained for the CNI-5, one can recommend: with up to 10 kW output, one utilizes a fuel layer with a thickness not greater than 4 μ. In addition, for all thicknesses in the 1-4 μ interval, a 0.2 cm separation between the layers is necessary for the attainment of maximum output. Results of the calculations point out the possibility of utilizing the research reactor for conducting chemonuclear experiments on a pilot scale.

The Possible Organization of the Industrial Synthesis of Hydrazine Based on a Chemonuclear Reactor

The investigation was conducted, using as an example a reactor utilizing chemonuclear fuel in the form of a 4 μ thick layer of UO_2 (90% pure) applied to an aluminum backing. The design of the chemonuclear element (CEL) consists of a multiple-set corrugated spiral with a 2 mm long corrugation, wrapped in a 5 cm diameter, stainless steel, cylindrical channel [10]. Water was used as a moderator material. The reactor's dimensions H × D = 3 × 3 m, the thermal output N = 500 MW, and the U^{235} charge is approximately 700 kg. The 10-group diffusion method [10] was utilized for the calculation of the reactor's neutron-physical characteristics.

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Necessary changes, taking into account the specific properties of the calculation of a chemonuclear reactor's operating period, were introduced on the basis of the results, discussed in [12]. The reactor's output was determined by summing the outputs of its individual zones. The output of each zone was found by summing the outputs of the individual chemonuclear channels O_c (within each channel, the absorbed dose rate can be considered constant along the radius and variable along the length).

According to this, for the output of a chemonuclear reactor, one notes

$$O_r = \sum_{m=1}^{7} n_m O_{c,m},$$

where n_m is the number of channels in zone m; $O_{c,m}$ is the output of a channel in zone m; m is the number of the reactor zone. The outputs of an individual channel in a zone were calculated relative to its average thermal output.

The average thermal output of a channel in a zone was found from the relation

$$N_{c,m} = \frac{N_0 q_m}{n_m},$$

where N_0 is the reactor's thermal output; q_m is that fraction of the total energy release in the m-th zone of the reactor.

For the determination of q_m in the multigroup diffusion approximation on the assumption that the spatial distribution of the energy release does not vary within the active zone during a time interval Δt_k, one can note

$$q_m = \frac{\int_{V_m} dV \sum_{j=1}^{10} \Sigma_{fj} \Phi_{j,k-1}(r)}{\int_{V_{a.z}} dV \sum_{j=1}^{10} \Sigma_{fj} \Phi_{j,k-1}(r)},$$

where V_m, $V_{a.z.}$ are the m-th zone and the total active zone volumes; Σ_{fj} is the macroscopic fission cross section; $\Phi_{j,k}$ is the integral of the neutron flux for the j-th group at the k-th moment of time. The output was calculated for a reactant pressure p = 10 abs. atm in the temperature interval from T_0 = 323°K up to $T_{a.z.}$ = 523°K. The results of the calculations are presented in Figs. 3 and 4.

The calculations showed that in such a reactor, one can produce 15,500 tons/yr of hydrazine with an average energy release G = 2.3 mole/100 eV, and an operating period for the reactor of ~500 days. The output of a single channel ranges from 120 tons/yr at the center of the active zone to 20 tons/yr at its periphery. This can account for the fact that in passing from the center of the active zone to its periphery the dose rate falls from $5.85 \cdot 10^{20}$ to $0.85 \cdot 10^{20}$ eV/cm^3 · sec in the time it takes for the average contact time to increase from 0.0375 to 0.26 sec. These two parameters compensate each other, therefore the concentration of hydrazine at the channel's exit does not vary in practice and consists of $(0.700\text{-}0.763) \cdot 10^{-4}$ mole /liter.

Thus, variation in the output corresponds in practice to a variation in the reactant's mass flow weight rate, which is 8.0 kg/sec at the center of the active zone and 1.36 kg/sec at its periphery. The plotted dependence of a channel's output on its thermal output indicates that this dependence has a linear character (see Fig. 4). This is associated with the fact that, under the conditions for an industrial reactor, we have a linear accumulation of the end product's concentration along the length of the channel. Derivation of the dependence permits one to carry out the calculation of the outputs of other active zones of the chemonuclear reactors.

It is seen from the diagram presented in Fig. 3, that the maximum value of the output occurs in the fifth zone, located at a radius of 70-90 cm. This is due to the fact that, in passing from the first zone to the seventh, in spite of the drop in the output of the individual channels, the number of channels in the zones rises. It also follows from the diagram that there are broad possibilities for the optimization of the active zone for a chemonuclear reactor for the purpose of increasing its output. Thus, the results obtained indicate the possibility for organizing hydrazine synthesis on the basis of a chemonuclear reactor on a large scale and permits one to carry out an analysis of the economic outlook for this process.

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NATURE AND THERMAL STABILITY OF RADIATION DEFECTS IN SINGLE-CRYSTAL TUNGSTEN

V. N. Bykov, G. A. Birzhevoi, M. I. Zakharova, and V. A. Solov'ev

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The damage suffered by bcc metals as a result of neutron irradiation is similar to that suffered by fcc metals [1]. At the present time the five stages in the annealing of defects in bcc metals based on the van Bueren [2] and Thompson [3] classifications have been the ones principally studied. There are certain indications as to the existence of a sixth stage, which appears after irradiation with large integrated fluxes [1, 4-6] or at high temperatures [7]. Stages in the annealing of radiation defects in tungsten are presented in Table 1.

An analysis of these data shows that certain ambiguities occur in the interpretation of the types of defects corresponding to different stages of annealing in tungsten. Furthermore, all earlier experiments were, as a rule, carried out with polycrystalline samples at doses of up to $1.5 \cdot 10^{21}$ neutrons/cm^2; the processes underlying the formation and annealing of defects may differ, however, very considerably in single crystals and polycrystalline aggregates, particularly for large integrated neutron fluxes.

We shall now consider the nature of the radiation defects in single-crystal tungsten irradiated at 450-500°C with a dose of $1.4 \cdot 10^{22}$ neutrons/cm^2 ($4 \cdot 10^{21}$ neutrons/cm^2 at an energy of $E > 1$ MeV), and the stability of these defects at temperatures up to 2200°C.

TABLE 1. Stages of Defect Annealing in Irradiated Tungsten

Temperature range, °K*	Annealing stages and substages	Activation energy, eV	Type of defect	Literature cited
20—100 15 30 38 60 75	I I_1 I_2 I_3 I_4 I_5	0,06	Up to 45°, recombination of Frenkel pairs; 45-100°, migration of free interstitial atoms	[1, 4]
100—400 190 270	II II_1 II_2	0,85—1,7	Not interpreted	[1, 4]
400—700 (0,15—0,17)	III	1,7—1,9	Intrinsic interstitial atoms, impurity interstitial atoms, vacancies	[4, 5, 8, 9—11]
720—920 (0,22—0,29) (0,22—0,25) (0,25—0,29)	IV IV_1 IV_2	No data	Bivacancies, impurities, impurity complexes	[4, 5, 9]
920—1270 (0,31—0,35)	V	3,1—3,3	Vacancies	[4, 5, 9, 12]
1270—1800 (0,35—0,45)	VI	No data	Not interpreted	[1, 4, 6]

*Maximum of the annealing rate shown in brackets as (T/T_m).

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TABLE 2. Resistivity of Irradiated and Nonirradiated Samples of Tungsten (Single-Crystal) and W–Re Alloys Measured at 298, 77, and 4.2°K

Characteristic of sample	298° K		77° K		4,2° K	
	ρ, $\mu\Omega \cdot$ cm	$\Delta\rho/\rho$, %	ρ, $\mu\Omega \cdot$ cm	$\Delta\rho/\rho$, %	ρ, $\mu\Omega \cdot$ cm	$\Delta\rho/\rho$, %
Nonirradiated tungsten	5,63	—	0,57	—	$10{,}2 \cdot 10^{-4}$	—
Irradiated tungsten	6,55	18	1,36	139	$9{,}5 \cdot 10^{-1}$	93000
Irradiated tungsten after annealing at up to 2200°C for 1 h	5,82	2,5	0,72	26	$2{,}6 \cdot 10^{-1}$	250
Tungsten + 0.1% rhenium	5,99	6,4	0,75	31,6	$1{,}0 \cdot 10^{-1}$	90
" +0,2% "	5,98	6,2	0,80	40,0	$1{,}5 \cdot 10^{-1}$	150
" +0,9% "	6,4	13,7	1,52	167	$4{,}4 \cdot 10^{-1}$	430
" +2,6% "	7,8	38,5	3,5	513	$7{,}7 \cdot 10^{-1}$	760

Note: The quantity $\Delta\rho = \rho_{irr} - \rho_{nonirr}$ or $\Delta\rho = \rho_{W+Re} - \rho_{W}$.

MATERIALS AND METHOD

We used electron-beam zone-melted tungsten single crystals with disorientation angles of 30"-30' between the subgrains and a dislocation density of $2 \cdot 10^6$ cm^{-2}. The impurity content of these crystals, according to chemicospectral analysis (wt. %), was: Ta $< 3 \cdot 10^{-2}$; Nb $< 1 \cdot 10^{-2}$; Mo $8 \cdot 10^{-3}$; Ni, Co, Zn $< 3 \cdot 10^{-3}$ (each); Cr $2.8 \cdot 10^{-3}$, Zr, Ti, Pb, Al, Ca, Sb, Ba $< 1 \cdot 10^{-3}$ (each); Sn, Bi $< 3 \cdot 10^{-4}$ (each); Fe, Mg, Mn, Cu, Cd, Ag $< 1 \cdot 10^{-4}$ (each). From the middle of a single-crystal bar [13] we cut samples 2.5 mm in diameter and 25 mm long. After machining, the work-hardened layer was removed by electropolishing.

The samples were irradiated in the active zone of a BR-5 reactor in hermetically-sealed tubes of standard packs. After irradiation, the samples and controls were annealed in a high-temperature vacuum furnace at a residual pressure of no greater than $1 \cdot 10^{-5}$ mm Hg and temperatures of 200-2200°C (in steps of 100°C) for 1 h (isochronous annealing), and at temperatures of 1000 and 1200°C for periods between 5 min and 380 h (isothermal annealing).

The resistivity ρ was measured at 298 and 77°K by a potentiometric method [9], the error for 30 measurements being under 1% at room temperature and 3.5% at the temperature of liquid nitrogen. For the measurements at 4.2°K we used a noncontact induction method [15] with a total ρ error of 5.5%.

RESULTS

The increase in the resistivity ρ of the tungsten samples due to irradiation was three orders of magnitude at 4.2°K, 139% at 77°K, and 18% at 298°K (Table 2).

Figure 1 shows the change in the electrical resistance of the irradiated and nonirradiated tungsten samples on continuous heating up to 1000°C. In the temperature range studied, the resistivity of the irradiated and nonirradiated samples increases linearly with rising temperature. The irradiation-induced resistivity increment ($\Delta\rho$ = 1.15 $\mu\Omega \cdot$cm) hardly changes at all on heating to 1000°C; this indicates a high thermal stability of the radiation defects in tungsten.

An analysis of the isochronous-annealing curve of the irradiated samples (Fig. 2) showed that annealing took place in three stages in the temperature ranges 500-800, 950-1200, and 1200-1900°C. The relative fall in $\Delta\rho$ at each stage was 20.2, 16.5, and 43.3% respectively. Starting from 1900°C the $\Delta\rho$ curve emerged on to a plateau.

The annealing spectrum shown in Fig. 3 indicates that the maximum annealing rates correspond to temperatures of 0.24, 0.35, and 0.45 T_m.

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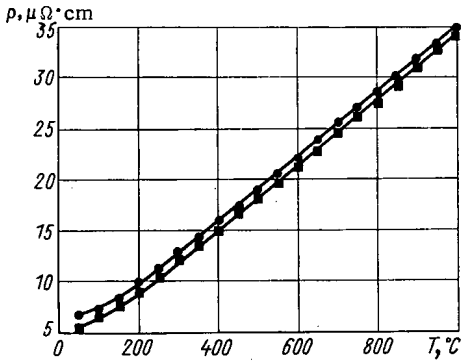

Fig. 1

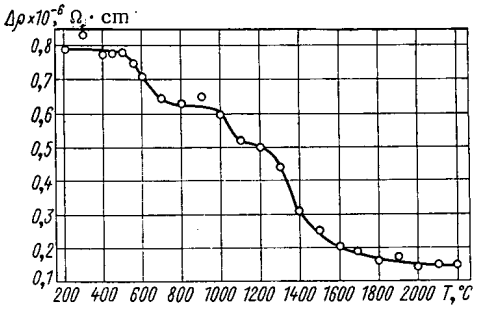

Fig. 2

Fig. 1. Change in the electrical resistivity of irradiated and nonirradiated samples of single-crystal tungsten on heating at 2 deg/min: ●) irradiated tungsten; ■) nonirradiated tungsten.

Fig. 2. Change in the resistivity increment (77°K) of irradiated single-crystal tungsten samples on isochronous annealing: $\Delta\rho = \rho_{irr}$ (annealing 1 h) – ρ_{nonirr} (annealing 1 h).

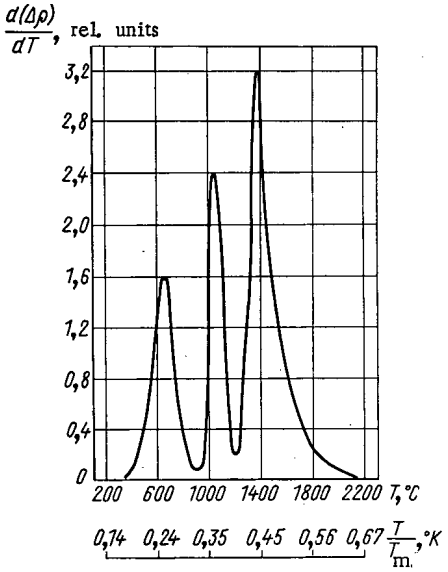

Fig. 3

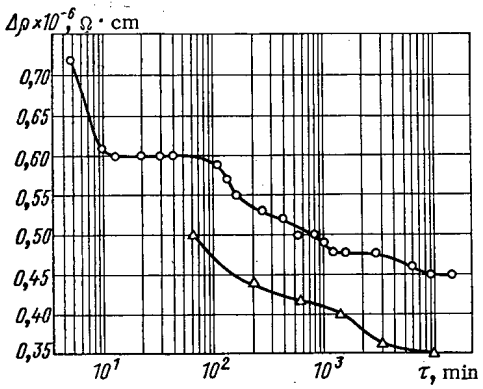

Fig. 4

Fig. 3. Annealing spectrum of the resistivity of irradiated single-crystal tungsten: $\Delta\rho = \rho_{irr}$ (annealing 1 h) – ρ_{nonirr} (annealing 1 h).

Fig. 4. Change in the resistivity increment (77°K) of irradiated single-crystal tungsten samples on isothermal annealing: $\Delta\rho = \rho_{irr}$ (T = const) – ρ_{nonirr} (T = const); ○) T = 1000°C; △) T = 1200°C.

Figure 4 represents the isothermal annealing curves of the irradiated samples. The curve corresponding to annealing at 1000°C shows two stages in the restoration of ρ. On raising the annealing temperature to 1200°C a third stage appears.

The activation energy Q of the annealing of radiation defects was determined by the method of combined isochronous and isothermal annealings [16]. The calculations were based on the equation

$$Q = \frac{kT_1T_2\ln(t_1/t_2)}{T_1 - T_2},$$

where T_1 and t_1 are the temperature (°K) and time of isothermal annealing, T_2 and t_2 are the temperature (°K) and time of isochronous annealing, and k is Boltzmann's constant. In order to determine the activation

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TABLE 3. Annealing of Defects in Single-Crystal Tungsten Irradiated with a Dose of $1.4 \cdot 10^{22}$ neutrons/cm^2 ($4 \cdot 10^{21}$ neutrons/cm^2 with an energy of E > 1 MeV) at 0.20-0.21 T_m

Temperature range of defect annealing, °K	Maximum of annealing rate, T/T_m	Activation energy, eV	Form of defect	$\Delta\rho$, %
773—1073	0,24	0,70±0,03	Slight accumulations of hydrogen atoms	20,2
1223—1473	0,35	3,2±0,3	Single vacancies, slight accumulations of vacancies	16,5
1473—2173	0,45	6,4±0,5	Complexes of defects (dislocation loops, pores)	43,3

energies we used the results of the isochronous (Fig. 2) and isothermal (Fig. 4) annealings of $\Delta\rho$. The resultant activation energies are shown in Table 3. The activation energy of the annealing stage with a maximum at 0.35 T_m was also calculated from the annealing spectrum (Fig. 3) by using the following equation [4]:

$$Q = 2.4k \frac{T_a^2}{\Delta T_a},$$

where T_a is the temperature corresponding to the maximum annealing rate, ΔT_a is the half width of the peak at half height. The calculated value of Q = 3.26 eV agrees with the value of Q = 3.2 ± 0.3 eV obtained by the first method.

DISCUSSION OF RESULTS

Thus, as a result of irradiation at 450-500°C with an integrated flux of $1.4 \cdot 10^{22}$ neutrons/cm^2 ($4 \cdot 10^{21}$ neutrons/cm^2 with an energy of E > 1 MeV), three types of radiation defects accumulate in single-crystal tungsten; these have activation energies of 0.70 ± 0.03, 3.2 ± 0.3, and 6.4 ± 0.5 eV, the maximum annealing rates lying at 0.24 T_m, 0.35 T_m, and 0.45 T_m respectively. According to the general classification of types of radiation defects the stage at 0.24 T_m corresponds to the fourth stage, that at 0.35 T_m to the fifth, and that at 0.45 T_m to the sixth.

The fifth stage in the annealing of tungsten defects has been studied most of all. According to the results of [4, 5, 12, 17] the fifth stage of annealing in tungsten has a maximum at (0.31-0.35) T_m and the activation energy is 3.1-3.3 eV, in good agreement with the activation energy obtained in the present investigation, 3.2 ± 0.3 eV. The activation energy at this stage corresponds to the energy of vacancy migration in tungsten [12]. On this basis we may conclude that the fifth stage in tungsten single crystals is due to the annealing of vacancies; this agrees with the conclusions of research on polycrystalline samples [4, 5, 9, 18, 19].

The fourth stage in the annealing of radiation defects was observed in several earlier investigations [4, 5, 9]; however, the activation energy for the annealing of the defects at this stage was not determined, and the processes taking place were interpreted as the annealing of bi- and trivacancies. However, the energies of migration of single and multiple vacancies in bcc metals are similar to one another [16], and considerably greater than the activation energy determined in the present investigation (0.70 ± 0.03 eV). All the interstitial impurities, apart from hydrogen, have migration activation energies greater than 1 eV [20]. One mechanism possibly explaining this stage of annealing is the migration of hydrogen atoms, not only those present before irradiation but also those formed as a result of (n, p) reactions. The migration energy of hydrogen in tungsten is 1 eV [21], close to the activation energy obtained in the fourth stage. Hydrogen has a very low solubility in tungsten [22]; it evidently occupies small pores, and is not annealed in the reactor, despite its low activation energy. On raising the temperature from 450 to 600°C in the annealing process, the solubility of hydrogen in tungsten increases by a factor of several times [22]; the hydrogen migrates to sinks and free surfaces.

The activation energy of the annealing stage with a maximum at 0.45 T_m is 6.4 ± 0.3 eV, which is close to the activation energy of self-diffusion in tungsten: 6.6 eV [4]. At this stage some 50% of the total increment in resistivity $\Delta\rho$ is annealed. After the completion of defect annealing at the fifth stage, Keys et al. [19] observed the annealing of $\Delta\rho$ at temperatures up to 1500°C [4], and the annealing spectrum exhibited a peak with a maximum at 0.45 T_m [6]. When studying molybdenum irradiated with a dose of

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$3.5 \cdot 10^{19}$ neutrons/cm^2 (E > 1 MeV) at 600°C [7] under the electron microscope, complex defects such as interstitial and vacancy loops (to use the terminology of Brimhall et al. [7]) 70-1000 Å in size were observed to vanish in the range (0.40-0.45) T_m, with an activation energy close to the activation energy of self-diffusion. All this leads to the conclusion that the annealing stage with a maximum at 0.45 T_m observed in the present investigation may be classified as the sixth stage, and may be associated with the annealing of complex defects.

An interpretation of the results of the annealing of radiation defects in single-crystal tungsten irradiated at (0.20-0.21) T_m with a dose of $1.4 \cdot 10^{22}$ neutrons/cm^2 is presented in Table 3.

After the complete annealing of the radiation defects there is still an appreciable difference between the resistivity of the irradiated and nonirradiated tungsten samples (Fig. 2, Table 2). Analogous data regarding the incomplete annealing of the resistivity increment of irradiated polycrystalline tungsten samples were obtained in [4, 5, 8, 9], and were explained as being due to the formation of rhenium as a result of (n, γ) reactions. Using the relationship between ρ and rhenium content [4, 5] (Table 2) in conjunction with x-ray spectral microanalysis, calculations of nuclear reactions, and measurements of magnetic susceptibility, the proportion of rhenium accumulating as a result of irradiation in the present experiments was estimated as ~0.2%. The amount of rhenium so formed (~0.2%) differed from that indicated in [4, 5] (3% Re), apparently because of the great difference between the neutron spectra of the reactors employed in the several cases.

CONCLUSIONS

1. The irradiation of single-crystal tungsten of the electron-beam zone-melted type with an integrated neutron flux of $1.4 \cdot 10^{22}$ neutrons/cm^2 ($4 \cdot 10^{21}$ neutrons/cm^2 with an energy of E > 1 MeV) at 450-500°C raises the electrical resistivity by 18% at 298°K, 140% at 77°K, and almost 1000 times at 4.2°K, and also causes rhenium to accumulate to the extent of 0.2 at. %.

2. We observed three annealing stages of the radiation defects, identified as follows: at 500-800°C ("stage IV"), small hydrogen aggregates; at 950-1200°C ("stage V"), single vacancies and small vacancy aggregates; at 1200-1900°C ("stage VI"), dislocation loops and pores. The activation energies for these three stages are 0.70 ± 0.03, 3.2 ± 0.3, and 6.4 ± 0.5 eV respectively, and the annealing-rate maxima occur at 0.24, 0.35, and 0.45 T_m.

3. The change in the resistivity of single-crystal tungsten on irradiation is associated with the formation of small aggregates of hydrogen atoms (20.2%), single vacancies (16.5%), complex defects (43.3%), and rhenium (20%).

4. A high integrated neutron flux, a high irradiation temperature, e.g., (0.20-0.21) T_m, and the absence of grain boundaries as sinks for defects lead to the predominant accumulation of complex defects in single-crystal tungsten; these are stable up to 1900°C and their chief effect is that of a change in electrical resistance.

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PRODUCTION OF TRANSURANIC ELEMENTS IN THE SM-2 AND MIR REACTORS

V. A. Davidenko, Yu. S. Zamyatnin,
V. V. Tsykanov, V. Ya. Gabeskiriya,
V. V. Gryzina, Yu. I. Gryzin,
V. V. Ivanenko, A. I. Kashtanov,
A. V. Klinov, Yu. P. Kormushkin,
B. I. Levakov, V. I. Mishunin,
Yu. G. Nikolaev, V. G. Polyukhov,
G. A. Strel'nikov, V. V. Frunze,
A. P. Chetverikov, Yu. V. Chushkin,
V. D. Gavrilov, V. I. Zinkovskii,
Yu. N. Luzin, and N. L. Fatieva

UDC 621.039.554

One ton of burnt-out nuclear fuel yields tens of grams of curium, hundreds of grams of neptunium and americium, and kilograms of plutonium. These elements are directly used in technology; they may also serve as initial or "starting" raw material for the production of heavier isotopes of transuranic elements, many of which possess useful properties.

The natural means of producing substantial quantities of heavy isotopes of curium and transcuric elements for research purposes at the present time is that of irradiating the initial materials in high-flux reactors. Owing to the great variety of properties characterizing the isotopes taking part in the chain of accumulation, different conditions of irradiation have to be used and different methods of processing the irradiated targets have to be adopted for each.

Under the conditions existing in the Scientific-Research Institute of Atomic Reactors, it proved convenient, for the accumulation of Pu^{242}, Am^{243}, and Cm^{244}, to make use of the MIR loop reactor, which has comparatively low flux densities of thermal and resonance neutrons but a large useful volume of the irradiation facilities. For accumulating heavy isotopes of curium and transcuric elements the multipurpose high-flux SM-2 reactor is employed (here the target may be irradiated in the neutron trap, the peripheral channels, and the fuel assemblies of the active zone). The combined use of these reactors gives a wide choice of irradiation conditions in respect of both flux density and neutron spectrum.

The principal characteristics of the SM-2 reactor were given in [1-3]. Since 1965 the reactor has operated at a nominal power of 75 MW. In addition to the production of transuranic elements, an extensive research program is being conducted in this reactor in relation to the behavior of irradiated materials and solid-state physics, as well as developing new fuel compositions and fuel elements for future power reactors; nuclear-physics work is being carried out with extracted beams (in particular, certain nuclear characteristics of the transuranic elements are being measured).

In the central channel of the SM-2, seventeen targets up to 10 mm in diameter and with active parts up to 350 mm long may be irradiated at the same time. The construction of the channel is designed for the loading and unloading of each target separately, which provides for the desired flexibility in carrying out irradiation. The total power of the targets may reach 1000 kW. The construction of the active zone of the reactor, consisting of individual fuel assemblies, allows for the loading of four special fuel assemblies, in each of which eight targets replace missing fuel elements. This enables us to irradiate the initial materials with neutrons of a harder spectrum.

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TABLE 1. Neutron Fluxes in the Irradiation Positions of the SM-2 and MIR Reactors

Irradiation position	Φ_T, neutrons/cm^2·sec	Φ_E, neutrons/cm^2·sec
Center of neutron trap in the SM-2	$3{,}9 \cdot 10^{15}$	$1{,}2 \cdot 10^{14}$
Active zone of the SM-2	$8{,}6 \cdot 10^{13}$	$6{,}7 \cdot 10^{13}$
Central channel of the MIR	$5{,}7 \cdot 10^{14}$	$2{,}7 \cdot 10^{13}$
Fuel-assembly space of the MIR	$4{,}6 \cdot 10^{14}$	$3{,}9 \cdot 10^{13}$

The MIR reactor was broadly described in [4]; it is intended for testing fuel assemblies. In order to use this reactor to accumulate transuranic elements at the same time, extra irradiation facilities were required. This requirement was satisfied by means of a specially constructed channel, lying in the center of the active zone. Eighty targets 10 mm in diameter and 480 mm long are placed in this on two levels. The construction of the channel enables any target to be loaded and unloaded. The total power of the targets in this channel may reach 2600 kW. In addition to this, irradiation may be effected in the fuel assemblies of the reactor. The annular construction of the fuel elements makes it possible to place a target up to 16 mm in diameter and up to 1000 mm long in the central space of the assembly. The power of a target such as this may be 140 kW for a fuel-assembly power of 4 MW.

The neutron fluxes and spectra for all the points of irradiation indicated were determined by calculation, with experimental normalization and verification. The calculations were carried out using a special set of computer programs [5] and a 26-group system of constants [6]. Preliminary calculations of the mean macroscopic cross sections in the thermal group were carried out by the method of [7]. The validity of the calculations was verified for the SM-2 reactor by comparing the experimental and calculated neutron fluxes. The thermal neutron fluxes were measured by the activation of gold foils, using the cadium-difference method, the epithermal neutron fluxes by the activation of resonance indicators. For the central, median, and peripheral cells of the central channel, the following thermal-neutron flux densities were obtained: $3.3 \cdot 10^{15}$, $3.1 \cdot 10^{15}$, and $2.7 \cdot 10^{15}$ neutrons/cm^2·sec respectively (the cadmium cutoff boundary was 0.68 eV). The measuring errors were no greater than 7%. The correctness of the flux calculations in the irradiation positions of the MIR reactor was confirmed by comparing the experimental and calculated distributions of energy evolution in the fuel assembly of the reactor. The distributions were measured by using thin metallic uranium foils. The absolute values of the neutron fluxes were obtained for a fuel-assembly power of 4 MW.

The results of these calculations are presented in Table 1. The thermal-neutron flux Φ_T is indicated for the energy range 0-0.215 eV. The epithermal flux (Φ_E) is given per unit interval of lethargy in the energy range 0.215-10^4 eV in all cases except for the active zone of the SM-2. Since the spectrum of the epithermal neutrons in the active zone of the SM-2 differs considerably from the Fermi distribution (Fig. 1), Table 1 gives the epithermal-neutron flux for the active zone per unit interval of lethargy in the energy range 0.465-10 eV. The data presented in Table 1 were obtained without any absorbing samples being in the irradiation positions. The depression of the flux arising from the insertion of samples was determined by using physical models of the reactors for specific targets.

In order to obtain the isotopes of transuranic elements, targets of the dispersion type were employed.

For the first cycle of irradiation, when the heavy isotopes of plutonium served as initial material, the targets were made by the simultaneous hot extrusion of an aluminum shell with a dispersion core made from a pressed mixture of aluminum powder and plutonium oxide. The high thermal conductivity of the construction materials used and the absence of thermal resistance between the core and the shell enabled high thermal loadings to be achieved in these targets for a comparatively low temperature of the core and low temperature gradients. For the next cycle of irradiation, in which the initial materials were isotopes of americium and curium, more simply prepared targets of the container type were employed. The cores of these targets consisted of aluminum capsules filled with a pressed mixture of aluminum powder and the oxide of the initial material. The capsules were enclosed in an aluminum tube, which was then sealed.

The airtightness of the targets was monitored during irradiation by reference to the radioactivity in the coolant.

In view of the satisfactory efficiency displayed by all these types of targets, there was no need to monitor their material characteristics systematically, except in the case of samples cut from targets which lost their airtightness during irradiation. In one case of the rupture of a hot-extruded dispersion target irradiated with an integrated flux of $6 \cdot 10^{22}$ neutrons/cm^2, the damaged section constituted a burn in the shape of a cavern. The reason for the burnt-out region was evidently a random nonuniformity in the

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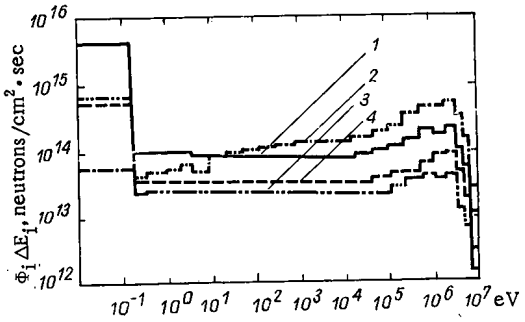

Fig. 1. Group neutron fluxes in the irradiation positions: 1) center of the neutron trap of the SM-2; 2) active zone of the SM-2; 3) central channel of the MIR; 4) water space of the fuel assembly of the MIR.

TABLE 2. Neutron Cross Sections (2200 m/sec) and Resonance Integrals (from 0.5 eV) Used for Calculating the Accumulation of the Transuranic Elements (b)

Isotope	σ_γ	I_γ	σ_f	I_f
Pu^{239}	270	240	740	330
Pu^{240}	280	8500	0	0
Pu^{241}	370	170	1000	550
Pu^{242}	18	1100	0	0
Am^{241}	750/75	2000/300	3	10
Am^{243}	90	2000	0	0
Cm^{244}	10	650	2	70
Cm^{245}	350	100	2000	700
Cm^{246}	3	110	0	0
Cm^{247}	70	200	270	1000
Cm^{248}	1,5	250	0	0
Bk^{249}	1700	2000	0	0
Cf^{250}	1800	5000	0	0
Cf^{251}	2000	300	4600	700
Cf^{252}	20	40	0	0

distribution of the initial material. As a result of prolonged corrosion the external diameter of these targets diminished by an average of 17%. It was therefore essential to make a careful choice of the thickness of the target shell in relation to the period and conditions of irradiation.

In order to select the optimum conditions for obtaining isotopes of transuranic elements, we studied the accumulation of the isotopes in different irradiation positions of the SM-2 and MIR reactors. To this end we proceeded as follows: 1) we calculated the rates of isotope accumulation on the basis of published cross sections of the interactions between neutrons and the nuclei incorporated in the chains of accumulation; 2) we measured the effective interaction cross sections of these nuclei with the reactor neutrons by irradiating thin samples, and at the same time measuring the integrated neutron fluxes; 3) we determined the quantities of accumulated isotopes from the results of the radiochemical reprocessing of the real irradiated targets, and chose a matched system of constants to describe the accumulation processes.

The reaction velocities in the isotope-accumulation chains were calculated by means of the following equation, using the resonance integrals given in Table 2, together with the cross sections for a neutron velocity of 2200 m/sec:

$$B_i = \sigma_T^i \Phi_T + I_i \Phi_E = \hat{\sigma}_i n v_0,$$

where B_i is the velocity of the nuclear reaction in the i-th isotope; $\hat{\sigma}_i$ is the effective Westcott cross section; nv_0 is the nominal Westcott flux; σ_T^i is the partial reaction cross section averaged over the Maxwell spectrum; and I_i is the resonance integral of the isotope.

In order to average the cross sections in the thermal group of neutrons, it was assumed that, in the energy range 0-0.215 eV, the cross sections of all the isotopes except Pu^{239}, Pu^{241}, and Am^{243} obeyed the 1/v law. For the three isotopes indicated, allowance was made for the contribution of resonances lying below the cadmium limit. The value of the neutron flux used for calculating the effective cross sections was found from the velocity of the reaction in the 1/v absorber and the known neutron spectrum. The resultant effective cross sections $\hat{\sigma}_i$ were compared with their values found experimentally. The extension of this simplified approach to the case of the hard spectrum of the active zone of the SM-2 leads to considerable errors.

For the experimental determination of the cross sections, thin samples of various isotopes of the transuranic elements were irradiated. The test isotopes were taken in quantities of 100-200 μg and deposited on an aluminum foil (area ~0.3 cm^2), and then loaded into individual aluminum capsules together with a uranium monitor containing ~50 μg of U^{235}. A set of capsules with different isotopes was loaded into an aluminum ampoule.

In analyzing the composition of the samples before and after irradiation a mass-spectrometer method was employed. The absolute quantity of the isotopes under examination was determined radiometrically and

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TABLE 3. Experimental and Calculated Values of the Effective Cross Sections of Isotopes of Transuranic Elements in the Irradiating Positions of the SM-2 Reactor (b)

Effective cross section	Isotope	Central channel		Active zone
		experiment	calculation	experiment
$\hat{\sigma}_a$	Pu^{239}	1477±22	1130	1590±120
$\hat{\sigma}_a$	Pu^{240}	871±12	800	2880±80
$\hat{\sigma}_a$	Pu^{241}	1450	1430	1530±80
$\hat{\sigma}_a$	Pu^{242}	86	86	690±30
$\hat{\sigma}_a$	Am^{241}	960±120	940	1800±100
$\hat{\sigma}$	$Am^{241}(n, \gamma)\,^{242}Am$	870±120	845	—
$\hat{\sigma}$	$Am^{241}(n, \gamma)\,^{242m}Am$	90±15	91	—
$\hat{\sigma}_a$	Am^{243}	215	210	1300±60
$\hat{\sigma}_a$	Cm^{244}	54	56	600±30
$\hat{\sigma}_a$	Cm^{245}	2970	2310	2900±120
$\hat{\sigma}_\gamma$	Cm^{245}	350	340	—
$\hat{\sigma}_a$	Cm^{246}	13	15	—
$\hat{\sigma}_a$	Cm^{247}	380	400	—
$\hat{\sigma}_\gamma$	Cm^{247}	90	80	—
$\hat{\sigma}_a$	Cm^{248}	14	20	—
$\hat{\sigma}_a$	Bk^{249}	(3800)	1760	—
$\hat{\sigma}_a$	Cf^{250}	2000	2040	—
$\hat{\sigma}_a$	Cf^{251}	6300	6410	—
$\hat{\sigma}_\gamma$	Cf^{251}	2100	1940	—
$\hat{\sigma}_a$	Cf^{252}	30	22	—

Note: The cross sections with the errors indicated in the table were measured with the aid of thin samples. The accuracy of the cross sections of Pu^{242}, Am^{243}, Cm^{244} was ±10%, that of the other isotopes ±15%. The cross section of Bk^{249} is approximate. The burn-up of Cf^{253} was not taken into account.

mass-spectrometrically using the isotope-dilution technique. The completeness of separation of the isotopes was checked by reference to the material balance, the quantity of fission products being determined by reference to the γ radiation of Cs^{137}.

The integrated neutron flux was determined from the change in the isotope composition of the uranium monitors, which enabled the integrated fluxes to be determined in the range $(1.5\text{-}9) \cdot 10^{21}$ neutrons/cm^2 to an accuracy of ±2%.

The results of our measurements of $\hat{\sigma}$ in the central channel and the active zone of the SM-2 reactor are presented in Table 3. A comparison of the resultant cross sections shows that an increase in the hardness of the neutron spectrum leads to a sharp rise in the $\hat{\sigma}$ of the isotopes Pu^{240}, Pu^{242}, Am^{243}, and Cm^{244}, which have high values of the resonance integrals. In this way, samples of plutonium, americium, and curium containing up to 65% Pu^{241}, up to 3% Am^{242m}, and up to 15% Cm^{245} were successfully obtained in the active zone of the SM-2 reactor, this being several times greater than the amounts of the isotopes in question in samples irradiated in ordinary thermal reactors.

The results obtained in experiments with thin samples cannot be entirely transferred to the case of real targets containing several grams of the initial material, owing to the self-screening effect. An exact calculation of self-screening is not always possible; the rate of accumulation of the isotopes in the real targets was therefore determined from the actual yield of these isotopes. In some cases analysis was accordingly conducted by cutting columns 1-2 mm high from the targets. The methods of analysis were the same as in the case of the thin samples.

After feeding the measured yield into an electron computer, the effective cross sections best fitting the experimental results were selected. As reference cross section we used the effective absorption cross section of Pu^{241} (1450 b), which depends very little on the neutron spectrum. The data so derived are also presented in Table 3. These quantities are to a considerable degree provisional, since they depend on the type of targets and the manner of loading these with the initial material. The agreement between the majority of the experimental cross sections (obtained from an analysis of real targets) and the calculated values may be attributed to the fact that the concentration of the isotopes has not yet reached a level at which self-screening would play an appreciable part.

On the basis of the measured cross sections we calculated the accumulation of the isotopes of curium, berkelium, and californium on irradiating Pu^{242} in the central channel of the SM-2 reactor. The results of the calculation are presented in Fig. 2.

The experimental data relating to the accumulation of californium in irradiated targets obtained by periodically measuring the neutron activity of the targets during the shut-down periods of the reactor are presented in Fig. 3. For recording the neutrons we used activation and track-type detectors. Curve 1 shows the growth in the total neutron activity as the transplutonic elements accumulate; curve 2, characterizing the accumulation of Cf^{252}, was obtained by subtracting the contribution of other spontaneously fissile isotopes and (α, n) reactions to the neutron activity from curve 1. The difference between curve 2 and the calculated curve 3 may be partly ascribed to the nonuniformity of the neutron flux with respect to the height of the targets and to the complexity involved in calculating the yield of californium under such conditions.

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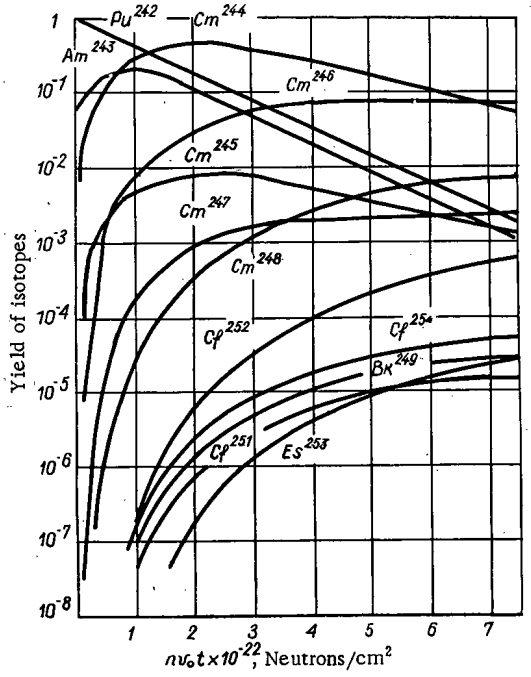

Fig. 2

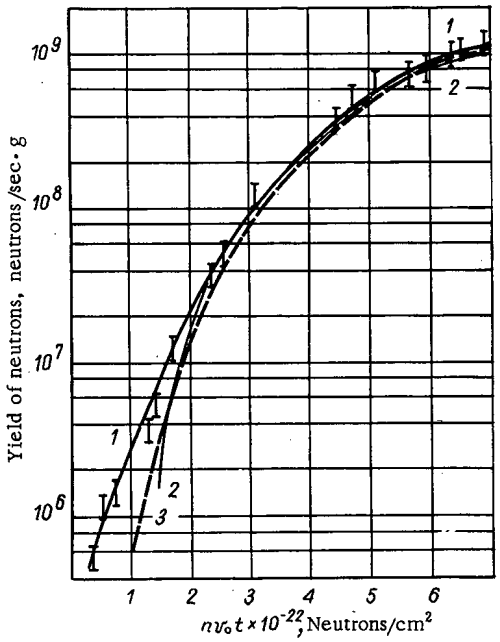

Fig. 3

Fig. 2. Accumulation of isotopes of the transplutonic elements by the irradiation of Pu^{242} in the central channel of the SM-2 reactor.

Fig. 3. Neutron activity of the target (per gram of Pu^{242}): 1) total neutron activity of the target; 2, 3) neutron activity of Cf^{252}, experimental and calculated respectively.

CONCLUSIONS

The relative rates of accumulation of the individual isotopes of the transuranic elements (and hence also the isotopic compositions of these elements) may vary over a wide range in accordance with the conditions of irradiation of the initial materials. The effective cross sections for the capture of the neutrons by even–even and odd–even nuclei increase substantially as the proportion of resonance neutrons in the reactor spectrum increases. Hence the irradiation of the original materials in the hard spectrum of the active zone of the SM-2 leads to the formation of elements with a high concentration of isotopes having an odd number of neutrons. This enables us to produce elements with sharply differing isotopic compositions, which in turn eases the study of the nuclear properties of individual isotopes.

The successful combination of the high thermal-neutron flux in the trap of the SM-2 reactor, the hard neutron spectrum in the active zone of this reactor, and the large spaces available for irradiation in the MIR enables us to accumulate the desired isotopes under almost optimum conditions in every case.

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SPUTTERING OF TRANSURANIUM ELEMENTS BY FISSION FRAGMENTS

B. M. Aleksandrov, I. A. Baranov,
A. S. Krivokhatskii, and G. A. Tutin

UDC 546.799

References [1-3] deal with studies of self-sputtering of fissionable isotopes by fission fragments. However, there is still insufficient experimental data to explain the mechanism of this phenomenon. In the literature there are few reports on sputtering of a substance by fission fragments from an external source [4, 5]. The purpose of the present work is to study sputtering of a substance by fission fragments originating inside the substance (Cf^{252} layers) and by fission fragments from an external source, and also to investigate the effect of the average fragment energy on the sputtering coefficients.

Self-Sputtering of Cf^{252}

We prepared by electrolysis four californium sources on platinum discs with the diameter of the active spot 8 mm and Cf density 8, 1.5, 0.8, and 0.2 $\mu g/cm^2$. To calculate the number of fragments arising in the layer during spontaneous fission of californium and passing through the layer surface, we took the half-life to be 85 yr. Collection of the sputtered Cf atoms was done on metallic discs which were placed above the sources at a distance of 0.9 mm. The number of transferred Cf atoms was determined by the α activity of the collector; the measurement accuracy was no worse than 7%. The number of Cf atoms sputtered by one fragment was calculated by dividing the total number of Cf atoms collected on the collector by the total number of fragments which pass through the surface of the layer (equal to the number of fission events). The exposure time was 1 h. Each point was measured during two or three exposures; the dispersion of the results was no more than ±15%.

We studied the dependence of the number of collected Cf atoms on the variation in polarity and field strength between the collectors and sources at atmospheric pressure (Fig. 1), on the air pressure (Fig. 2), and on the variation of distance between the collector and the source (Fig. 3). The number of Cf atoms sputtered on the average by one fragment in a vacuum (10^{-2} torr) and collected on the collector in the absence of an electric field is 3800, 150, 75, and 50 for sources with Cf density 8, 1.5, 0.8, and 0.2 $\mu g/cm^2$,

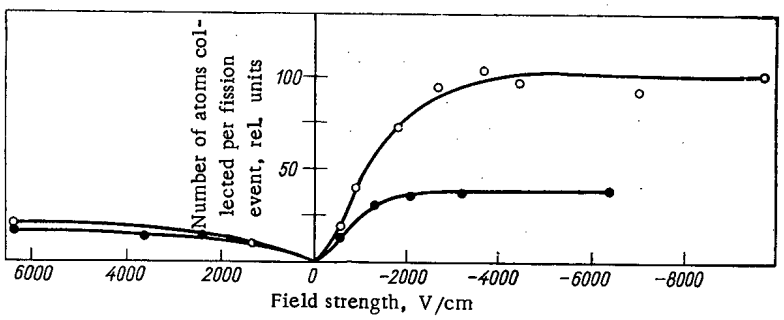

Fig. 1. Dependence of the number of collected Cf atoms on the variation of polarity and field strength between collectors and sources; density: 1.5 $\mu g/cm^2$ (open circles) and 0.2 $\mu g/cm^2$ (dark circles).

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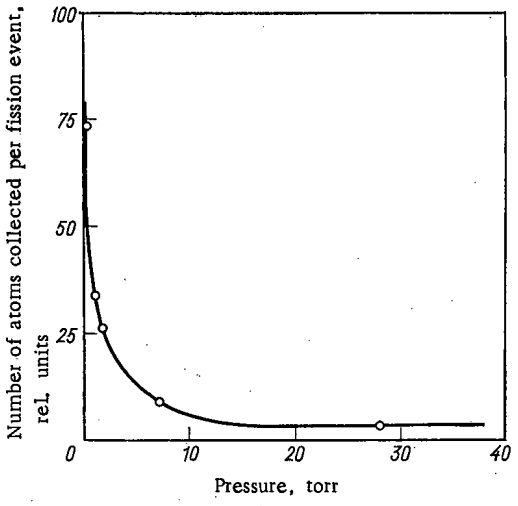

Fig. 2

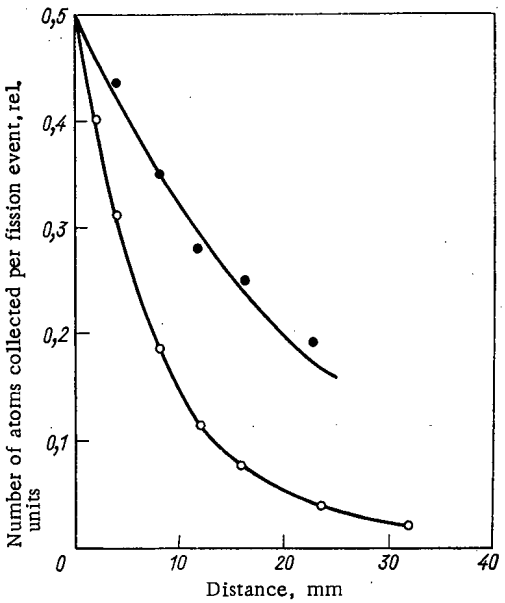

Fig. 3

Fig. 2. Dependence of the number of collected Cf atoms on the variation of air pressure with no electric field.

Fig. 3. Dependence of the number of collected Cf atoms on the variation of the distance between the Cf collector and source at pressure 10^{-2} torr with no electric field. ●) experimental; ○) calculated according to the data of [6] on the assumption that the sputtered atoms are emitted from the layer with equal probability in all directions.

respectively. Using the techniques of vitreous track detectors of fission fragments, we observed groups of Cf atoms on the collectors, the largest of which consisted of $2 \cdot 10^4$ Cf atoms.

Sputtering of Transuranium Elements by Fission Fragments from an External Source

The apparatus which we used in these experiments is shown in Fig. 4. We used Cf^{252} as the source of fission fragments and layers of Pu^{238}, Pu^{239}, and Am^{241} on thick metal backings as sputtering substances. The number of atoms of these isotopes in the sputtered layers and on the collectors was determined by their α activity. When the collimator was used, the fragments entered the sputtering substance almost perpendicularly; the light fragments at an average energy of 65 MeV and the heavy fragments, 47 MeV. Without the collimator, these values were 85 and 60 MeV, respectively. The energy of the fragments was measured by a surface-barrier silicon counter which was put in place of the sputtered layer. The exposure time in sputtering the layers was 12-24 h, depending on the half-life of the isotope being sputtered. The experiments were conducted at atmospheric pressure in order to minimize the transfer of Cf atoms to the shielding nickel film due to the self-sputtering of the fission-fragment source, which we expect from the previous section. The characteristics of the sputtered layers and the experimental results are shown in Table 1. Control measurements with these layers, both at atmospheric pressure with field strength 3500 V/cm (negative on the collector), and in a vacuum with no electric field without fission fragments from an external source showed that 0.2-2 atoms of Pu or Am collect at the collectors for each α decay in the layer. In order to elucidate the role of α particles and recoil nuclei which are formed in the α decay process in the self-sputtering of the material, a layer of Pu^{238} was irradiated as in Fig. 4 without the collimator by a stream of particles (also from Pu^{238}) 20 times more intense than the natural number of α particles arising in the sputtered layer and passing through its surface. It is clear that the recoil nuclei of the external (more intense) α source were trapped by the Ni films and could not reach the sputtered layer. It turned out that an increase in the irradiation of the sputtered layer only by α particles from the external source did not noticeably change the number of Pu atoms collecting at the collector per unit time. From this it follows that in all cases of self-sputtering of thin α sources the fundamental role in sputtering of the material is played, evidently, not by α particles, but by recoil nuclei from α decay, which have kinetic energy ~90 keV. Table 1 takes account of the results of the control measurements, i.e., the effect of α decay.

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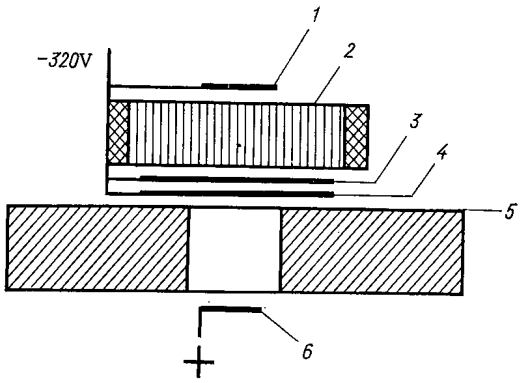

Fig. 4

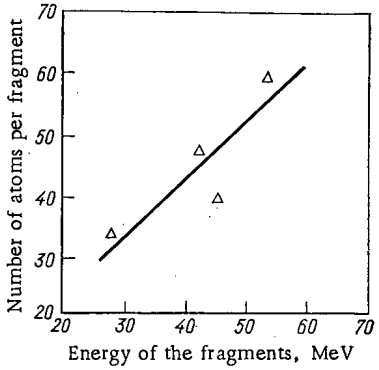

Fig. 5

Fig. 4. Diagram of the experiments on sputtering of a substance by fission fragments from an external source and on collection of atoms on a thin collector backing: 1) source of Cf^{252} fission fragments; 2) copper collimator 1.3 mm thick with collimation angle ±8°; 3) thin shielding nickel film approx. 100 $\mu g/cm^2$; 4) thin nickel collector film; 5) plastic diaphragm 0.9 mm thick; 6) sputtered layer of plutonium or americium. Negative potential is applied to 1, 2, 3, and 4; positive potential (320 V) is applied to 6.

Fig. 5. Dependence of the number of sputtered atoms on the energy of the fragments.

We studied the dependence of the sputtering coefficient of the atoms on the energy of the fission fragments. We irradiated a layer of americium whose density was 2 $\mu g/cm^2$. We made measurements using a collimator as in Fig. 4. The energy of the fragments was varied by moderating them in films of various thicknesses. It turned out that, when the energy of the fragments is increased on the average for a heavy group from 21 to 47 MeV, and for a light group from 34 to 65 MeV, the number of atoms sputtered by one fragment increases from 32 to 60 (Fig. 5). The accuracy of reproducing the results was the same as in the first section (±15%).

DISCUSSION OF RESULTS

The self-sputtering coefficients of thin Cf^{252} sources, found in the present work, are 10^2-10^3 atoms per fragment, depending on the density of the layer, and they approximately coincide with the data of [2], but they are approximately two orders of magnitude lower than the self-sputtering coefficients of thin Cm^{244} layers [3]. However, the self-sputtering of thin Cm^{244} layers should be linked, apparently, fundamentally with the recoil nuclei which appear during α decay of Cm^{244}, and not with the fragments of spontaneous Cm fission. In fact, the period of spontaneous Cm^{244} fission is $\sim 10^6$ times greater than the period of its α decay, and the self-sputtering coefficients of the substance by recoil nuclei from α decay are significant, as was shown by the control measurements of the present work (0.2-2 atoms/nucleus recoil) and the data of [7] (0.1-10 atoms/ion with energy up to 100 keV).

Examining the data on self-sputtering of Cf layers given in Figs. 1-3, one can see that the collection of atoms with a positive potential on the collector is 2-4 times smaller than the collection of atoms with negative potential, which in turn is 55-75% of the collection of atoms in a vacuum without an electric field. When the air pressure is 4-5 torr in the absence of a field, a small portion of the sputtered atoms collects on the collector, i.e., the mean free path of the majority of atoms at atmospheric pressure is less than 4-6 μ. The collection of atoms in a vacuum decreases noticeably more slowly with increasing distance than should follow from the assumption of equally probable emission of the sputtered atoms in all directions. Thus, the angular distribution of the material sputtered by the fragments is characterized by preferential emission in the direction perpendicular to the surface of the sputtered layer. Inasmuch as the fragments escape from the Cf layers in various directions with equal probability, the dependence obtained can be explained by sputtering of the material from craters of a definite depth, and not from the surface of the layers. The data obtained for the self-sputtering of Cf layers allow one to choose the optimal conditions of preparation of thin spectrometric Cf^{252} sources by the method of self-sputtering, and also to choose the conditions of their storage and use.

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TABLE 1. Sputtering of Plutonium and Americium by Fission Fragments from an External Source

Sputtered isotope	Thickness of the active layer, $\mu g/cm^2$	Number of collected atoms of Pu or Am in the calculation per fission fragment from the external source		Method of preparing layers and type of compound
		without collimator	with collimator	
Pu^{238}	0,4	—	50	Thermal sputtering in vacuum; plutonium dioxide
Am^{241}	2	130	70	Thermal sputtering in vacuum; americium dioxide
Pu^{238}	60	100	60	Electrolysis and annealing of the layer; plutonium dioxide
Pu^{239}	70	900	—	Electrolysis without annealing of the layer; plutonium hydroxide, desiccated in air

The results of the studies of the sputtering of thin layers of Pu and Am by fission fragments from an external source show that, in this case, on the average, 10^2-10^3 atoms are sputtered by one fragment. It should be noted that two layers of plutonium which are approximately identical in their density have extremely different sputtering coefficients: 100 and 900 atoms/fragment. Apparently, the quality of the surface and the type of compound of the sputtered element are significant and special investigations are needed in this area. The number of atoms sputtered by one fragment when a collimator is used is approximately 1.5 times smaller than without a collimator. This can be linked to the fact that in the latter case a certain number of fragments arrived at the layer at large angles to its surface.

The dependence of the number of sputtered atoms on the energy of the fragments indicates that the mechanism of sputtering (and, consequently, the mechanism of radiation damage in a substance) is linked to the unit ionization losses of the fragments, and not to the energy losses of the fragments to elastic collisions along the track. It follows from our results that, the greater the kinetic energy of the fragments, the greater the number of atoms which are sputtered from a thin layer of a material. It is known that ionization losses of fragments are greater at the start of the track and less at the end, while energy losses of the fragments to elastic collisions increase towards the end of the path. Possible energy-transfer mechanisms which could explain the results are an ion burst [8] or a thermal electron peak [9].

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U^{238} RADIATIVE CAPTURE CROSS SECTION FOR 5 TO 20 MeV NEUTRONS

Yu. G. Panitkin and V. A. Tolstikov

UDC 539.172.4

The neutron radiative capture cross section in U^{238} is needed for fast-reactor calculations. In addition, a knowledge of the neutron radiative capture cross section is of interest in the refinement of models of the nucleus and of nuclear reactions. This paper is a continuation of previously published work on neutron radiative capture in U^{238} over a broad range of neutron energies [1-3].

The neutron radiative capture cross section in U^{238} was measured over the neutron energy range 5-20 MeV. The measurements were made at electrostatic accelerators with maximum energies of 2.5 and 5 MeV using the activation method. The reaction D(d, n)He^3 was used as a neutron source in the energy range 5-7 MeV. A fission chamber with a layer of U^{235} was used as a neutron flux monitor. Samples were placed directly on the wall of the fission chamber. Induced activity was measured with a Ge—Li detector using the 74 keV γ line. After subtraction of the background from the backing, the integral under the 74 keV peak corresponds to the induced activity of U^{238}. Before measurement of induced activity, U^{238} fission products were removed from the samples by chemical means.

The background from neutrons scattered in the target chamber of the accelerator was measured as the deviation from the inverse square law when the sample and chamber were placed at various distances from the target; it amounted to 1-2% of the quantity measured in the direct beam.

Inelastic scattering by structural materials in the target leads to the appearance of low-energy neutrons, which have a much greater capture probability than that of neutrons from the D(d, n)He^3 reaction. Because of the lack of data on inelastic scattering of neutrons at energies above 4 MeV, measurements of neutrons inelastically scattered at the face of the target were made by means of an equivalent target face "addition" placed on the face of the target. In this situation, the contribution from neutrons scattered at the face of the target is determined from the difference of two experimentally measured values: 1) sample activation or fission chamber count when working with the target; 2) sample activation or fission chamber count when working with the target plus the "addition."

The fraction of scattered neutrons is

$$I_{p_1}/I_0 = (I_A/I_0 - 1)\, e^{an\sigma},$$

where $I_0 = I + I_{p1}$; $I_A = I_0 + I_{p2}$; I_0 is the fission chamber count and sample activation when working with the target; I is the fission chamber count and sample activation from "direct" neutrons from the target; I_{p1} is the fission chamber count and sample activation from neutrons scattered by the target structure; I_A is the fission chamber count and sample activation for operation of target plus "addition"; I_{p2} is the fission chamber count and sample activation resulting from neutron scattering in the "addition"; a is a constant which depends on the irradiation geometry; $n\sigma$ is the microscopic absorption cross section for neutrons in materials of the "addition" along the path of the scattered neutron from the point of origin to the point of irradiation. For a U^{238} sample, this contribution was approximately 10-12% depending upon the neutron energy and ~2% for the fission chamber.

In bombardment of a target by a beam of accelerated deuterons, injection of deuterons into the target backing occurs. As a result, the D(d, n)He^3 reaction takes place at lower deuteron energies than at the surface of the target. The background contribution of such neutrons was measured by replacement of the

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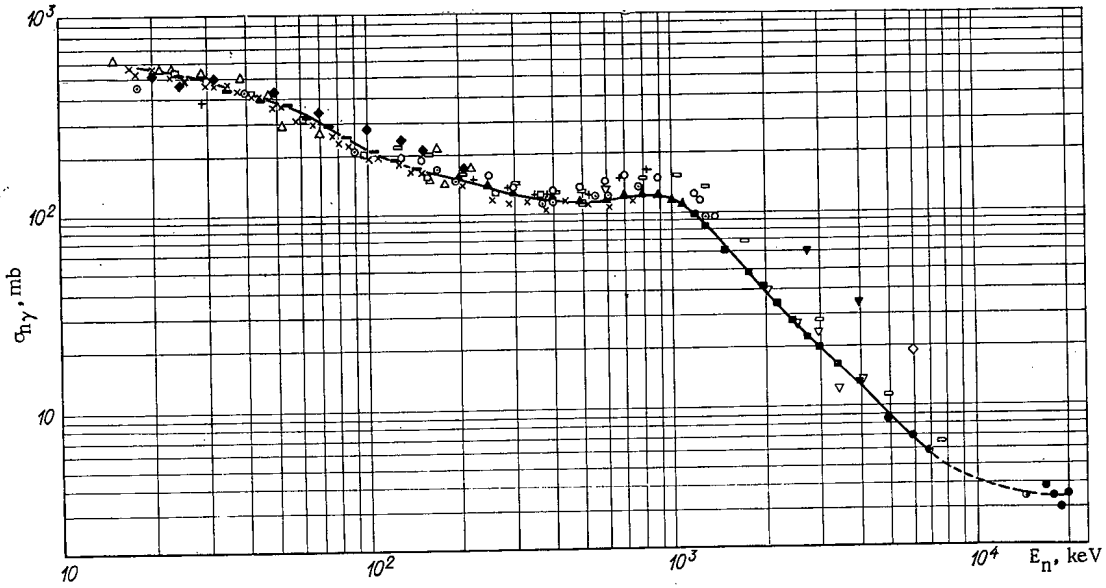

Fig. 1. Radiative capture cross section of U^{238}: ●) present work; ■) [1]; ▲) [2]; ■) [3]; □) [4]; ▭) [6]; ▽) [7]; ▼) [8]; ○) [9]; ○) [10]; ×) [11]; +) [12]; +) [13]; –·–) [14]; △) [15]; ◇) [16]; ◑) [18].

TABLE 1. Measured Radiative Capture Cross Sections

E_n, MeV	N^{238}/N^{235}	σ^{235}/σ^{Al}, b/mb	σ^{238}, mb
5,0±0,115	0,066±0,008	1,09	8,3±1
6,0±0,136	0,053±0,007	1,11	6,8±0,9
7,0±0,160	0,032±0,006	1,59	5,8±1,1
17,0±0,260	0,157±0,045	50±10	3,7±1,3
18,0±0,235	0,174±0,055	40±8	3,3±1,2
19,0±0,250	0,152±0,066	40±8	2,9±1,4
20,0±0,285	0,284±0,150	25±5	3,36±1,9

Note: Matching of the cross section for neutron flux monitoring with aluminum was done at 5 MeV.

deuterium target with a molybdenum backing. For a U^{238} sample, this contribution was 10-80% of the value measured in the direct beam depending on the energy of the incident deuterons and was of the order of 2-25% for the fission chamber.

The layer of U^{235} in the fission chamber contains other fissile nuclei as impurities which contribute to the fission chamber count. The correction for this effect can be determined from the expression

$$N_5^k = \frac{N_5^{1k} N_5 \sigma_5^k}{\sum_{ik} N_i \sigma_{ik}},$$

where N_5^k is the "true" fission chamber count for neutrons of energy k; N_5^{1k} is the experimentally measured fission chamber count for neutrons of energy k; N_5 is the fraction of U^{235} nuclei in the fission chamber layer; σ_5^k is the fission cross section of U^{235} for neutrons of energy k; N_i is the fraction of fissile nuclei of the i-th kind in the fission chamber layer; σ_{ik} is the fission cross section of the i-th component of the fission chamber layer for neutrons of energy k. The correction was approximately 4%.

The T(d, n)He^4 reaction was the source of 17 to 20 MeV neutrons. The reaction Al^{27}(n, p)Mg^{27} was used as the neutron flux monitor. The sample was placed together with the neutron flux monitor – an aluminum foil. The induced activity of sample and flux monitor was measured with a Ge–Li detector in the appropriate range of γ-ray energies. Before measurement of induced activity in the sample, fission products of U^{238} were removed from the sample by chemical means.

The background from neutrons scattered in the target chamber of the accelerator and inelastic scattering by structural materials in the target were measured as described above and amounted to ~2% and ~10% respectively.

As in the previous case, injection of deuterons into the target occurs during irradiation of the target by a flux of accelerated deuterons leading to the creation of an additional neutron group from the D(d, n)He^3 having a much greater capture probability than that for neutrons from the T(d, n)He^4 reaction. The background contribution from such neutrons was measured by replacement of the tritium target by a backing having a titanium layer not saturated with tritium. For U^{238}, this contribution was 10-80% of the value measured in the direct neutron beam depending on the energy of the incident deuterons and the time of the next irradiation; it was of the order of 2-20% for the aluminum foil.

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The results are given in Table 1 and Fig. 1. The figure also shows data obtained earlier by the authors [1-3] and other results [7-17].

In the neutron energy range 4-7 MeV, the error in resultant radiative capture cross section for U^{238} is the root-mean-square error of the experiment including errors in the introduced corrections but not including errors in the fission cross section of U^{235} and in the reference capture cross section of U^{238}. The radiative capture cross section at 24.4 keV, which is 516 mb [4], was used as the reference cross section for neutron radiative capture in U^{238}. The fission cross section for U^{235} was taken from [5]. It should be pointed out that the data from [11] given in Fig. 1 were normalized at 30 keV to the value of the averaged radiative capture cross section given in [17]. The figure clearly shows that our results are 20-30% lower than those of [6] in this energy range.

In the neutron energy range 17-20 MeV, the error in the resultant radiative capture cross section for U^{238} is the root-mean-square error of the experiment including the errors in the corrections used and in the cross section for the $Al^{27}(m, p)Mg^{27}$ reaction [19, 20]; however, the error in the reference cross section of U^{238} taken from [4] was not taken into account. Unfortunately, there are no sufficiently reliable data which can be used for comparison in this range of neutron energies. It should be noted that the radiative capture cross section falls insignificantly for neutron energies above 14 MeV.

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PRODUCTION OF SPONTANEOUSLY FISSIONING ISOMERS WITH NANOSECOND LIFETIMES IN α-PARTICLE REACTIONS

Yu. P. Gangrskii, Nguen Kong Khan, and D. D. Pulatov

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In some nuclei of the actinide series, isomeric states are observed with half-lives of 10^{-9}–10^{-2} sec which mainly decay by spontaneous fission [1-4]. The unusual properties of these states (small spin and high excitation energy, marked increase in the probability for spontaneous fission, correlation of isomer formation and induced fission) indicate their connection with a complex structure for the fission barrier. Recent calculations [5, 6] indicate the dependence of nuclear potential energy on deformation is not described by a simple parabola and the actual fission barrier has a minimum in the region of the saddle point. Sometimes this minimum is sufficiently deep so that there is a level system within it with the lowest level being isomeric (the barrier separating the first and second potential wells being the reason for suppression of γ radiation from the isomeric level). A study of spontaneously fissioning isomers makes it possible to obtain information about the shape of the fission barrier and about nuclear properties for anomalously large deformations.

The purpose of this paper is the determination of the extent of spontaneously fissioning isomers and the measurement of the production cross section for these states in α-particle reactions over a broad range of A and Z.

EXPERIMENTAL METHOD

The experiments were performed at the U-200 isochronous cyclotron of the Laboratory of Nuclear Reactions, JINR. The energy of the α particles accelerated in the cyclotron was 36 MeV. Energy reduction was achieved by means of aluminum filters.

Measurement of the time of flight of recoil nuclei [7] was used to determine the half-life of spontaneously fissioning isomers. The experimental arrangement is shown in Fig. 1. A collimated beam of α particles is incident on the target; ejected recoil nuclei, travelling a certain distance depending on the lifetime of the isomeric state, decay into two fragments, one of which is recorded by a dielectric detector. The relative location of target and detector was such that incidence on the detector of fragments from induced fission in the target was eliminated. Muscovite mica was used as the dielectric detector. After irradiation, the mica was etched in concentrated hydrofluoric acid for 2-3 h at 18°C and examined under a microscope.

The half-life of a spontaneously fissioning isomer formed in the reaction was determined from the radial distribution of tracks in the mica. Figure 2 shows radial distributions of tracks computed for various half-lives and measured experimentally for isomers of Pu^{240} and Cm^{243}. It is clear the accuracy of the measurements is low, particularly for half-lives greater than 50 nsec. For greater accuracy in the half-life measurement, therefore, the angle of incidence of the fragments at the mica was also measured (this was usually done in the case of previously unknown isomers). From the value of the angle and the coordinate of the track, one can determine the distance covered by the recoil nucleus before decay and, consequently, also the times involved.

Fission fragments leave tracks in the mica if the recoil nucleus fissions at a distance greater than 1 mm from the target. This makes it possible to measure half-lives down to 0.5 nsec with high efficiency

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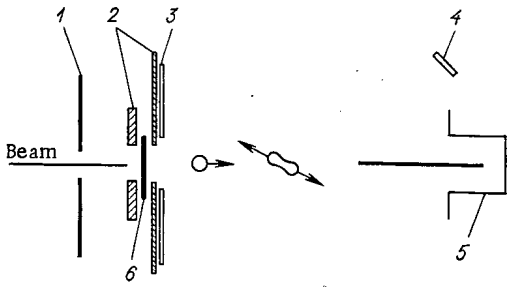

Fig. 1

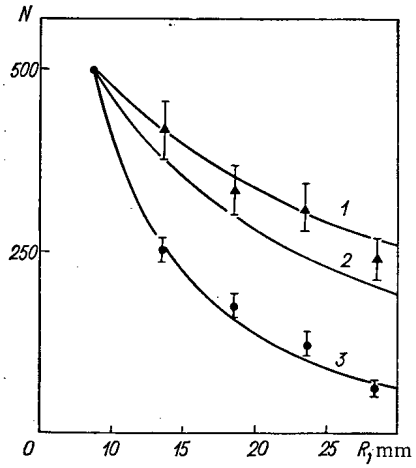

Fig. 2

Fig. 1. Experimental arrangement: 1) collimator for α-particle beam; 2) target holder; 3) detector of delayed fission fragments; 4) detector of prompt fission fragments; 5) Faraday cup; 6) target.

Fig. 2. Radial distribution of tracks in mica: ▲) Pu^{242} (α, 3n)Cm^{243} reaction; ●) U^{238} (α, 2n)Pu^{240} reaction; solid curves were computed from experimental geometry for various half-lives, 1) 100 nsec; 2) 40 nsec; 3) 5 nsec.

(more than 5%). This technique is especially suitable for the observation of short-lived spontaneously fissioning isomers because a background from long-lived emitters of fission fragments is practically nonexistent (decay of the recoil nuclei occurs sufficiently far from the detectors).

The main source of background was fission of uranium contained in the mica through the action of neutrons created in interactions of α particles with collimator, absorbers, and target. By selecting mica with a low uranium content ($<10^{-6}$%), one can measure reaction cross sections down to 10^{-33} cm^2.

The intensity of the α-particle beam was determined with a Faraday cup. In addition, the yield of fragments from prompt fission in the target was measured with a dielectric detector (silicate glass) located near the Faraday cup.

Determination of Reaction Cross Section

In the experiment, the ratio of the number of fragments at the detectors for delayed and prompt fission was measured. In order to obtain from this ratio the ratio of the cross section for isomer formation, σ_i, and the cross section for prompt fission, σ_f, it is necessary to take into account the efficiency of fragment detection and the effective thickness of the target.

The detection efficiency for fragments from prompt fission was calculated from the experimental geometry. A correction was introduced for the anisotropy of the angular distribution. In the case of delayed fission, the detection efficiency depends on the half-life. The measured angular distribution of fragments from delayed fission turned out to be isotropic within the limits of experimental error (15%); therefore no correction for anisotropy was introduced.

In the experiments, target thicknesses of 0.2-0.4 mg/cm^2 were used; this is less than the range of the fragments and greater than the range of the recoil nuclei. Consequently, fragments from prompt fission escape from the entire thickness of the target while recoil nuclei come only from the surface layer. The thickness of this layer was computed on the basis of the range of heavy nuclei in matter [8]. However, the actual thickness of the layer from which recoil nuclei escape is usually less than the calculated value because of contaminants on the surface of the target. To determine the effective thickness of the layer, the yields of Pu^{236} and Cm^{240} recoil nuclei were measured for the U^{235}(α, 3n) and Pu^{239}(α, 3n) reactions, for which the cross sections are known [9, 10]. The measurements showed that the actual thickness of the layer from which the recoil nuclei Pu^{236} and Cm^{240} escaped was 30% of the calculated value. This experimentally obtained effective target thickness was used in the determination of the ratio σ_i/σ_f. The error

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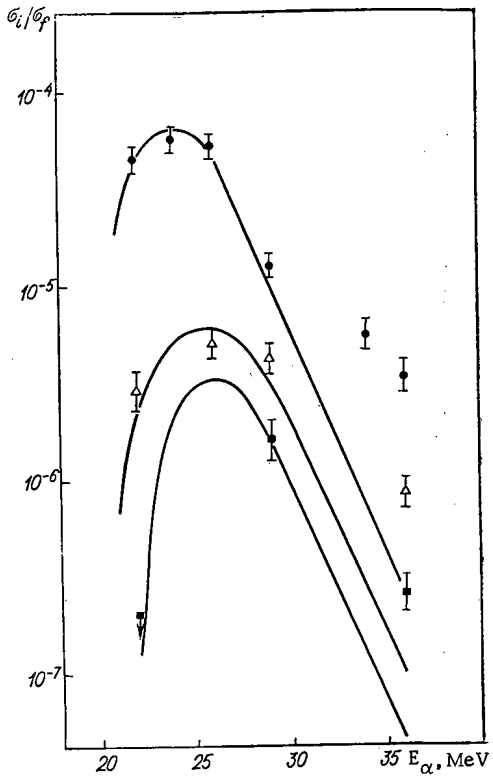

Fig. 3. Dependence of the ratio σ_i/σ_f in the reactions; ●) $U^{238} + \alpha$; △) $U^{235} + \alpha$; ■) $U^{233} + \alpha$.

in the measurement of the cross section ratio was 50% and was mainly associated with the uncertainty in the effective thickness of the target.

Since the cross section for prompt fission is practically the same as the cross section for compound nucleus formation in α-particle reactions, the ratio σ_i/σ_f is the probability of a reaction with the evaporation of a given number of neutrons. In the statistical theory of the nucleus, this probability is given by the expression [11]

$$P(E, n) = I(\Delta_n, 2n-3) - I(\Delta_{n+1}, 2n-1);$$
$$\Delta_n = \frac{E - \sum_1^n B_i}{T}, \quad (1)$$

where I (Δn, 2n – 3) is the incomplete Γ function; E is the excitation energy; n is the number of neutrons emitted; B_i is the binding energy of a neutron, and T is the nuclear temperature. The energy dependence of the reaction probability calculated in this way has the shape of a Gaussian curve, for which the position of the maximum depends on the number of emitted neutrons. Experimentally, deviations from the theoretical curve are often observed. However, these deviations are not so large as to upset the identification of reaction products if the number of emitted neutrons is small (two or three). Therefore a curve calculated from Eq. (1) was passed through the experimental points; the position of the maximum made it possible to determine the number of emitted neutrons and, consequently, the isotope produced in the reaction.

EXPERIMENTAL RESULTS

Uranium Isotopes

Only two spontaneously fissioning isomers of uranium are known – U^{236} and U^{238} – with respective half-lives of 100 and 250 nsec [4]. One can obtain spontaneously fissioning isomers of uranium with mass numbers 232-234 by irradiation of a Th^{232} target with α particles having energies of 22-36 MeV. The absence of tracks in the detectors from delayed fission fragments corresponds to an upper limit of the cross section for the production of these isomers equal to 10^{-32} cm^2, which is 1000 times lower than the cross sections for the production of the known isomers of U^{236} and U^{238}. This may mean that in uranium isotopes with A = 232-234 either the lifetime of the isomeric states is less than 0.5 nsec or these states decay by means of γ radiation.

Plutonium Isotopes

Targets of U^{233}, U^{235}, and U^{238} are irradiated in order to produce spontaneously fissioning isotopes of plutonium. For all three targets, spontaneously fissioning isomers are observed with half-lives of 30, 70, and 5 nsec respectively. From the positions of the maxima of the excitation function, it is clear (Fig. 3) that the (α, 2n) reaction occurs in all targets, i.e., the known spontaneously fissioning isomers of Pu^{235}, Pu^{237}, and Pu^{240} are formed [2, 12]. In the region of higher α-particle energies (above 30 MeV), a noticeable increase of the measured ratios over those calculated from Eq. (1) is observed. This is associated with either a contribution from direct reactions or the formation of spontaneously fissioning isomers in (α, 3n) or (α, 4n) reactions with similar half-lives.

Curium Isotopes

Spontaneously fissioning isomers of curium with half-lives of 20 and 80 nsec were produced by the irradiation of Pu^{239} and Pu^{242} targets. Measurement of the excitation functions established that these half-lives belonged to the known spontaneously fissioning isomers of Cm^{241} (20 nsec) and Cm^{243} (80 nsec) [4, 12].

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TABLE 1. Cross Sections for the Formation of Spontaneously Fissioning Isomers in α-Particle Reactions

Isomer	$T_{1/2}$, nsec	Reaction	E_α, MeV	σ_i/σ_f, $\times 10^{-6}$	σ_i, μb	σ_g, mb	σ_i/σ_g, $\times 10^{-4}$
Pu^{235}	30	$U^{233}(\alpha, 2n)$	26	3,2	1,6	7	2,3
Pu^{237}	70	$U^{235}(\alpha, 2n)$	25	6,5	2,9	15	1,9
Pu^{240}	5	$U^{238}(\alpha, 2n)$	24	65	20	48	4,2
Cm^{241}	20	$Pu^{239}(\alpha, 2n)$	26	2,5	0,8	12	0,67
Cm^{243}	80	$Pu^{242}(\alpha, 3n)$	32	2,5	1,5	20*	0,75
Bk^{243}	5	$Am^{241}(\alpha, 2n)$	25	1,6	0,48	33*	0,14
Bk^{242}	$\geqslant 100$	$Am^{241}(\alpha, 3n)$	35	0,2	0,16	6*	0,27
Bk^{245}	2	$Am^{243}(\alpha, 2n)$	24	1,0	0,25	50	0,05
Bk^{244}	$\geqslant 30$	$Am^{243}(\alpha, 3n)$	34	0,25	0,20	18	0,11

*Calculated values of σ_g.

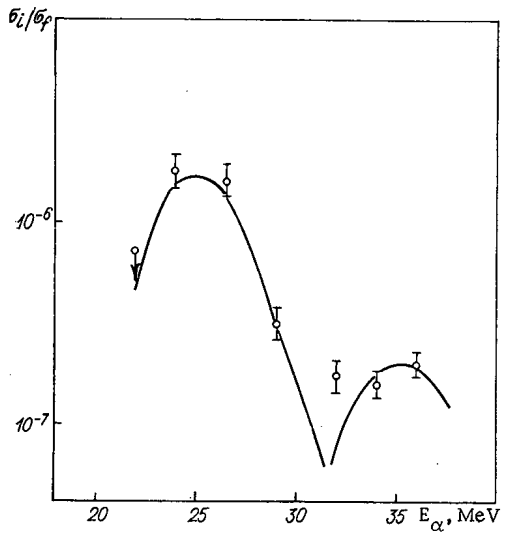

Fig. 4. Dependence of ratio σ_i/σ_f in the $Am^{241} + \alpha$ reaction.

Berkelium Isotopes

Spontaneously fissioning isomers of berkelium are still practically unstudied. Known only is an isomer of Bk^{245} ($T_{1/2}$ = 2 nsec); in addition, there are indications of the existence of an isomer with a half-life of ~100 nsec [13]. In the irradiation of targets containing the isotopes Am^{241} and Am^{243} with low-energy α particles (less than 30 MeV), there are observed spontaneously fissioning isomers with half-lives of 5 and 2 nsec respectively. If the α-particle energy exceeds 30 MeV, longer-lived isomers appear with half-lives of the order of 30 and 100 nsec respectively. From the shape of the excitation functions (Fig. 4), one can suppose that the short-lived isomers belong to Bk^{243} (5 nsec) and Bk^{245} (2 nsec), and the long-lived isomers belong to Bk^{242} (30 nsec) and Bk^{244} (100 nsec). Apparently, the same systematics hold for the half-lives of spontaneously fissioning isomers of berkelium as for the isomers of americium – longer half-lives in the odd–even nuclei [3].

Table 1 gives the measured ratio σ_i/σ_f of the cross sections for isomer production and prompt fission for all isomers obtained in this work at the α-particle energy E_α corresponding to the maximum of the excitation function. For the plutonium isomers, the cross section ratios measured here agree within limits of error with the results obtained in [12]. Since the cross sections for prompt fission are known, one can obtain the cross section for the production of spontaneously fissioning isomers from the measured ratios. For comparison, Table 1 also shows the cross sections for the formation of the ground state in the same nuclei. These cross sections were measured for most of the nuclei [9, 10, 14]; for the remainder, they were calculated on the basis of the known cross sections for compound nucleus formation and the ratios of neutron and fission widths.

DISCUSSION OF RESULTS

Table 1 also shows the isomeric ratios (ratios of the cross sections for production of the nucleus in the isomeric and ground states). In the isomers of plutonium, these ratios are practically the same as in the known long-lived isomers of americium [15]; in the isotopes of curium, they are somewhat less, and lower by an order of magnitude in the isomers of berkelium. At the same time, in isotopes of a given element, the isomeric ratios are of similar values.

Within the framework of the double-humped barrier model, one can judge how the shape of the fission barrier changes with increasing Z from the behavior of the isomeric ratios. This model supposes a two-step mechanism for populating the isomeric state (first, achievement of a deformation corresponding to the saddle point and then the emission of a neutron) and a strong interaction between collective and one-particle motions of the nucleons. The formation of spontaneously fissioning isomers therefore occurs by

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decay of a compound nucleus which is in the second potential well, i.e., having a saddle point deformation and an excitation energy reduced by the deformation energy. In this case, the probability of isomer formation will be proportional to the time the nucleus remains in a deformation corresponding to the second well, and to the level density in the second well [16]. The first quantity depends on the ratio of the heights of the outer and inner barriers; the lower the outer barrier, the more rapidly the nucleus passes through the second potential well on the way to fission. The second quantity is determined by the depth of the second well. Consequently, the reduction in isomeric ratios with increasing Z observed in this work is apparently related to the fact that the second potential well becomes less deep. This indicates either an increase in the energy of the isomeric state or a reduction in the height of the second barrier.

In conclusion, the authors are grateful to G. N. Flerov for continuing interest in the work, to V. S. Alfeev for providing smooth operation of the U-200 cyclotron, and to A. I. Sergeeva for examining the dielectric detectors.

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SR^{90} AND Cs^{137} CONCENTRATIONS IN THE BALTIC SEA IN 1970*

L. M. Ivanova, L. I. Gedeonov,
V. N. Markelov, Yu. G. Petrov,
A. G. Trusov, and É. A. Shlyamin

UDC 621.515

The practice of disposing of various industrial waste products (including those in atomic industries) in rivers, seas, and oceans is quite an old one. There are now regions on the earth where rivers, and in some cases seas and oceans, have a high concentration of radioactive materials. As atomic-energy installations become more widespread, the number of such regions may increase, thereby increasing the danger of further radioactive contamination. This is particularly true of the industrialized countries and thus of the water in the seas and oceans surrounding these countries.

All the countries bordering the Baltic Sea are industrially developed and currently using nuclear fuel. In Sweden, e.g., the Studsvik atomic center is near the Baltic Sea. The (low-level) radioactive waste from the center has been poured into Tvern Bay for several years. This waste has been monitored constantly in an effort to prevent high local concentrations. A study has shown [1] that the water exchange in the Tvern Bay–Baltic Sea system provides the necessary dilution of radioactive waste, so this waste is still being poured into the bay.

In addition to the worldwide atmospheric fallout, the Baltic region now has industrial sources of radioactive contamination.

In view of the particular hydrological conditions of the Baltic Sea, its use for removing radioactive waste should be approached very cautiously. The radioactive-contamination level must be monitored constantly, especially for long-lived nuclides.

We report here the results of a radiochemical study of the Sr^{90} and Cs^{137} concentrations in several regions of the Baltic Sea. Water samples were collected during the second voyage of the research vessel Akademic Vernadskii, from Leningrad.

Since there are no drifting or buoy stations in the Baltic part of the voyage, no deep samples were collected.

From the samples collected we can follow the contamination level in the surface layer of the Baltic Sea over a broad area (in the Gulf of Finland and in the eastern and southern parts of the Baltic Sea). During the voyage six water samples (200 liters each) were collected in the Baltic Sea, and two samples were collected in the Gulf of Finland. Figure 1 shows the points at which the samples were collected, between February 10 and 16, 1970. The water samples were concentrated by the standard procedure [2]. Because of the low salinity of the water in the Baltic Sea, ammonium chloride was not added to the samples during the concentration. The Sr^{90} and Cs^{137} concentrations were determined from the Baltic Sea samples (in all the samples the Cs^{144} concentration turned out to be below the sensitivity of the detection method used). The results of the Sr^{90} and Cs^{137} determination are shown in Table 1. Samples 1 and 2 were collected in the central part of the Gulf of Finland (near Gogland Island). The mean Sr^{90} and Cs^{137} concentrations in these samples were 2 and 1.9 disintegrations/min · liter, respectively. The Sr^{90} and Cs^{137} levels fell off slightly toward the Danish straits, although their concentrations remained above 1 and 1.5 disintegrations /min · liter, respectively.

*Based on results obtained during the second voyage of the research vessel Akademik Vernadskii.

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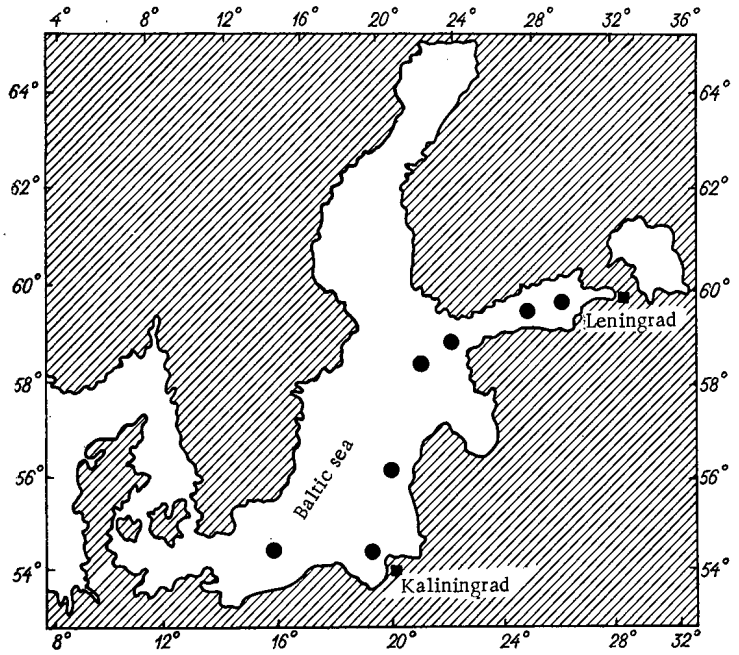

Fig. 1. Sample-collection points in the Baltic Sea.

TABLE 1. Sr^{90} and Cs^{137} Concentrations in the Baltic Sea in February, 1970*

Sample No.	Collection date	Collection point	Coordinates of collection point		Concentration, disintegrations/min·(100 liters)		Cs^{137}/Sr^{90} ratio
			north	east	Sr^{90}	Cs^{137}	
1	10	Gulf of Finland	60°	27°45′	210±32	195±33	0,9
2	10	The same	60°00′	26°16′	200±28	193±25	1,0
3	11	Baltic Sea	59°35′	23°06′	175±25	181±22	1,0
4	11	The same	59°03′	21°40′	153±22	193±22	1,3
5	11	" "	56°54′	20°28′	169±24	192±19	1,1
6	12	" "	54°57′	19°35′	178±25	181±17	1,0
7	16	" "	54°58′	15°51′	115±17	165±22	1,4
8	16	" "	54°58′	15°51′	123±18	—	—

*The samples were collected at sea level.

The ratio of the Cs^{137} concentration to the Sr^{90} concentration in the Gulf of Finland was approximately equal to one, while in the Baltic Sea this ratio was slightly higher. In the Gulf of Finland, where the salinity is lowest and where the water is shallow, sorption of cesium by mud and sediment is apparently more effective. The Sr^{90} and Cs^{137} behavior in the Gulf of Finland is probably similar to that of these isotopes in rivers and lakes.

For comparison, we also analyzed water samples from the Atlantic Ocean. Table 2 shows the measured Sr^{90} and Cs^{137} concentrations in surface samples taken in the central Atlantic at the latitude of the Baltic Sea and during the same time period. The mean Sr^{90} and Cs^{137} concentrations were the same: 0.23 disintegration/min · liter. Comparison of these values with the Sr^{90} and Cs^{137} concentrations in the Baltic Sea showed that in 1970 the contamination of the Baltic Sea by these isotopes was more than six times that in the Atlantic Ocean.

Figure 2 shows the Sr^{90} and Cs^{137} distributions in the surface water of the Baltic Sea and Atlantic Ocean in the range 53-60° N. The difference between the contamination levels of the Baltic Sea and the Atlantic Ocean is not unexpected, because the Baltic Sea is largely a closed basin which does not have a good communication with the ocean and whose mean depth is less than 100 m.

The water in the Baltic Sea comes primarily from rivers and precipitation. The salt balance is governed by the inflow of water from the North Sea. Under these conditions, worldwide radioactive

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TABLE 2. Sr^{90} and Cs^{137} Concentrations in the Atlantic Ocean in 1970*

Sample No.	Station No.	Collection date	Coordinates of collection point		Depth at collection point, m	Concentration disintegrations/min·(100 liters)		Cs^{137}/Sr^{90} ratio
			north	west		Sr^{90}	Cs^{137}	
37	43	March 2	55°43′	16°36′	423	22±4	22±8	1,0
39	44	March 4	53°48′	23°10′	3795	24±4	23±8	1,0

*Samples collected at sea level.

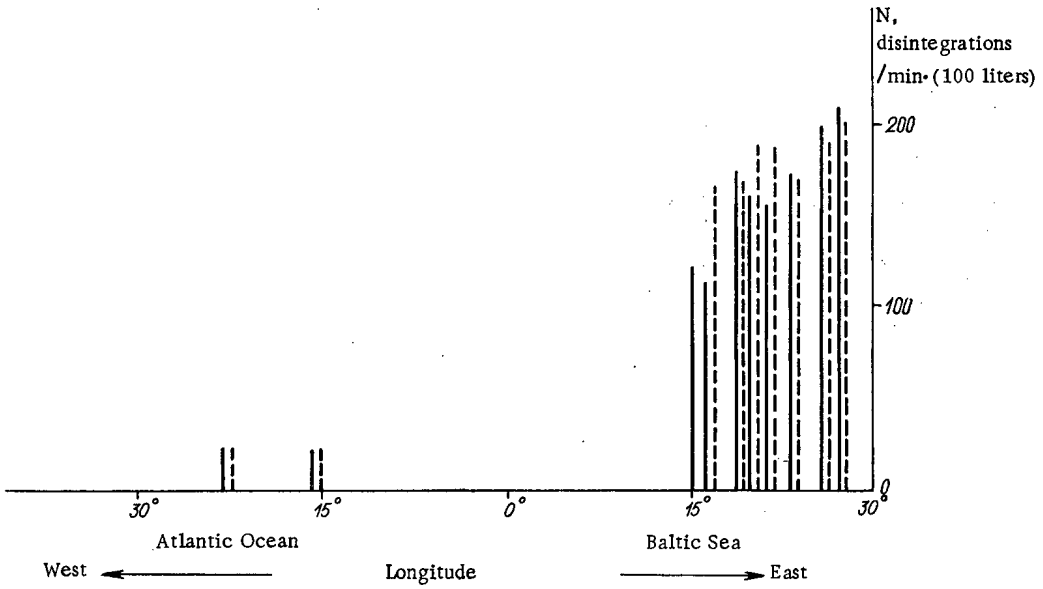

Fig. 2. Sr^{90} concentration (solid lines) and Cs^{137} concentration (dashed lines) in the Baltic Sea and Atlantic Ocean.

contamination associated with atmospheric fallout and river water is diluted to a much lesser extent than in the ocean.

To determine the Sr^{90} and Cs^{137} concentrations which could be expected in the Baltic Sea on the basis of radioactive fallout alone, we used data on the accumulation of Sr^{90} and Cs^{137} on land near Leningrad [3]. For a long time there was no solid basis for transferring dry-land data to the surfaces of bodies of water, but a long study in the Atlantic Ocean and on land (at the same latitude) has revealed no appreciable difference between the radioactivity levels due to atmospheric fallout [4].

According to [3], the Sr^{90} and Cs^{137} accumulations at the surface near Leningrad at the end of 1969 were 42 and 82 $\mu Ci/km^2$, with radioactive decay taken into account. If we adopt a mean depth of 55 m for the Baltic Sea, we find that the Sr^{90} and Cs^{137} concentrations due solely to atmospheric fallout on the water would be 0.8 and 1.5 pCi/liter, respectively.

The rivers flowing into the Baltic Sea annually bring in ~450 km^3 of water, of which ~1/5 comes from the Neva River. According to [5], the Sr^{90} concentration in the Neva in 1962 was 0.4 pCi/liter, while that in 1964 was 0.7 pCi/liter. Atmospheric fallout reached maximum levels in these years. Assuming a maximum Sr^{90} concentration of 0.7 pCi/liter, and assuming that this value was maintained for 15 yr (clearly an overestimate), we can determine the degree to which the rivers could affect the Sr^{90} concentration in the Baltic Sea. Under these conditions, ~5300 Ci of Sr^{90} could enter the Baltic Sea from rivers during a 15 yr period; this input would correspond to a concentration of 0.2 pCi/liter, i.e., ~1/4 of the concentration due to direct atmospheric fallout of Sr^{90} on the surface of the water. Summing the two sources, we find the expected concentration to be ~1 pCi/liter.

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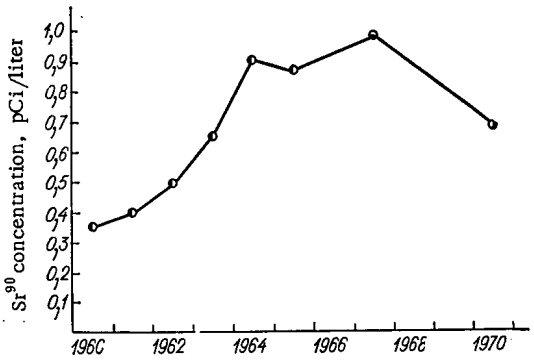

Fig. 3. Changes in the Sr^{90} concentration in the Baltic Sea from 1960 to 1970, including data from [6, 7].

The Sr^{90} concentration in the Baltic Sea measured in 1970 (0.7 pCi/liter) is very nearly equal to that calculated from the Sr^{90} input, with water exchange, sorption, and biological and other processes in the water neglected. Taking into account the rough nature of the estimate, which has an extremely limited experimental base, we cannot conclude that there is a stable Sr^{90} concentration in the Baltic Sea which has accumulated as a result of worldwide Sr^{90} fallout. As the fallout level drops, the concentration of this isotope will also drop, although it would be difficult to expect an appreciable drop due to water exchange.

In this connection is is interesting to note the changes in the Sr^{90} concentration in the Baltic Sea over the last 10 yr, from 1960 to 1970 (Fig. 3). It follows from Fig. 3 that the Sr^{90} level reached a maximum in the Baltic Sea in 1964-1967, due to the high fallout rate in 1962-1963. Characteristically, the Sr^{90} concentration was still high in 1967, although the fallout rate fell significantly after 1964.

Seas of this type typically display a delayed reaction to a decrease in the input of atmospheric Sr^{90}. As a result of the high fallout rate, an appreciable increase in the Sr^{90} concentration was observed in the surface water of the Black Sea in 1963 [8]. As the Sr^{90} fallout rate subsequently decreased, the concentration in the surface water of the Black Sea remained at a high level for a long time before it began to decrease. The water area of the Baltic Sea is 1/16 of that of the Black Sea, so the possibilities for dilution of the water is considerably lower. The long-term preservation of a high contamination level in the Baltic Sea is thus apparently plausible.

Consequently, it follows from the Sr^{90} concentration determined in the Baltic Sea over the period 1960-1970 (Fig. 3) that the concentration of this isotope has varied according to the variations in the Sr^{90} input from the atmosphere. We can therefore assume that over the next decade the governing factor in the contamination of the Baltic Sea will be the rate of worldwide radioactive fallout.

The data obtained in 1970 revealed a tendency for a decrease in the Sr^{90} and Cs^{137} concentrations in the Baltic Sea, but the concentrations of these isotopes are still high, far above their concentrations in the Atlantic Ocean, and in both cases the level is governed by worldwide radioactive fallout.

The radioactive contamination of the Baltic Sea must be monitored particularly carefully in view of the development of atomic power installations. Since observations have been carried out only in a few regions, there is a need for a broader study of the contamination of the Baltic Sea, including a study of the radioactivity of deep water and of the bottom sediment.

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A NEW METHOD FOR MEASURING THE REACTIVITY OF A NUCLEAR REACTOR

B. P. Shishin

UDC 621.039.515

The extension of the "double overcompensation" method to generalized reactivity offers added possibilities for measuring the supercriticality of a nuclear reactor, reactivity measurements included.

The purpose of the present article is to lay the groundwork for a method for determining reactivity on the basis of measured decay constants of prompt neutrons of a subcritical reactor and critical reactor, when the breeding properties of the system are deliberately varied.

The discussion is based on the ω-model of the reactor, where the eigenvalue of the problem is the ω-reciprocal prompt neutron period. Four neutron balance equations are written in operator form, as well as the corresponding adjoint equations:

$$M_0 n_0 = \omega_0 n_0; \quad (1a) \qquad M_0^+ n_0^+ = \omega_0 n_0^+; \quad (1b)$$
$$M_1 n_1 = \omega_1 n_1; \quad (2a) \qquad M_1^+ n_1^+ = \omega_1 n_1^+; \quad (2b)$$
$$M_2 n_2 = \omega_2 n_2; \quad (3a) \qquad M_2^+ n_2^+ = \omega_2 n_2^+; \quad (3b)$$
$$M_3 n_3 = \omega_3 n_3; \quad (4a) \qquad M_3^+ n_3^+ = \omega_3 n_3^+ \quad (4b)$$

where M is the excess neutron production rate operator and n the neutron density. Equations (1a), (1b) refer to a supercritical reactor, Eqs. (2a), (2b) and Eqs. (3a), (3b) correspond to critical reactors in the ρ-model (ρ being the reactivity), converted from the supercritical state when the first and second compensation parameters operate separately. Equations (4a), (4b) describe the neutron balance in a subcritical reactor, converted from the supercritical state with the two compensation parameters operating jointly.

As a result of multiplying the direct equation through by the function n^+, and multiplying the adjoint equation through by the function n, integrating with respect to all the variables over their range of variation, and subtracting one expression from the other, we arrived at the relationship between the reciprocal period of the supercritical reactor and the measured values of ω_1, ω_2, and ω_3:

$$\omega_0 = \omega_1 + \omega_2 - \omega_3 + \delta\omega_2 - \delta\omega_0, \quad (5)$$

where $\delta\omega_2$ and $\delta\omega_0$ are correction terms whose values range from zero to the value of the decay constant for a critical reactor. If one of the compensation parameters is homogeneous poisoning of the system by a "1/v"-absorber of neutrons, then

$$\delta\omega_2 - \delta\omega_0 \equiv 0. \quad (6)$$

The reactivity margin can be determined from the Simons–King equation, if the value of ω_0 and the ratio of the effective fraction of prompt fission neutrons to the effective fission neutron generation time $(\beta/\Lambda)_0$ are known. Strictly speaking, this functional is measured for critical states of the reactor (in the ρ-model). Measurements of the ratio β/Λ cannot be termed rigorous for other reactor states. The best approximation to the ratio $(\beta/\Lambda)_0$ must be measurements of the ratio β/Λ in a critical reactor poisoned by a homogeneous 1/v-neutron absorber, since the neutron fields coincide in that case. The difference in the functionals can be related to the difference between the adjoint function of a critical poisoned reactor and the corresponding function of a supercritical unpoisoned reactor in the ρ-model. If that difference is negligible, then $(\beta/\Lambda)_0 = -\omega_1$, and the formula for the reactivity then acquires the form

$$\rho_0 = \beta_0 \frac{\omega_3 - \omega_2}{\omega_1}. \quad (7)$$

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The result (7) can be rigorously applied to a homogeneous bare reactor. In the case of an unreflected uranium–water assembly, the results of the reactivity determination based on Eq. (7) to within ±5% coincided with independent measurements of the reactivity $d\rho/dH$ by the method up to 15 β to 20 β. The maximum differences in the values of ω_1 and ω_2 were 50% in that case.

THE THEORY BEHIND THE "DOUBLE OVERCOMPENSATION" METHOD

B. P. Shishin

UDC 621.039.515

The "double overcompensation" method is a way of determining the supercriticality of a nuclear reactor from the measured subcriticality (and vice versa) when the multiplying properties of the reactor are deliberately varied. The present article is devoted to a more rigorous validation of the method within the framework of a generalized arbitrary-critical model.

Direct and adjoint equations of the neutron balance are stated in the generalized arbitrary-critical model for the original supercritical reactor, for two critical reactors derived from the supercritical one by allowing the first and second compensation parameters to take effect separately, and also for the subcritical reactor arrived at when those parameters take effect jointly:

$$M_0 n_0 = R_0 N_0 n_0; \quad (1a) \qquad M_0^+ n_0^+ = R_0 N_0^+ n_0^+; \quad (1b)$$

$$M_1 n_1 = 0; \quad (2a) \qquad M_1^+ n_1^+ = 0; \quad (2b)$$

$$M_2 n_2 = 0; \quad (3a) \qquad M_2^+ n_2^+ = 0; \quad (3b)$$

$$M_3 n_3 = R_3 N_3 n_3; \quad (4a) \qquad M_3^+ n_3^+ = R_3 N_3^+ n_3^+ \quad (4b)$$

where M is the excess neutron production rate operator; R is the generalized reactivity; N is an operator specifying the specific reactor model involved.

After multiplying Eq. (1a) by n_3^+ and multiplying Eq. (4b) by n_0, integrating with respect to all the variables over the entire range of variation of those variables, and subtracting one equation from the other, we end up with the functional relation

$$2\frac{\langle n_3^+ M_0 n_0\rangle}{\langle n_3^+ N_0 n_0\rangle} - \frac{\langle n_0 M_1^+ n_3^+\rangle + \langle n_0 M_2^+ n_3^+\rangle}{\langle n_3^+ N_0 n_0\rangle} = R_0 - R_3\frac{\langle n_0 N_3^+ n_3^+\rangle}{\langle n_3^+ N_0 n_0\rangle}, \quad (5)$$

from which we derive the equality of the subcriticality of the unperturbed reactor, expressed in terms of the generalized reactivity (the conventional reactivity, the inverse period of the reactor, etc.), the subcriticality with sign reversed, of a doubly overcompensated reactor:

$$R_0 = -R_3. \quad (6)$$

The conditions imposed are

$$N_0 = N_3, \; N_0^+ = N_3^+, \quad (7)$$

and, in addition, the neutron density distribution functions and the adjoint functions of the critical and noncritical reactors must not diverge markedly, i.e., so that the value of the functional

$$[\langle n_0 M_1^+ n_3^+\rangle + \langle n_0 M_2^+ n_3^+\rangle]\,\langle n_3^+ N_0 n_0\rangle^{-1}$$

will not exceed a prespecified amount corresponding to the accuracy required in the reactivity measured. These criteria place limitations on the practical choice of compensation parameters.

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Among the compensation parameters in question are poisoning of a reactor by uniformly distributed neutron absorber, since the neutron fields can be perturbed relatively slightly in that case. Experiments have demonstrated the applicability of the theory to determinations of the supercriticality of homogeneous unreflected assemblies, in terms of the reciprocal instantaneous period and reactivity corresponding to 10 β, to within 5%.

CALCULATION OF THE HEAT EXCHANGE IN CORE FLOW AND OF THE HYDRODYNAMICS IN LAMINAR FLOW OF COOLANTS IN REGULAR FUEL ELEMENT LATTICES

V. I. Subbotin, P. A. Ushakov,
A. V. Zhukov, and N. M. Matyukhin

UDC 621.039.546:536.24

Heat exchange for coolants with vanishingly small Prandtl numbers for a two-dimensional velocity profile is considered. A boundary value problem is substituted for the conjugate fuel element–coolant problem by introducing the generalized fuel element parameter ε_k [1]. A linear system of equations has been derived for determining the coefficients of the Fourier series:

$$T_W = \overline{T}_W + \Sigma a_k \cos k\varphi;$$

$$x\frac{d}{d_r}\overline{\alpha}_m - \frac{x}{1}\left(1+\frac{d}{d_r}\right)\overline{\beta}_m + \sum_{fi}^{ni} a_k \frac{k}{2}\left[(1+\varepsilon_k)\,x^{k-1}\overline{C}_{km} + (1-\varepsilon_k)x^{k-1}\overline{D}_{km}\right] = 0,$$

where i = 6 and k, m = 6, 12, ..., 6n for a triangular fuel element lattice, i = 4 and k, m = 4, 8, ..., 4n for a square lattice; n is the number of harmonics; $T_W = tW\lambda_f/\bar{q}^k$ is the dimensionless local temperature of the wall; x = s/2R is the relative lattice spacing; R is the outside radius of the fuel element jacket; s is the spacing between the centers of fuel elements; λ_f is the thermal conductivity of the coolant; and $\bar{q}$ is the specific thermal flux, averaged over the perimeter.

The universal coefficients, i.e., the mean values of the functions

$$C_{km} = \cos^{-k}\varphi\cos m\varphi\cos(k-1)\varphi;\quad \alpha_m = \frac{\cos m\varphi}{\cos\varphi};$$

$$D_{km} = \cos^k\varphi\cos m\varphi\cos(k+1)\varphi;\ \beta_m = \begin{cases}0 & \text{for } k \neq m\\ 1/2 & \text{for } k = m,\end{cases}$$

averaged over the perimeter, are tabulated.

An analytical expression for the Nusselt numbers has been derived (see Fig. 1). In the figure, ξ_1 is the ratio of the inside jacket radius to the outside radius,

$$m = \frac{\lambda_W - \lambda_0}{\lambda_W + \lambda_0},\quad \varepsilon = \frac{\lambda_W}{\lambda_f}\cdot\frac{1 - m\xi_1^{2k_0}}{1 + m\xi_1^{2k_0}},$$

where λ_W and λ_0 are the thermal conductivities of the jacket and the rod, respectively. The particular case ($\varepsilon_k \to \infty$, i.e., t_W = const along the perimeter) corresponds to the solution of the hydrodynamic problem concerning laminar flow.

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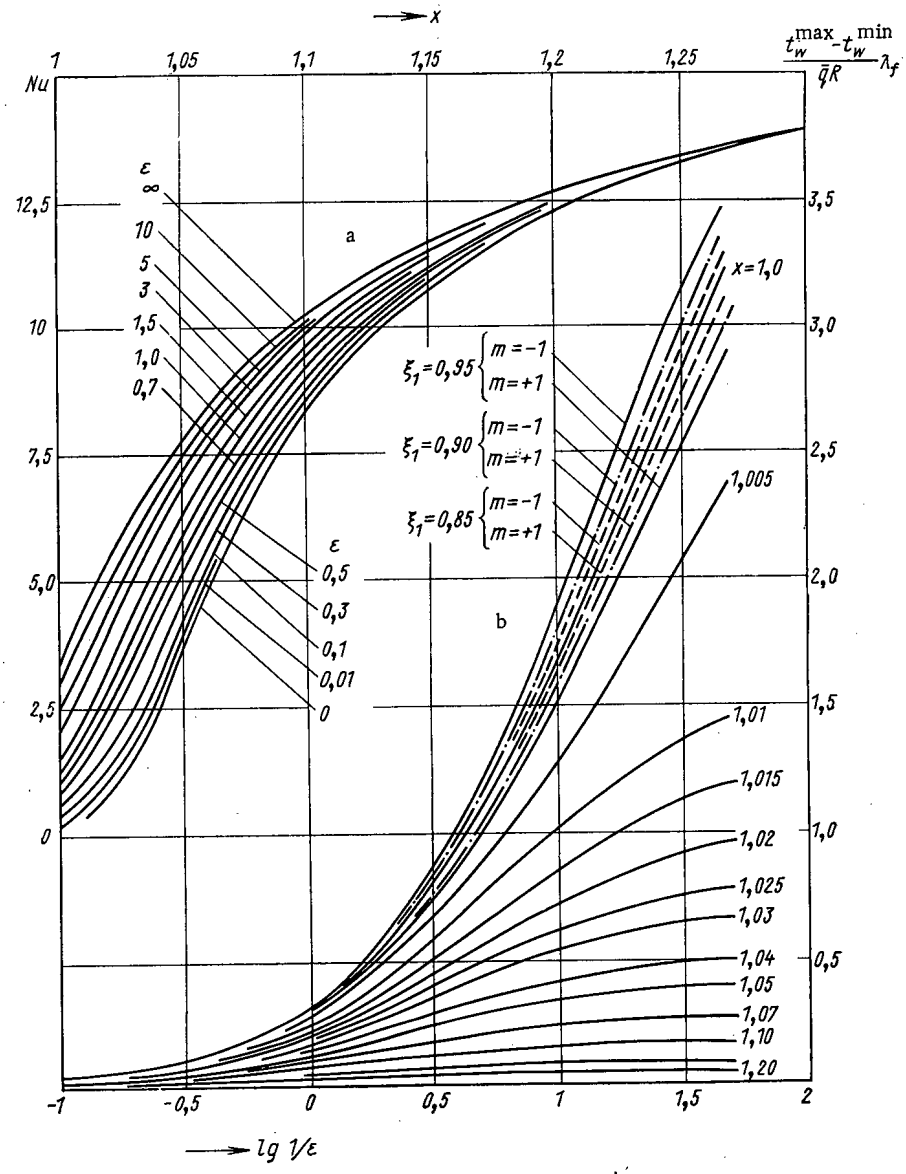

Fig. 1. Dependences Nu = f(x) and $(t_W^{max} - t_W^{min}/\bar{q}R)\lambda f = f(\varepsilon)$ for core flow in triangular lattices of fuel rods (a and b, respectively).

The possibility of generalizing data on the approximate parameter ε_{k0} calculated with respect to the fundamental harmonic k_0 of the Fourier series has been demonstrated, i.e., the concept brought forward in [1] has been confirmed (see Fig. 1). Our results are compared with the data from [2] and other papers.

The solution holds for axisymmetric fuel elements with an arbitrary number of jackets and a uniform contact resistance along the perimeter.

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COMPLETE ISOTOPE SEPARATION IN PHOTOCHEMICAL PROCESSES

Yu. G. Basov

UDC 621.039.335

The article deals with the different aspects of isotope separation in single-stage photochemical processes and discusses the effect of monochromatic light on binary isotope mixtures. The application of laser light is presently difficult since the wavelengths of laser generators do not coincide with the absorption bands of isotopes. The difficulties can be avoided by using lasers with continuously adjustable frequencies corresponding to ultraviolet light in vacuum so that the light quanta energy is sufficient to break the molecular bonds in the irradiated material. This problem has not yet been solved technically. A more general method is to cut out specific ultraviolet lines by means of interference filters.

Consider three cases of interaction of monochromatic light with molecules which fully describe the process of photochemical isotope separation. In the first case, molecules of one isotope resonantly absorb light radiation and the absorption lines do not overlap. If the emission lines of the light and the absorption lines of one isotope coincide there is a strong selective excitation of only one isotope and thus also complete separation. If however (second case) the lines coincide partially, total separation still takes place but at a lower rate than in the first case. Partial separation occurs if the isotope absorption lines overlap partially (third case) and the emission lines of the light source coincide with the absorption lines of one isotope. For the last case the isotope separation factor has been found as

$$\alpha = \frac{N_2 \Delta\nu_2 A_1}{N_1 \Delta\nu_1 (A_2 - B)}, \quad (1)$$

where N_1 and N_2 are the isotope concentrations; $\Delta\nu_1$ and $\Delta\nu_2$ are the band widths at half their maximum intensity; A_1 and A_2 are integral intensities of natural absorption bands equal to areas under the lines of the separated isotopes; and B is the fraction of the area under the absorption line of the second isotope that does not coincide with the emission band of the source (or with the absorption band of the first isotope).

Expression (1) indicates that α approaches unity as B approaches zero and that $\alpha \to \infty$ when $B \to A_2$, i.e., complete separation takes place. For the more general case when the emission line only partially overlaps the absorption lines of the two isotopes, the separation factor is

$$\alpha = \frac{N_2 \Delta\nu_2 (A_1 - B_1)}{N_1 \Delta\nu_1 (A_2 - B_2)}, \quad (2)$$

where B_1 and B_2 are areas under the absorption lines of the first and second isotopes that do not coincide with the emission line of the source.

The dissociation energies of the H_2 and D_2 isotopes of gaseous hydrogen are 4.780 and 4.823 eV, respectively. Thus, for total separation their mixture should be irradiated together with a substance that reacts chemically with atoms or excited molecules of hydrogen. Monochromatic light with a wavelength 2593.7 Å is used for irradiation. The emission band width should not exceed 23.1 Å in the 2570.6-2593.7 Å interval. For oxygen isotope molecules O_2^{16} and O_2^{18} with dissociation energies 5.0636 and 5.0692 eV, respectively, the band width of emission resonantly absorbed by O_2^{16} should not exceed 0.0056 eV. Total separation can be most easily achieved with isotope molecules whose dissociation or excitation energies differ considerably (e.g., the isotope mixtures H_2-D_2, NH_3-ND_3, etc.).

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LINEAR ELECTRON ACCELERATORS FOR RADIATION FLAW DETECTION

V. M. Levin, V. M. Nikolaev,
V. V. Rumyantsev, and B. N. Tronov

UDC 621.384.644:620.179.15

The design and application of waveguide linear electron accelerators for radiation flaw detection is discussed.

Electron accelerators operating at energies of 4 to 20 MeV are most suitable for the inspection of thick materials of different densities. Further energy increase is, as a rule, undesirable. A comparison of existing linear electron accelerators, betatrons, and microtrons proved that linear accelerators have important advantages in the noted energy interval. The intensity of linear accelerator bremsstrahlung is

TABLE 1. Linear Electron Accelerators for Flaw Detection

Accelerator model	Company and country	Maximum energy, MeV	Maximum bremsstrahlung intensity at a distance of 1 m from target		Diameter of effective exposure field at a distance of 1 m from target, cm	Length of iris waveguide, m	Accelerator microwave power input, MW	Average target current, μA	Energy control range, MeV	Focal spot diameter on target, mm	Weight of mobile radiator unit, kg	Dimensions of mobile radiator unit, mm	Maximum thickness of irradiated steel†
			W/m²*	R/min									
LUÉ-15-1.5 [2]	EIEI USSR	15/13	800/1500	10000/20000	300	2,5	7	100/285	5—15	2,5/4	5500	4500× ×1500× ×2000	500/535
LUÉ-10-1[2]	The same	8—10	120—130	1800—2000	200	—	—	0—70	3—10	1,5—2	2000	2750× ×1000× ×800	400
SL-69‡	Mullard, England	4,3	30	600	300	1	2	170	—	2	2000	2700× ×1500× ×1500	300
X—Band 6 MeV‡	"Vickers" England	6	12	200	320	1	1	33	—	—	—	—	—
Linac-8 [3—5]	HVEC$_0$—ARC$_0$, USA	8	360	6000	500	1,5	1—5	375	—	5	—	—	400
Linac-25 [3,5]	HVEC$_0$—ARC$_0$, USA	25	550	6000	260	—	—	15	—	1	—	—	500
Mevaray-1500‡	The same	7,5	90	1500	—	—	—	95	—	—	2000	1200× ×1500× ×1200	350
V-7706 [3, 5, 6]	"Variant association, USA	9—10	35—50	500—700	280	1,6	1,9	20	—	1	—	—	—
V-7709 [3, 5, 6]	The same	25	2200/450	25000/6000	105	1,3×2	7,8×2	60/15	—	2/1	—	—	550
Linatron-400 [7]	" "	4	25	400	390	0,3	2	140	—	2	550	1500× ×760× ×760	—
Linatron-1500 [7]	" "	7,5	90	1500	250	1,2	2	100	—	—	—	—	—
Argus-300 ‡	CSF, France	10	170	2400	—	2,4	4	100	6—10	2	5000	2900× ×1500× ×1800	—
ML-15R [8]	Mitsubishi, Japan	12	330	4400	250	1,8	4	96	8—13	—	—	—	400 at 2000 R/min

*Bremsstrahlung intensity in W/m² calculated from intensity in R/min [9]. The cited values are rounded off figures.
†Exposure time taken as 10 min. Target film distance 2 m. X-ray films of various sensitivities were used.
‡According to company literature and data published in Mater. Evaluation Journal.

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many times higher than the intensity of industrial betatrons [1]. As a result, the exposure time in radiography of thick articles is considerably shorter and the screen image considerably brighter.

Table 1 lists the principal performance characteristics of some linear electron accelerators manufactured expressly for radiation flaw detection and operation in industrial conditions. Two models of such accelerators were designed at the D. V. Efremov Institute of Electrophysical Instrumentation; their designation is LUÉ-15-1.5 and LUÉ-10-1. The bremsstrahlung intensity provided by these accelerators at a distance 1 m from the target exceeds 10,000 and 1800 R/min. The accelerators allow radiographs to be taken of steel samples 600 mm thick or more (radiographs of steel 500 mm thick obtained in 10 min).

It is noted that the design of such accelerators requires solution of certain specific problems associated with the preparation of reliable targets for operation at high current densities (the electron beam diameter on the target is 1.5-2 mm), with increasing the effective bremsstrahlung field, with improving the three-dimensional maneuverability of the radiator unit, and with optimization of the accelerator operation.

It is suggested that for selecting the accelerator operating conditions (the electron current and energy for a given microwave generator power and given product characteristics) the minimum inspection time is a more suitable optimality criterion than maximum bremsstrahlung intensity. In general, the current corresponding to minimum inspection time is not the same as the current corresponding to maximum bremsstrahlung intensity.

Our accelerators allow selection of optimum energy and current of accelerated electrons depending on the thickness, chemical composition, and density of the inspected product.

The construction of the LUÉ-10-1 x-ray head is described.

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USE OF NONLINEAR RESONANCES OF BETATRON OSCILLATIONS FOR SLOW EXTRACTION OF PARTICLES

Yu. S. Fedotov

UDC 621.384.6.07

Nonlinear resonances of betatron oscillations are widely used in systems for slow extraction of particles from accelerators. In some accelerators, such systems have been in operation for several years [1-5], and they have been designed or are being installed in others [6, 7].

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The article provides the results obtained in investigating the dynamics of series of nonlinear resonances to be used for slow extraction. Expressions suitable for calculating the basic parameters of the system are given.

If there are nonlinear terms up to the third power inclusive, the averaged equations for the k-th order resonance can be written in Hamiltonian form [8] for the canonic variables $|a|^2$ and ψ, using the Hamiltonian

$$\mathcal{H} = \sum_{k=1}^{4} \frac{|A_m|}{k} |a|^k \cos(k\psi + \alpha_m) + \sum_{k=1}^{2} |B_n| |a|^{k+2} \cos(k\psi + \beta_n) + 2\pi\delta |a|^2 + \frac{3}{4} K_{\text{cub}} |a|^4. \quad (1)$$

Hamiltonian (1) is more complete in comparison with the expression given in [8]. The second term in (1) describes the (k – 2)-th order resonance besides the k-th order resonance excited by a nonlinearity of the k – 1 power. By taking into account this term and using the general method, we can also investigate the first-order resonance with a quadratic nonlinearity for an integer Q [1-3] and the second-order resonance with a cubic nonlinearity for a half-integer Q.

The resonances are analyzed as in [7], where the phase trajectories – separatrices – passing through the fixed singular points of the Hamiltonian system $d|a|^2/dN = d\psi/dN = 0$ are investigated.

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OCCUPIED HYDROGEN LEVELS IN A HOT PLASMA AND THE RELATIONSHIP BETWEEN RADIATION AND IONIZATION RATE

V. A. Abramov, É. I. Kuznetsov, and V. I. Kogan

UDC 533.9.082.74:621.039.667.4

When investigating plasmas in Tokamak systems, it is important to know the average lifetime for charged particles in the plasma. This time is related to the ionization rate which, in its turn, is related to the intensity of the radiation for the quanta of a given hydrogen spectrum line. In addition, knowledge of the absolute occupied, excited hydrogen levels is found to be extremely helpful in spectroscopic studies.

The quantity ζ, the average number of ionizing events per quantum of the Balmer series, was first introduced and calculated (disregarding stepwise processes; i.e., in the coronal limit $n_e \to 0$) in [1]. Calculation of the occupied hydrogen levels, taking into consideration stepwise processes, and the value of ζ

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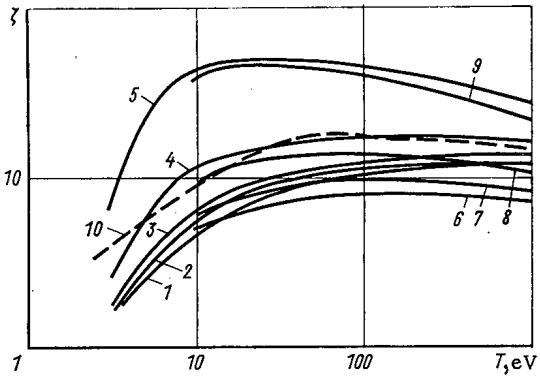

Fig. 1. Dependence of the average number of ionization events per quantum of the H_α line on the temperature. Results of the present work: 1) $n_e = 10^8$ cm^{-3}; 2) 10^{11} cm^{-3}; 3) 10^{12} cm^{-3}; 4) 10^{13} cm^{-3}; 5) 10^{14} cm^{-3}. Results in [3]: 6) 10^{10} cm^{-3}; 7) 10^{12} cm^{-3}; 8) 10^{13} cm^{-3}; 9) 10^{14} cm^{-3}. 10) Results in [1].

per quantum of the H_α line was carried out in [2]. The results of the calculation of ζ for the H_α line (the method of calculation is not mentioned) were given in [3], which, for small n_e (10^{10}-10^{12} cm^{-3}), exceed by two to six times the results obtained in [2], but are close to the data obtained in [1].* According to Dimock et al. [3], these discrepancies result from the fact that inaccurate values for the radiative transition probabilities A(p, q) are used in [2].

The discrepancy shown in the values of the quantity ζ (taking account of the present limitations to its precision) is fairly large; consequently, we decided to recalculate the occupations in accordance with the method used in [2]. In this paper, the results of the calculation are shown for the case where the occupied hydrogen levels have p equal to 2-5 and intensity ratios for the Balmer lines, H_α/H_β, in the 3-1500 eV temperature range. Results of the calculation of the coefficient ζ are compared with the data in [1-3] (at the same time, the values of ζ, presented in [1], corresponding to the number of ionization events per "average" quantum, are scaled to the H_α quantum by multiplying by 5/3 [1]). Comparison of the calculations of the occupations with [2] shows that in the latter paper it is assumed that there was an appreciable (by a considerable factor) excess in the occupation of the p = 3 level for small n_e, which also caused, in particular, a corresponding underestimation of ζ. As is seen in Fig. 1, the values obtained for ζ agree quite satisfactorily with those calculated in [3].

It is obviously impossible to explain the assumed error in [2] by the uncertainties in the radiative transition probabilities; however, this is in disagreement with Dimock et al. [3] (possibly motivated by our unsubstantiated remarks in [2] in connection with some disagreement with the results in [4]). In fact, provided $n_e \to 0$ $\zeta \sim A_{31}/A_{32}$, the value of ζ is insensitive to the primary possible source of error in A(p, q), which is the use of asymptotic ($p \gg 1$, $q \gg 1$) values for the A(p, q); this error in the A(p, q) does not exceed 20-30%. (Nevertheless, in the present work, precise values of the A(p, q) [5] were used.)

Apparently, the source of error in [2] is traceable to some kind of error in numerical calculation on the computer. In any case, one should recognize that in [2] the authors underestimated the importance of the discrepancy in the results of the calculation of the occupations with the data in [4] and the values of ζ in comparison with those in [1] (one should take into account that, for small values of n_e, the conditions approach the coronal limit, considered in [1]).

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CONCERNING AUTOMATIC PROCESSING OF INFORMATION AT ATOMIC POWER PLANTS

V. S. Ermakov, V. S. Kakhanovich, R. A. Kal'ko, and E. K. Zalivako

UDC 621.039.5

Fast processing of information concerning such generalized parameters as block efficiency, reactor power, etc., is particularly important in atomic power plants.

Information about reactor heat output can be used to calculate technical and economic indicators, automatic reactor unloading, etc. The heat produced by a reactor during the time $\tau = \tau_2 - \tau_1$ is given by

$$Q = \int_{\tau_1}^{\tau_2} q_s \, d\tau - \int_{\tau_1}^{\tau_2} q_w d\tau \; \partial J \,, \tag{1}$$

where q_s and q_w are thermal capacities of the superheated steam entering the turbine and of the feed water after the last high-pressure heater respectively, J/sec.

Because of the small volumes of the evaporator and separator, a water and steam balance is established after a considerable time. Then

$$Q = \int_{\tau_1}^{\tau_2} g_w (i_s - i_w) \, d\tau \; \partial J \,, \tag{2}$$

where g_w is the water flow, kg/h; i_s and i_w are the steam and water enthalpies, J/kg. Equation (2) is suitable for simulation by a calorimeter circuit in measuring the rate of feed water flow by electromagnetic or inductance flowmeters involving square root extraction (GSP transmitters).

If the flowmeter transmitter is a differential manometer, expression (2) changes to

$$Q = \int_{\tau_1}^{\tau_2} k_1 \alpha k_t d^2 \sqrt{h\rho} \, (i_s - i_w) \, d\tau = k_2 \int_{\tau_1}^{\tau_2} \sqrt{k_t^2 (i_s - i_w)^2 h\rho} \, d\tau \; \partial J \,. \tag{3}$$

where h is the pressure differential across the constriction nozzle, N/m^2; ρ is the water density, kg/m^3; k_1 and k_2 are constant factors; d is the nozzle diameter; and α and k_t are coefficients of discharge and heat expansion of the nozzle, respectively.

Atomic plant calorimeters based on Eqs. (2) and (3) as well as those used to measure the heat of water and steam are similar to calorimeters employed for these purposes in conventional boilers [1].

Measurements of heat output of the steam generator of the Novo Voronezh Atomic Power Plant proved that the heat error due to neglecting water pressure in the range 28-38 bar and steam pressure (temperature) does not exceed 0.1% and 0.15% respectively. Allowing for the random nature of variation of the water and steam parameters, the resultant error amounts to 0.2%.

For a water-cooled water-moderated power reactor expression (3) becomes (neglecting losses in the primary loop)

$$Q = \sum_{1}^{n} k_n \int_{\tau_1}^{\tau_2} \sqrt{h \, (x - k_3) \, \frac{k_4 - t_w}{k_5 + t_w}} \, d\tau \; \partial J \,, \tag{4}$$

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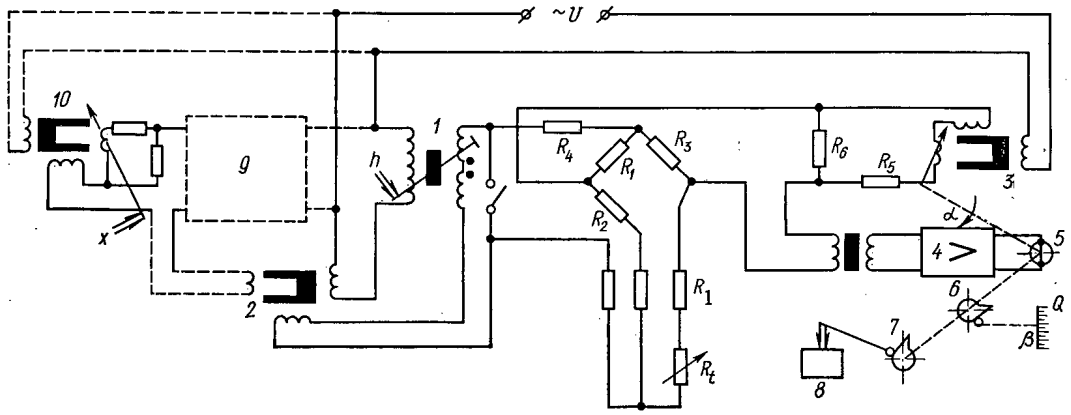

Fig. 1. Circuit diagram of TÉV-6 calorimeter: 1) differential manometer; 2) feedback converter of electrical signal repeater; 3) compensation converter; 4) electronic amplifier; 5) reversible motor; 6) reference template; 7) output template; 8) frequency converter for SCh integrator; 9) electrical signal repeater; R_1-R_4) measuring circuit resistors; 10) steam moisture controller; R_l) lead resistance; $\beta \equiv q \equiv \sqrt{\alpha}$ is the pointer (recorder) displacement.

where x is the degree of steam dryness; k_3-k_5 are constant factors; and k_n is the calibration factor of the n-th calorimeter.

For normal operating conditions of the Novo Voronezh Atomic Power Plant (p_S = 2-32 bar, x = 1.0-0.98, t_w = 130-190°C, p_w = 36 bar), expression (4) becomes

$$Q = \sum_{1}^{n} k_n \int_{\tau_1}^{\tau_2} \sqrt{h\,(x-0.399)\,\frac{110.70-R_t}{480.86+R_t}}\,d\tau\,\partial J, \qquad (4a)$$

where R_t is the instantaneous resistance of the 21st calibration thermometer. The error in (4a) does not exceed ±0.06% and practically does not increase the resultant error due to the accepted assumptions.

Equation (4a) has been used as a basis for a TÉV-6 calorimeter whose experimental model has been tested in the Novo Voronezh Atomic Plant steam generator (Fig. 1). According to bench tests, the principal error of the calorimeter does not exceed ±1.0%. The circuit section shown in dashed lines takes into account steam moisture provided a moisture meter with controller 10 is included. As shown by calculations, neglecting moisture variations gives rise to an additional error of up to 1.0% for each 1.0% change in moisture.

For safety purposes, reactor power limitation, and for calculation of the block performance parameters we have designed a TÉVS calorimeter with improved reliability and dynamic properties (Fig. 2).

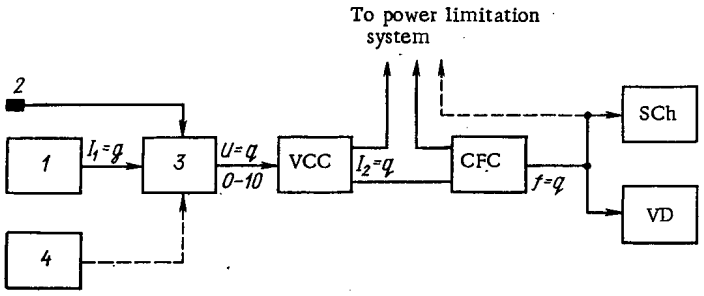

Fig. 2

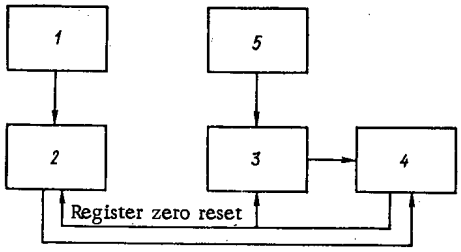

Fig. 3

Fig. 2. Block diagram of TÉVS calorimeter: 1) flowmeter with standard dc current output I_1 = 0-5 mA or 0-20 mA; 2) resistance thermometer: 3) noncontacting measuring circuit; 4) live-steam moisture controller.

Fig. 3. Block diagram of reactor efficiency measuring circuit: 1) calorimeter totalizer $Q = \Sigma\int q d\tau$; 2) divisor register $\int_{\tau_1}^{\tau_2} q_p d\tau$ = const; 3) dividend register $\int_{\tau_1}^{\tau_2} N d\tau$; 4) efficiency register $k\int_{\tau_1}^{\tau_2} N d\tau$; 5) generator electricity meter $\int N d\tau$.

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The measuring channel of the calorimeter including the power control output contains no electromechanical elements. Feed water flow can be measured by an electromagnetic (fast-response) flowmeter, a differential manometer, or GSP transmitters. With a commercial TSP-5071B resistance thermometer having a time constant of not more than 9 sec, the dynamic properties of the circuit meet the demands required of a reactor power limitation system. The voltage to current converter VCC (I_2 = 0-5 or 0-20 mA) and the current to frequency converter CFC (4-8 kHz) used for connections to an SCh integrator and VP auxiliary recorder are units of the KTS LIUS electronic system. For a recorder, which does not belong to the power limitation circuit, one can use a VSCh type recorder or any potentiometric recorder connected into the I_2 current circuit. A multipoint recorder can be used to record the heat production of all system generators simultaneously.

The circuit shown in Fig. 2 is also suitable for use in the primary loop of the reactor.

The reactor efficiency is measured in accordance with the equation

$$\eta = \frac{\int_{\tau_1}^{\tau_2} N\, d\tau}{\left(\int_{\tau_1}^{\tau_2} q_r\, d\tau\right)_{\text{const}}} = k_6 \int_{\tau_1}^{\tau_2} N\, d\tau, \tag{5}$$

where N is the electrical power of the generator, J/sec; q_r is the reactor heat capacity, J/sec; and k_6 is a constant factor.

The operation of the circuit shown in Fig. 3 is based on measuring the electric energy produced by the generator during the consumption of a constant amount of heat generated in the reactor for a variable operation cycle $\tau = \tau_2 - \tau_1$. The variable-cycle method of measuring reactor efficiency has some advantages over the constant-cycle method presently in use. The calorimeters described above serve as the reactor heat power integrators, a type SAZU-670D electrical power meter measures the generator power. The operation of the efficiency meter can be understood with the aid of expression (5) and Fig. 3 which illustrates the implementation of the method.

The methods and instrumentation described above make it possible to automate the most difficult calculations, to improve the accuracy of measurement, to reduce the number of groups, and to improve the economical efficiency of reactor operation by using on-line information provided by computing devices. The proposed algorithms can also be used in monitoring and control devices for calculation of the generalized parameters.

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COMPARISON OF HIGH-FLUX RESEARCH REACTORS

A. Tsykanov

UDC 621.039.572

Criteria which may be used to compare high-flux reactors of various types are given in [1]. One of these may be termed the "ideal efficiency" of a reactor and represents the usefully employed fraction of the neutrons generated within the reactor:

$$\eta_0 = \frac{\sum_{i=1}^{n} V_{ei} \Sigma_{ai} \overline{\Phi}_i}{7.5 \cdot 10^{16} Q}, \quad (1)$$

where V_{ei}, Σ_{ai}, and Φ_i are the experimental volume, permissible macroscopic neutron absorption cross section by the samples, and the averaged neutron flux for the i-th experimental arrangement of the reactor, respectively; Q is the reactor power, MW; and n is the number of experimental arrangements.

Since the cost of irradiating a sample depends on the nuclear fuel burnup and the reactor utilization factor with time, we must multiply the quantity η_0 by the permissible relative fuel burnup α and the reactor utilization factor K_u ($K_u = t_p/t_c$, where t_p is operating time of the reactor within the calendar time t_c). The higher the product $\eta_0 \alpha K_u$, the better is the reactor.

The inadequacy of such a comparison is that these three quantities are mutually dependent and variation in one will cause variation in the others. As a result, it is difficult to determine the way in which these quantities must vary to improve reactor properties and consequently, this method can only be used to evaluate reactors with fixed η_0, α, and K_u.

The present paper discusses a general method of comparing high-flux reactors, permitting the determination of the individual variations of the reactor parameters entering into the criteria for reactor comparison. It is not possible to recommend a single criterion for reactor comparison since it is always necessary to consider two questions: the speed of obtaining the information on the irradiated samples, and the economics of this process. The first problem is, as before, determined by the output of the research reactor, which may be presented in the form

$$\Pi = \sum_{i=1}^{n} \overline{\Phi}_i \Sigma_{ai} V_{ei} \text{ neutrons/sec.} \quad (2)$$

The second question, earlier characterized by the product $\eta_0 K_u \alpha$ can be determined as resulting from the cost of the usefully employed neutrons in the reactors. In actuality, the more economical is that reactor in which the usefully employed neutrons are less expensive.

In agreement with the work of [2], the cost of one hours operation of a research reactor with a utilization factor K_u is determined by the expression

$$C = \frac{T}{K_u} + \frac{gQ}{\alpha} C_g, \quad (3)$$

where T is the total operating cost of the reactor exclusive of the nuclear fuel cost relative to one h of calendar time; C_g is the price of one kg of manufactured fuel, g is the consumption of nuclear fuel per MWh of thermal power, given in kg/Mwh, and Q is expressed in megawatts. For one h of operation the useful output is the following number of neutrons:

$$N = 3600\Pi = 3600 \sum_{i=1}^{n} \overline{\Phi}_i \Sigma_{ai} V_{ei}. \quad (4)$$

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Consequently, the price of one usefully employed neutron is equal to

$$S=\frac{T}{3600K_u\sum_{i=1}^{n}\bar{\Phi}_i\Sigma_{ai}V_{ei}}+\frac{gQC_g}{3600\alpha\sum_{i=1}^{n}\bar{\Phi}_i\Sigma_{ai}V_{ei}}. \quad (5)$$

With the calculation of (1), Eq. (5) can be rewritten in the form

$$S=\frac{0.37\cdot10^{-20}}{\eta_0}\left[\frac{T}{K_uQ}+\frac{gC_g}{\alpha}\right]. \quad (6)$$

The obtained relation better characterizes the efficiency of a high-flux reactor and permits the determination of the contributions of the physical parameters (through η_0 and α), and also the fixed cost and the fuel-contributed cost of operation.

The expression (5), using (2), assumes the following form:

$$S=\frac{2.78\cdot10^{-4}}{\Pi}\left[\frac{T}{K_u}+\frac{gQC_g}{\alpha}\right]. \quad (7)$$

From this it can be seen that more economically favorable results arise from those high-flux research reactors which have high outputs, lower operating costs, lower ratios of Q/α, and which permit operation at high utilization factors.

The obtained relations permit a certain optimization of the characteristics of research reactors if use is made of these relations not for comparison of existing reactors, but for the determination of more favorable parameters of their operation for design. We show this possibility by the example of a selection of optimal fuel burnup fraction.

From (7) it is seen that the fuel cost component price per neutron is

$$S_T\approx\frac{Q}{\Pi\alpha}. \quad (8)$$

Here the dependence of the quantity g on the properties of the reactor can be neglected. Consider a reactor of the beam-catcher type, similar to the SM-2 reactor [3, 4]. The neutron flux in the catcher (or catchers) of such reactors is, in the first approach, proportional to the averaged thermal loading $\bar{q}_V$:

$$\bar{\Phi}\approx\bar{q}_V\approx\frac{Q}{V_c}, \quad (9)$$

where V_c is the core volume. Consequently, for given properties and dimensions of experimental arrangements of a reactor its output is

$$\Pi\approx\frac{Q}{V_c}. \quad (10)$$

For a given core loading the reactivity excess in a fixed state of poisoning and fuel burnup will depend on the working core volume excess (in comparison with critical core volume). For a working core volume not exceeding four fifths of critical volume the dependence of reactivity on volume can be presented with a satisfactory accuracy by

$$\rho=A\ln\frac{V_c}{V_{cr}}\%, \quad (11)$$

and the reactivity loss on burnup is

$$\Delta\rho_b=\frac{B}{V_p}\%/\text{MWh}, \quad (12)$$

where V_{cr} is the critical core volume, and A and B are constants depending of the reactor properties. The reactivity loss on burnup is

$$\rho_b=\rho-\rho_p=A\ln\frac{V_c}{V_p}, \quad (13)$$

where ρ_p is the reactivity loss for fixed reactor poisoning, V_p is the core volume, the reactivity excess of which is equal to the reactivity required for compensation of the fixed poisoning.

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After this, it is easy to obtain an expression for the burnup:

$$\alpha \frac{Ag}{Bg_0} \ln \frac{V_c}{V_p}, \tag{14}$$

where g_0 is the concentration of nuclear fuel in the fuel elements of the reactor.

Putting (10) and (14) into (8) we obtain

$$S_T \approx \frac{V_c}{\ln V_c/V_p}. \tag{15}$$

Analyzing expression (15) it is easily shown that the quantity S_T is a minimum for $V_c/V_p = 1$. Consequently, the optimum relative burnup is

$$\alpha_{opt} = \frac{Ag}{Bg_0}. \tag{16}$$

For example, for a SM-2 reactor (for which A = 14%; B = $57 \cdot 10^{-4}$ liter · % · MWh; g = $5.3 \cdot 10^{-5}$ kg/MWh; and g_0 = 0.55 kg/liter) the optimum burnup is $\alpha \approx 0.23$, which is close to the value obtained in [5].

It is necessary to note that, for a more accurate determination of the optimum burnup we must minimize the total cost of utilized neutrons, although estimation of the fixed cost generally increases the optimum burnup in all by several percent.

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THE SORPTION OF BORIC ACID ON ANION EXCHANGE RESINS FROM SOLUTIONS SIMULATING THE CIRCUIT WATERS OF ATOMIC REACTORS AND CONDITIONS OF ITS DESORPTION

F. V. Rauzen and E. A. Shakhov

UDC 621.039.7

Several studies have been devoted to the sorption of boron-containing ions on anion exchange resins [1-5]. It has been established that sorbed borate ions are displaced from the anion exchange resin by anions of strong acids [4].

The amount of sorbed boric acid increases with increasing concentration of it in the initial solution. This increase is explained by the fact that with increasing boric acid concentration its sorption on the anion exchange resin occurs as a result of anions containing several atoms of boron. The sorption of boric acid from solutions also depends on the degree of basicity of the exchanger.

In this work we determined the total exchange capacity of anion exchange resins with respect to a boron-containing anion. The content of the initial solution, simulating the composition of circuit waters, was: 5-6 mg/liter potassium hydroxide, 40 mg/liter ammonia, 2-3 g/liter boric acid; pH of solution about 8.

Filtration of the solution through the ion exchange resins was stopped when the concentration of boric acid in the filtrate and that in the initial solution were equal. The results obtained are cited in Table 1. Just as we should have expected, of the solutions cited, close to neutral, greater capacity is possessed by the anion exchange resin with a quaternary ammonium base – AV-17. Such capacity of the anion exchange resin AV-17 with respect to boric acid is evidence that in the circuit water at pH 8 it exists in the form of a polyacid. If orthoboric acid were in the solution, then the capacity of the anion exchange resin AV-17 would be 1.5-3 g-eq/liter, although it is known that with respect to anions of strong acids it usually does not exceed 0.7-0.8 g-eq/liter. Substituting the equivalent weight of univalent ions of penta- and tetraboric acids, we find that the capacity of AV-17 corresponds to the value indicated above. It may be assumed that the circuit waters contain penta- and tetraboric acids, and that sorption on the anion exchange resins is accomplished on account of their univalent anions.

Little information has been published on the desorption of boric acid. It has been reported that boric acid can be desorbed from a strongly basic anion exchange resin only by solutions of alkali hydroxides; a solution of ammonia is unsuitable for this purpose [2]. However, no information is cited on the consumption of potassium hydroxide and its optimum concentration in the regenerate.

In this work we carried out the desorption of boron-containing anions with 0.1-1 N solutions of alkali hydroxides; in addition, we obtained data on the displacement of boron-containing anions from the anion exchange resin by solutions of ammonia and pure water. The results obtained are shown in Fig. 1. It is evident that a decrease in the volume of the regenerate is achieved by increasing its concentration: a 1 N solution of alkali hydroxide can entirely displace the boron-containing ions with two column volumes of the solution, while a 0.2 N solution of the alkali hydroxide requires five column volumes. Solutions of ammonia and water displace boron-containing ions very slowly.

The experiments conducted showed that desorption proceeds rather rapidly and completely when two column volumes of a 0.5 N solution of alkali are used. Then the anion exchange resin must be washed with three column volumes of water.

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TABLE 1. Total Exchange Capacity of Anion Exchange Resins with Respect to Boron-Containing Anions from a Solution Containing 2 g/liter Boric Acid

Anion exchange resin	AN-18*	AN-31	AN-22	AM	AV-17
Total exchange capacity	45	60	80	80	130

*Data of [2]; initial solution contained 3 g/liter H_3BO_3.

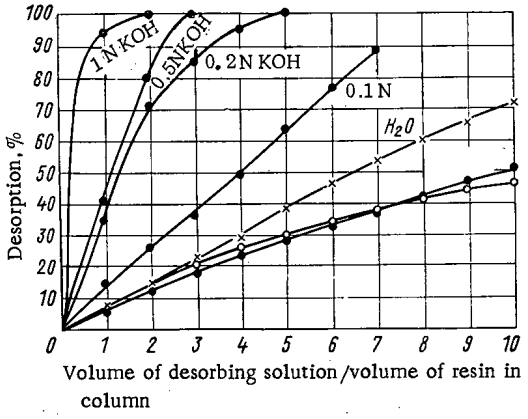

Fig. 1. Desorption of boron-containing anions.

Thus, as a result of sorption and desorption the concentration of boric acid in the regenerates can be increased 60-80-fold in comparison with the circuit water.

The determination of the solubility of the compound formed in the alkaline regenerate and its dependence on the temperature permitted us to assume that tetraborate is present in this solution. Its conversion to boric acid can be accomplished in two ways: with the aid of a cation exchange resin or by the process of electrodialysis. Both methods were tested.

As a result of filtration of the desorbing solution through the cation exchange resin KU-2 in the H^+ form or by its electrodialysis in a three chamber cell with anion exchange and cation exchange membranes, solutions of boric acid close to saturation were obtained.

The circuit waters used contain not only boric acid, but also corrosion products and radioactive isotopes. To obtain pure boric acid the circuit waters should be preliminarily purified on a cation exchange resin and an anion exchange resin.

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MECHANICAL PROPERTIES OF 1Kh16N15MZB AND 1Kh18N10T AUSTENITIC STEELS CARBURIZED IN LIQUID SODIUM

I. N. Luk'yanova, B. A. Nevzorov, and O. V. Starkov

UDC 669.15

Austenitic steels immersed in liquid sodium coolant which contains carbon as impurity or is in contact with low-alloy perlite steel absorb carbon, which impairs their plastic properties. Therefore to determine the serviceability of artifacts made of austenitic steels, especially the thin-walled casings of fuel elements, it is important to know how their mechanical properties depend on their carbon contents. For example, it is known that raising the carbon contents of thin-walled specimens of steel 316 (USA) to 0.25 wt. % leads to a twofold reduction in their specific elongation [1].

We have performed experiments in which thin plates of austenitic steels 1Kh18N10T and 1Kh16N15MZB were carburized in sodium (about as pure as that in a reactor) for 1-100 h at 500-800°C. The source of carbon was U-8 carbon steel. This method yielded specimens with various carbon contents between 0.1 and 1 wt. %. The mean carbon content of the specimen plates, which were 51 × 9 × 0.5 mm in size, and of the dumbbell type, was determined by chemical analysis to within $\pm 2 \cdot 10^{-2}$ wt. % and by weighing to within $\pm 3 \cdot 10^{-4}$ g. Brief-duration mechanical tests were performed at 20 and 650°C in an R-5 tensile tester. We tested specimens either immediately after carburization or after isothermal soaking in argon at 650°C for 500 or 1000 h. The microhardness was measured in a PMT-3 microhardness meter.

The relation between the mechanical properties of the specimens and their carbon contents was found by calculating the coefficients of the polynomial

$$(\delta, \sigma_B) = A_0 + A_1 C + A_2 C^2 + A_3 C^3 \quad (1)$$

by the method of least squares [2] with the aid of a computer for 30-45 experimental points, where δ is the relative elongation in percent, σ_B is the strength in kg/mm^2, C is the carbon content of the steel in wt. %, and A is a constant.

Analysis of the results revealed that the strengths of the steels decrease somewhat as the carbon content rises, obeying the following laws:

For steel 1Kh16N15MZB with 0.07-0.8 wt. % carbon at 20°C,

$$\sigma_B^{20} = [(62.0 + 37.5C) \pm 4.1] \text{ kg/mm}^2. \quad (2)$$

At 650°C,

$$\sigma_B^{650} = [(38.0 + 10.0C) \pm 3.8] \text{ kg/mm}^2. \quad (3)$$

For steel 1Kh18N10T with 0.09-0.35 wt. % carbon at 650°C,

$$\sigma_B^{650} = [(36.5 + 6.5C) \pm 3.0] \text{ kg/mm}^2. \quad (4)$$

The yield point σ_S of these steels increases with the carbon content, until it equals their strength. During carburization the microhardness of the steels increases from 250 kg/mm^2 for the original steel to 800 kg/mm^2 for steels containing about 1 wt. % of carbon. The microhardness is not a unique function of the carbon content, because it is also influenced by the carburization temperature, the rate of cooling, and the method of treating the metallographic sections.

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Of the properties tested, the one which was most sensitive to changes in the carbon content was the relative elongation, which after carburization in sodium varies according to the following equations.

For steel 1Kh16N15MZB with 0.07-1 wt. % carbon at 20°C,

$$\delta^{20} = (54.69 - 105.22C + 50.01C^2)\ \%; \quad (5)$$

at 650°C,

$$\delta^{650} = (27.93 - 39.23C + 10.5C^2)\ \%, \quad (6)$$

if the root-mean-square deviation is $\overline{\xi}_{sq} = \pm 1.56$.

For steel 1Kh18N10T with 0.09-1.0 wt. % carbon at 20°C,

$$\delta^{20} = (54.26 - 96.39C + 39.55C^2)\ \%; \quad (7)$$

at 650°C,

$$\delta^{650} = (30.52 - 70.97C + 39.10C^2)\ \%, \quad (8)$$

if $\overline{\xi}_{sq} = \pm 1.53$.

When steel 1Kh16N15MZB was kept in argon at 650°C we found that during the first 500 h there is an additional fall in plasticity of the carburized specimens owing to leveling-out of the carbon concentration over the cross section of the specimen and the disappearance of the less-carburized more-plastic middle sections of the specimens. After heat treatment in argon for 500 or 1000 h, the relation between the relative elongation of steel 1Kh16N15MZB and its carbon content follows the equation

$$\delta^{20} = (39.18 - 90.9C + 51.55C^2)\ \% \quad (9)$$

where $\overline{\xi} = \pm 5.35$.

These empirical equations enable us to estimate the mechanical properties for a given carbon content and the permissible carbon content for a given set of mechanical properties, and also to estimate the sensitivities $d\sigma/dC$, $d\delta/dC$ of the mechanical properties of the steels to changes in carbon content during carburization in sodium.

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YIELDS OF Bi^{205}, Bi^{206}, AND Bi^{207} FROM LEAD IRRADIATED WITH PROTONS OR DEUTERONS

P. P. Dmitriev, N. N. Krasnov,
G. A. Molin, and M. V. Panarin

UDC 539.172.12

The bismuth isotopes Bi^{205} ($T_{1/2}$ = 15.3 days), Bi^{206} ($T_{1/2}$ = 6.24 days), and Bi^{207} ($T_{1/2}$ = 30.2 yr) can be obtained only from reactions with charged particles. The most effective way of making these isotopes is irradiation of lead with protons or deuterons.

In this article we describe measurements of the yields of Bi^{205}, Bi^{206}, and Bi^{207} in relation to the energy of the bombarding particles when thick lead targets are irradiated with protons or deuterons. We used the cyclotron at the Physico-Energetic Institute. The yields of Bi^{205}, Bi^{206}, and Bi^{207} were measured for the maximum particle energies listed in Table 1. The experimental graphs of the yields of Bi^{205}, Bi^{206}, and Bi^{207} vs bombarding particle energy are shown in Figs. 1 and 2.

As we see from Table 1, the literature data on the yields of Bi^{206} and Bi^{207} are very scanty and contradictory [1-5]. There are no data whatever on the yields of Bi^{205}. This situation (with respect to Bi^{205} and Bi^{206}) is largely due to the fact that the quantum yields of the gamma lines of Bi^{205} and Bi^{206} have been determined only comparatively recently [6].

The method by which we measured the yields of Bi^{205}, Bi^{206}, and Bi^{207} were broadly similar to those described in [7]. The proton and deuteron energies were varied by means of copper decelerating foils. The integral irradiation current to the lead specimens was measured by means of monitoring foils. The activities of the Bi^{205}, Bi^{206}, and Bi^{207} were determined by means of the sizes of the photopeaks formed by the emitted gamma quanta with certain energies: Bi^{205}, E_γ = 1.766 MeV (yield 27%); Bi^{206}, E_γ = 1.720 MeV (yield 36%); Bi^{207}, E_γ = 0.570 MeV (yield 98%), E_γ = 1.063 MeV (yield 77%), and E_γ = 1770 MeV

TABLE 1. Data on Yields of Bi^{205}, Bi^{206}, and Bi^{207}

Formation reaction	Energy threshold of reaction, MeV	Content of original isotope, %	Data on yields: particle energy, MeV	yield, μCi/μA·h	Reference
Pb^{206} (p 2n) Bi^{205}	11,61	25,1	22,1±0,22	244±36	Present authors
Pb^{207} (p 3n) Bi^{205}	18,37	21,2			
Pb^{206} (pn) Bi^{206}	4,4	25,1	22,1±0,22	310±46	The same
Pb^{207} (p 2n) Bi^{206}	11,17	21,2			
Pb^{208} (p 3n) Bi^{206}	18,58	52,3			
Pb^{207} (pn) Bi^{207}	3,2	21,2	22,1±0,22	0,41±0,05	" "
Pb^{208} (p 2n) Bi^{207}	10,56	52,3	20	0,8±0,5	[1]
Pb^{204} (dn) Bi^{205}	—	1,4	22±0,23	58±8,7	Present authors
Pb^{206} (d 3n) Bi^{205}	13,91	25,1	22±0,23	352±53	The same
Pb^{206} (d 2n) Bi^{206}	6,67	25,1	13,5	30	[5]
Pb^{207} (d 3n) Bi^{206}	13,47	21,2	19	64	[3]
			25	200	[2]
			30	850	[4]
Pb^{206} (dn) Bi^{207}	—	25,1	22±0,23	0,31±0,05	Present authors
Pb^{207} (d 2n) Bi^{207}	5,46	21,2			
Pb^{208} (d 3n) Bi^{207}	12,91	52,3			

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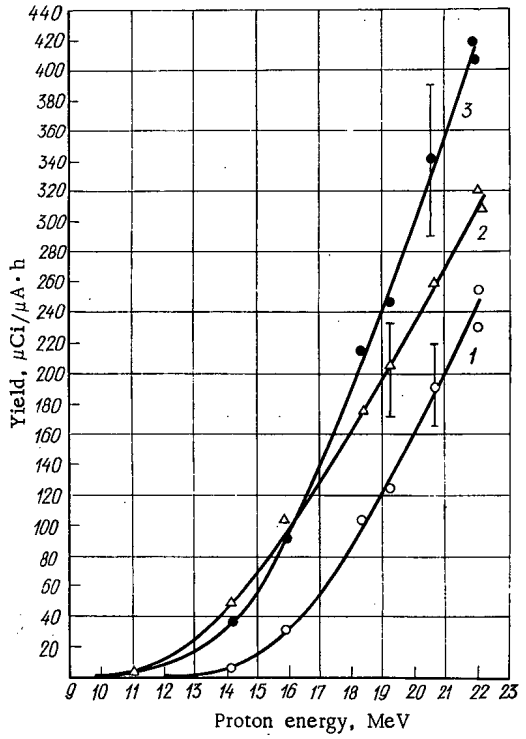

Fig. 1

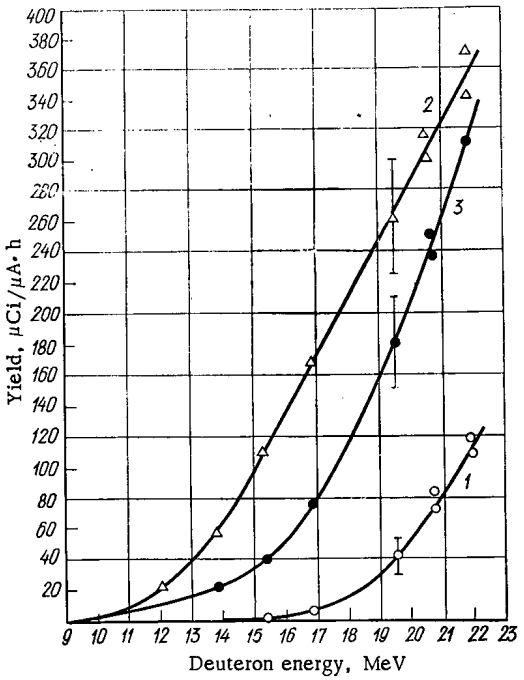

Fig. 2

Fig. 1. Yields of Bi^{205}, Bi^{206}, and Bi^{207} vs proton energy, for thick lead targets. 1) Bi^{205}; 2) Bi^{206}; 3) Bi^{207} (× 1000).

Fig. 2. Yields of Bi^{205}, Bi^{206}, and Bi^{207} vs deuteron energy, for thick lead targets. 1) Bi^{205} (×2); 2) Bi^{206}; 3) Bi^{207} (×1000).

(yield 9%). These values of $E\gamma$ and the quantum yields are quoted from [6]. The choice of lines $E\gamma$ for measuring the activities of Bi^{205} and Bi^{206} was dictated by the facts that they are adequately intense and are hardly at all distorted by the Compton distribution of gamma quanta at higher energies. The photopeaks were measured with a gamma spectrometer with NaI(Tl) crystals 40 × 40 mm and 70 × 70 mm in size, together with a 256-channel pulse analyzer. The photoefficiency of the gamma spectrometer was determined with the aid of a set of MAGATE (International Atomic Energy Agency) standards.

Owing to the small difference between the energies of the lines of Bi^{205} and Bi^{206} they were not resolved by the gamma spectrometer and were observed together as one. Separation was effected by means of the difference between the half-lives of Bi^{205} and Bi^{206}. Five to seven days after irradiation we measured the photopeak which is the sum of the photopeaks of the gamma lines at 1.766 MeV (Bi^{205}) and 1.720 MeV (Bi^{206}). The measurements were repeated after 2.5 months. By this time the measured photopeak was due to Bi^{205} only plus a small contribution from the gamma line at 1.770 MeV (Bi^{207}). After decay of the Bi^{205} (about eight months after irradiation) we measured the photopeak of Bi^{207}. This enabled us to correct the value of the previously measured photopeak of Bi^{205} for the contribution E_γ = 1.770 MeV from Bi^{207}. The activity of Bi^{206} was determined by subtracting the photopeak of Bi^{205} from the overall photopeak measured five or six days after irradiation. The root-mean-square error of the measured yields of Bi^{205}, Bi^{206}, and Bi^{207} was estimated as ±15%.

The bismuth was not radiochemically separated from the lead, because when lead is irradiated with protons or deuterons, radioactive isotopes which might interfere with the measurements are not formed in appreciable amounts.

From the data it follows that the optimum method of obtaining Bi^{205} and Bi^{207} is irradiation of lead with protons, whereas for Bi^{206} deuterons are preferable.

Among other methods of making Bi^{205}, Bi^{206}, and Bi^{207} we can mention irradiation of lead and thallium with α particles. Here we should expect to get a lower yield of the isotopes owing to the shorter ranges of the α particles.

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XXII SESSION OF THE COMECON PKIAÉ

V. A. Kiselev

The XXII session of the COMECON Permanent Commission on the peaceful uses of atomic energy (PKIAÉ SÉV) was held in Moscow, July 4-7, 1972.

Participating in the session were delegations from Bulgaria, Hungary, German Democratic Republic, Rumania, the Soviet Union, and Czechoslovakia. The progress achieved by the Commission in realizing measures envisaged in the Comprehensive Program of further deepening and improvement of collaboration and development of socialist economic integration of COMECON member-nations came under discussion. Informational reports from the USSR delegation on the building of a water-cooled water-moderated power reactor plant with a 1000 MW electric power rating for nuclear electric power generating stations were discussed, as well as research findings on dissociating gases as potential new coolants for fast reactors. Pathways for further collaboration in those areas were mapped out.

A report by the director of the international economic association on nuclear instrumentation, Interatominstrument, on the work of the association was accepted for information. The commission also adopted some appropriate recommendations and resolutions on the development of collaboration between COMECON member-nations in the field of reactor science and engineering, nuclear power, nuclear instrumentation, radiation processes and radiation facilities, and radiation safety.

The deliberations of the Commission took place in an atmosphere of mutual understanding and businesslike collaboration.

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COLLABORATION DAYBOOK

A conference of specialists on monitoring and control of nuclear reactors and nuclear power plants was held April 4-7, 1972, at Zakopane (Poland), in accordance with PKIAÉ SÉV work plans. Recommendations were elaborated on ways to improve forms of coordinating scientific research work. Close attention was given to preparations for the science and industry conference on "Monitoring and control of nuclear reactors and nuclear power plants" scheduled for October 1973 in Poland, under COMECON (SÉV) auspices. The agenda and program of the conference were worked out in detail.

The conference program covers various theoretical and technical aspects of the development of systems for monitoring and control of research reactors and power reactors of the VVÉR type. The main purpose of the conference is to lay down the optimum preconditions for a broad exchange of experience and results of scientific research work carried out in COMECON member-nations, as well as exchanges of views on technical forecasts extrapolated to the Eighties in the field of the development of control systems for nuclear power stations using VVÉR type high-power reactors.

In addition to these general topics concerning control of nuclear power facilities and nuclear power plants, the conference agenda will also cover:

1) use of computers to process technological process information and to control nuclear facilities, and also computerized design of control systems from the outset;
2) topics concerning equipment and techniques for in-pile monitoring of reactor parameters, and utilization of the results of in-pile measurements for reactor control;
3) technical progress in systems of reactor monitoring, control, and protection (including fuel-clad leak testing and nuclear power station radiation safety);
4) technical progress in the field of equipment components and components of monitoring and control systems for water-cooled water-moderated power reactors.

Review papers are also to be prepared for the conference.

The schedule of preparations and arrangements for the conference worked out by the Polish delegation was approved. Preliminary deadlines were set for submission of abstracts or annotated abridgments of papers (November, 1972) and for the texts of complete reports (May, 1973).

The program, agenda, and arrangements for the conference were approved at the XXII session (July, 1972) of the PKIAÉ.

The third session of the KNTS on radiation equipment and technology was held April 18-21, 1972, in Czechoslovakia, in accordance with the PKIAÉ SÉV work plan. Participating in the work of this session were members of the SÉV Council and experts from Bulgaria, Hungary, East Germany, Poland, Rumania, the USSR, Czechoslovakia, and representatives of the SÉV [COMECON] Secretariat.

According to the agenda approved by the Council for the conference, 13 topics were scheduled for consideration, the principal topics being organization of radiation processing of foodstuffs and agricultural products on a full industrial scale, and measures to be taken to expedite practical acceptance of the method in the national economy of the interested countries.

The conference participants arrived at the concensus that basic efforts in the field of radiation processing of foodstuffs and agricultural products should be concentrated on the development of unified procedures of public-health evaluation of irradiated products. Measures to get this method accepted on a

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regular basis in the national economy of the interested countries are to be taken jointly with specialists conducting research within the framework of the SÉV Permanent Commission work plan on the food processing industry, by setting up a special team of experts consisting of scientists experienced in the design and development of radiation facilities, food processing and food technology experts, and public health and medical personnel.

One important phase of the work of the KNTS on radiation equipment and technology (KNTS-RT) was to correlate such documents as the "Basic terminology for radiation equipment, technology, and economics" and the "Provisional technical requirements for research, multipurpose, and special-purpose facilities for radiation processes."

Measures geared to facilitate exchange of experience and scientific and technical information were discussed and coordinated, and the program of a conference on implementation of high-level radiation facilities and radiation technology (scheduled for Budapest, October 2-4, 1972) was approved. An informational report on types of accelerators suitable for industrial purposes, and information on progress in drawing up a report covering training of specialists in the field of radiation equipment and radiation technology were heard.

A report prepared by the KNTS-RT Secretariat on the activities of the KNTS-RT during 1971 was confirmed, and the basic trends in the continuing work of the KNTS-RT were approved.

In conformity with the KNTS-RT workplan, a conference of a group of experts charged with working out plans of procedure for engineering cost evaluations of the effectiveness of radiation equipment was held on April 18-19, 1972. Delegations from all the countries expressed great interest in the topic, and their representatives took an active part in the conference of experts and did useful work on greater refinements in the further elaboration of the first draft of the procedural plan.

The session took place in an atmosphere of fraternal collaboration and complete mutual understanding in all the topics under discussion. Attention should be drawn to the excellent organization of the work of the conference on the part of the Czechoslovak delegation.

The fourteenth session of the PKIAÉ SÉV work team on reactor science and engineering met May 16-20, 1972, in Mamaie (Rumania). Specialists from Bulgaria, Hungary, East Germany, Poland, Rumania, the USSR, and Czechoslovakia participated, as well as colleagues of the COMECON Secretariat.

Programs of collaboration in the field of monitoring and control of research reactors, equipment for in-pile measurements, physics of shielding against penetrating radiations, were discussed. A work plan for materialization of the program of collaboration in the field of improvements in water-cooled water-moderated power reactors was corrected and approved.

The program of collaboration agreed upon has provisions for expansion and unification of the efforts of COMECON member-nations in the solution of current problems pertaining to nuclear power development.

The first KNTS session on fast reactors was held May 30 to June 1, 1972, at Obninsk (USSR), in accordance with a PKIAÉ SÉV decision to set up that working body.

Delegations from Bulgaria, Hungary, East Germany, Poland, the USSR, Czechoslovakia, and colleagues of the COMECON Secretariat took part in the deliberations.

The participants at this session became familiarized with the status of work going on in the COMECON member-nations in the field of fast reactors, and agreed upon a plan for carrying out the program for collaboration in the field of scientific and technical research on fast reactors, and also discussed a number of organizational problems.

It was pointed out that unification of the efforts of scientists and engineers of the COMECON member-nations will contribute to the successful solution of the problems encountered in building large low-cost nuclear power stations based around fast reactors.

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INFORMATION

III ALL-UNION CONFERENCE ON ACTIVATION ANALYSIS

A. A. Kist

The III All-Union conference on activation analysis was held on May 10-12, 1972, at Tashkent. The conference attracted over 500, to discuss some 270 papers and communications.

The President of the Academy of Sciences of the Uzbek SSR, A. S. Sadykov, addressed introductory remarks to the participants. In his report to the plenary session, I. P. Alimarin took note of the fact that the activation method had emerged from behind the walls of laboratories in recent years and had begun to win acceptance under production conditions. G. N. Flerov presented a discussion of the possibilities open for utilization of accelerated multiply charged ions in activation analysis, and evaluated various ways of solving the problem. A review of modern equipment and instruments for activation analysis was presented in a report by A. S. Shtan' (see below).

Three panels were organized: 1) general topics, activation analysis equipment, and use of digital computers; 2) instrumental techniques; 3) chemical and radiochemical techniques.

The first panel attracted attention to work on low-cost readily available sources of activating radiation. Impressive success can be seen in the building of specialized automatic facilities for activation analysis. Oxygen determination facilities are now being used in the national economy. Several reports of a theoretical nature and developments of components in automated systems dealt with completely automated activation analysis.

The extremely widespread use of semiconductor γ-radiation detectors is typical of instrumental activation analysis. The number of research efforts in which activation by charged particles or activation by γ-photons is used was increased considerably. Papers presented at this panel are characterized by an intimate tie-in with the current needs of the national economy, as reflected in the choice of media to be analyzed. Not only the total composition of the specimens is studied in instrumental activation analysis, but efforts are made to determine the impurity distribution throughout the volume of the specimen. That problem is solved through the use of autoradiographic techniques in the investigation of the composition of biological specimens (V. F. Stepanenkov et al.), metals (V. S. Vasil'ev et al.), crystals (Sh. A. Vakhidov et al.).

Papers with a distinct radiochemical orientation are characterized by the use of modern chemical methods for isolating the elements present in small concentrations in various host matrices, including those of complex composition or containing highly activable elements. Quite a few papers dealt with methods for determining elements of the platinum group (É. E. Rakovskii and colleagues; A. G. Ganiev and colleagues).

Chemical treatment of the specimen prior to activation is carried out in order to simplify the procedure for finding the total content of an element, or finding an element existing in a certain state. As was demonstrated in the reports, low-cost Po–Be sources can be used in preliminary separation of the element. For example, ore concentrations of gold were determined using a low-level neutron source, as described by a paper presented by G. S. Nikanorov et al. The use of activation to determine trace quantities of pesticides in waters, in the soil, and in foodstuffs, showed greatest promise in the study of forms of chemical elements (G. I. Gofen et al.).

It can be pointed out that all types of test specimens, and all of the major techniques and methods of activation analysis, are reflected in practice in the work done by Soviet researchers. For example, consider determination of gold, which was the subject of the largest number of papers, including those on applications of activation analysis to the study of gold geochemistry, on methods of gold prospecting (biogeochemical methods in particular), on determinations of run-of-mine gold and of gold in various products,

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in pure materials, and in specimens of biological origin. Several variants of neutron activation, both instrumental, and chemical and radiochemical, are being used to solve these problems. In addition, activation by γ-photons through the use of linear electron accelerators, microtrons, betatrons, and other machines is being widely used. Gold determinations are now automated to a considerable degree. The entire problem of gold determinations over the entire range of practical concentrations is being solved with success by the methods of activation analysis. The statement of the problem of the extension of geological services concerned with gold determinations to the several variants of activation analysis (depending on the specific requirements) is entirely appropriate.

The interest of analysts in the economic side of the question, in the ultimate fate of their developments, and in application to sampling techniques, was confirmed by the discussion from the floor on the representativeness of the specimens. Even though certain solutions presented were not fully worked out, this discussion can be regarded as most timely.

The conference participants expressed their gratitude to the Presidum of the Academy of Sciences of the Uzbek SSR and to the personnel of the Institute of Nuclear Physics for the good work done in organizing and carrying out the conference.

The proceedings of the conference will be published by "FAN" press (Tashkent) in 1973. The IV conference on activation analysis is scheduled for 1975.

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EQUIPMENT AND INSTRUMENTAL BASE FOR ACTIVATION ANALYSIS IN THE USSR*

A. S. Shtan'

Neutron Sources for Activation Analysis

The development of activation methods of analysis in the USSR has been due primarily to the development of various radiation sources. For several years sources have been designed specifically for activation analysis.

Broad possibilities are open for research on activation analysis at IRT, VVR, and TVR type research reactors developed and built over the past two decades at various scientific research centers in our country. These reactors are distinguished by high neutron flux density (to $n \cdot 10^{13}$ neutrons/$cm^2 \cdot sec$), and feature a large number of vertical and horizontal channels suitable for use in neutron activation analysis.

Nuclear reactors of type RG-1M (IVV-3) and IIN-3 have been developed especially for neutron activation analysis, and are used as a basis for the development of standard activation analysis laboratory plans.

The RG-1M (IVV-3) type reactor has a power rating of ~5 kW, and features a thermal flux density of $\sim 10^{12}$ neutrons/$cm^2 \cdot sec$ in the central channel.

The IIN-3 reactor is capable of functioning in a pulsed mode with a neutron yield $\sim 10^{15}$ neutrons/pulse $\cdot cm^2$ and at a stationary power level ~10 kW with a neutron flux density in the central channel $\sim 10^{12}$ neutrons /$cm^2 \cdot sec$, and $\sim 2 \cdot 10^{11}$ neutrons/$cm^2 \cdot sec$ on the surface of the pressure vessel.

A RG-1M reactor, and a specially designed activation analysis laboratory based on the reactor, were commissioned over a year ago at the A. P. Zavenyagin mining and metallurgical combine in Noril'sk.

An activation analysis laboratory outfitted with a pneumatic shuttle system and the necessary equipment was also organized around an IIN-3 reactor at the I. V. Kurchatov Institute of Atomic Energy.

The PS-1 neutron multiplier (a subcritical assembly), which is capable of producing $\sim 10^7$ to 10^8 neutrons/$cm^2 \cdot sec$ depending on the flux generated by the primary neutron source, can be used to solve process monitoring problems in the metallurgical, chemical, mining and ore processing, and other branches of industry, and also in neutron activation analysis of medical and agricultural specimens.

Neutron generators with evacuated type NG-160 and NG-150I tubes, and with type NGI-1, NGI-4, or NGI-5 sealed-off tubes, are meeting with widespread acceptance in laboratory practice and in production work.

At the present time, the NG-150I neutron generator with accelerating voltage to 150 kV, beam current up to 3 mA on target, and neutron yield to $2 \cdot 10^{11}$ neutrons/sec, has been put into production service. NGI-5 type generators, with neutron yields $\sim 6 \cdot 10^8$ neutrons/sec, are also being manufactured in quantity lots.

Neutron isotope sources are being used in continuous process monitoring and also in various instruments and facilities, where high stability on the part of the yield of the neutron source, and continuous long-term performance, are crucial requirements. Po^{210}, Pu^{239}, and Pu^{238} neutron sources are already in

*Abbreviated text of report presented at the III All-Union conference on activation analysis.

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TABLE 1. Thresholds for Determination of Various Elements by γ-Ray Activation, Using Quantity-Manufactured LUÉ Linear Accelerators, % (Specimens weighing 100 g)

LUÉ model	10^{-1}—10^{-2}	10^{-2}—10^{-3}	10^{-3}—10^{-4}	10^{-4}—10^{-5}	10^{-5}—10^{-6}	10^{-6}—10^{-7}	10^{-7}—10^{-8}
LUÉ-8-5 (8 MeV, 700 μA)	Sn	Y, Rh, Ba W, Pt	Br, Sn, Ag Er, Lu, Ir Hg, Ge, Pb U, Th	In, Cd, Au Se, Hf, Be D			
LUÉ-15 (15 MeV, 500 μA)		Na, Mn, Co	Rh, Ce, Im Mg, Ca, V Dy, OS	Cs, Cr, Fe Ni, As, Nb I, Eu, Cd, Re IN, Tl, Si, Y, Yb, Pt	Ti, Mo, K, N, As Ge, Se, Br, Pd Cd, Sn, Ho, Lu Hg, Pb, Hf	En, Ta, P, Cl Zn, Rb, Ru Ag, In, Sb, Te Ba, Sm, Au, U Th, Be	F, Sc, Cu Ga, Sr, Zn Pr, Nd

production applications. Sources using Cf^{252} and Cm^{244} have been developed, and production of those sources is to be organized in the near future.

Gamma-ray activation analysis using betatrons, microtrons, and linear accelerators as sources has undergone substantial development in recent years. But analytical potentialities and the practical value of the method are still underestimated.

Several types of betatrons are being manufactured for these applications, with energies of the accelerated electrons in the 5 to 50 MeV range, and bremsstrahlung intensities to 200-250 r/min · m (B5M-25, B-25/30, B-4D, B-50/50 betatrons). Microtrons and linear accelerators are of greatest interest in γ-ray activation analysis. MD-10, MT-20, and MR-30 microtrons have been developed. The electrons are accelerated to energies of 10, 20, and 30 MeV, and the respective bremsstrahlung intensities are 2000, 8000, and 16,200 r/min · m. The respective neutron yields, when converters are placed in the beam path, are $5 \cdot 10^{10}$, 10^{11}, and $2 \cdot 10^{11}$ neutrons/sec.

Technical specifications have been worked out and industrial-scale manufacture of the microtrons is scheduled.

Type LUÉ-8-5 (5V) linear electron accelerators, beam power ~5-7 kW, current to 0.7 mA, have been developed and are now in production. The LUÉ-15-10 lineac machine, beam power to 10 kW and current to 0.7 mA, is also available. By using converters, the neutron yield can be stepped up to $5 \cdot 10^{11}$ neutrons/sec (in the case of the LUÉ-8) or $2 \cdot 10^{13}$ neutrons/sec (in the case of the LUÉ-15).

The analytical possibilities in γ-ray activation analysis employing the LUÉ-8 and LUÉ-15 lineacs are indicated in Table 1.

Delivery of Specimens from Radiation Source to Detector

Special systems for delivering the specimen from the radiation source to the detector have been devised in order to ensure safe handling of high-level activation sources, and of irradiated specimens. In addition, these systems make it possible to speed up materials handling and to shorten the time between activation and measurement, so that the sensitivity of the analysis can be increased when necessary.

A set of components and modules for the Element pneumatic shuttle system has been developed and is being readied for quantity production; this set is intended for the construction of automatic activation analysis systems of different purpose and different levels of complexity. These systems can be divided into two groups: single-conductor systems with a single transport trunk cable and twin-conductor systems with separate trunk cables for the specimen and the standard.

Any system can be fashioned with transport trunk cable 12 mm or 28 mm in inner diameter. The set of components and modules includes the following elements that can be used to build up systems of different levels of complexity: routing distributors, reloading modules, irradiation positions, measurement positions, packaging and uncrating gear, reencapsulators, sample leak testers, air distributors, controllers governing the system of a system built up from elements of the set either manually or automatically. These systems can be employed in scientific research organization or at industrial enterprises equally well.

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TABLE 2. Nuclear Physics Equipment for Activation Analysis

Equipment	Purpose	Some characteristics
General-purpose Lena USS-1 coincidence scintillation spectrometer	Measurement of β-ray spectra and γ-ray spectra	NaI (Tl) cylinder $\varnothing$ 40×40 mm $\varnothing$ 63×63 mm $\varnothing$ 150×100 mm
General-purpose Angara coincidence scintillation spectrometer	The same	The same
Langur semiconductor spectrometer	Activation analysis in physics research and medicine	Makeup: detector module with Ge (Li)-detector, BUS-01 preamplifier, control console with ÉS-2
LPRA system of laboratory and industrial scale radiometric equipment	Accessories for radiometric and spectrometric equipment	Supplies: + 1.5 + 6 + 12 + 24 V; speed $4 \cdot 10^4$ to $5 \cdot 10^4$ pulses/sec
Multichannel analyzers AI-128-2 AI-256-6 AI-1024-4 AI-1024-8 AI-4096-2 AI-4096-3M AI-16000M	Pulse-amplitude and time analyses of emission spectra	Peak loading $5 \cdot 10^4$ pulses/sec; four AI-4096-3M analyzers incorporated in AI-16000M in measuring subsystem
Interfacing modules with computer (type AM-1 device for transfer of data from MAA to computer)	Data readout from MAA and transfer of data by multiconductor telephone cable to computer memory bank	Data transfer time 1 sec, data in M2 code, data transfer range up to 1000 m, number of binary or binary-decimal bits transmitted: 20

Measuring Equipment

Considerable progress has been made in recent years in the development of measuring equipment and spectrometric equipment, equipment automating analytical procedures, decoding and interpretation of γ-ray spectra, and computer processing of experimental results (Table 2).

Needs for measuring equipment are determined by the problems to be solved through the use of the equipment.

Depending on the nature and volume of the analytical work, various types of recording devices are available for use. Among those developed and already in production are:

1. General purpose Angara coincidence scintillation spectrometer.
2. Langur semiconductor spectrometer.
3. LPRA system of laboratory and production radiometric equipment; this system includes a set of components and 20 distinct modules (pulse amplifiers, pulse-amplitude and time selectors, counters, and so on) designed for construction of radiometric equipment and the simplest spectrometric equipment. The modules are designed for mounting on standard racks and to be supplied from standard unitized Aleksandrit power packs. The basis for the construction of electronic measuring devices in this system are the transistorized functional modules capable of performing standard data converting and signal processing operations at an average pulse repetition rate of $4 \cdot 10^4$ to $5 \cdot 10^4$ pulses/sec. The modules of the LPRA system replace the modules of the Nabor-M and Nabor-T systems.
4. Multichannel pulse analyzers. The AI-128-2 and AI-256-2 multichannel pulse analyzers are designed to measure the distribution of random pulses in height, while the AI-1024-4 analyzer is designed for time measurements. The AI-4096-2, AI-4096-3, and AI-4096-3M multichannel pulse analyzers can also be used in these applications. The last two types of analyzers are capable of processing data and operating in operational control modes like conventional general-purpose computers with programs stored in an internal memory store. The AI-16000M measuring complex incorporates four AI-4096-3M multidimensional analyzers, each of which reads out information

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TABLE 3. Modules of the LPRA System

Module	Purpose	Replacing module in system	
		Nabor-M	Nabor-T
BUI2-10	Amplification and shaping of signals from scintillation detector module	BU-2 amplifier	—
BUI2-12	Amplification of signals from scintillation detector modules with NaI, CsI crystals and with proportional counters	—	—
BUI-13	Amplification of signals from semiconductor detector and ionization chambers	—	—
BSA2-08	Discriminator-expander and integral discriminator	BD-5 discriminator	BD-9 discriminator
BSA2-09	Differential discriminator with independent threshold setting	—	BD-8 discriminator
BSA2-10	Differential narrow-channel discriminator	BD-2 discriminator	—
BSV2-07, BSV2-08, BSV2-09	Triple coincidence gates, τ = 0.2 to 1 msec	—	BS-7 fast coincidence gate
BSV2-10, BSV2-11, BSV2-12	Double coincidence gates, τ = 60 to 200 nsec	—	BS-8 fast coincidence gate
BK2-10	Combination logic device (slow coincidences and anti-coincidences gated)	BS-6 fast coincidence gate	—
UIO2-07	Linear-logarithmic average frequency meter (n = 0.2 to 40,000 pulses/sec	BI-2, BI-3 ratemeters	BI-8, BI-9, BI-11 ratemeters
USO2-08	Difference type average frequency meter (n = 0.2 to 40,000 pulses/sec	—	BI-10 ratemeter
USO2-02	Two decades with binary-decimal readout	—	—
USO2-03	Decade with decimal readout (resolving time 6 μsec)	—	—
USO2-04	Decade with decimal readout (resolving time 2 μsec)	—	—
BATs2-09	Controls (start, reset) for counters	—	—

in both analog and digital form. This system is capable of performing pulse-height analysis and time analysis simultaneously.

The large volume of data obtained in activation analysis of specimens of intricate and complex composition requires mathematical processing by machine, and a direct link to measuring and recording equipment operated on-line with a computer.

The AM-1 interfacer has been developed for readout of data from multichannel analyzers and transfer of the data by multiconductor telephone cable directly to the internal memory of a digital computer (fundamental operating mode). In addition to the mode in which data is written directly into the memory store of a digital computer, data can be read out from the analyzer and punched on tape with the aid of a paper tape punch telegraph equipment (RTA) and PL-150 (or PL-80) tape puncher. The data are encoded on the punched tape in the second international telegraph code with all of the auxiliary codes and symbols needed to write the tape into a computer.

The data transfer device is of modularized design, so that its capabilities can be expanded by replacing some modules and adding others (e.g., data can be transferred from one computer to another, digital data can be taken from different recording devices and routed to a supervisory control panel, etc.).

Special-Purpose and General-Purpose Activation Analysis Arrangements (Table 4)

The Neitron-4 activation analysis facility, now in quantity production, has found wide acceptance in geological prospecting and exploration work. This system, which employs an isotope neutron source, can perform two-component analysis of 30 to 40 samples weighing 50 to 70 g each within 6 h, and can analyze them for content of aluminum, silicon, fluorine, manganese, indium, copper, and other elements.

In recent years, neutron activation facilities have been devised to aid ultimate analysis in terms of short-lived isotopes, using neutron generators with sealed-in tubes and continuous evacuation as the neutron sources.

The K-1 and K-2 Facilities. The principal purpose for which the K-1 facility was designed is to express quantitative determinations of the content of oxygen in various materials (steel, titanium, copper,

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TABLE 4. Special-Purpose and General-Purpose Activation Analysis Facilities

Nomenclature, type	Purpose	Basic features
Equipment for oxygen determinations (K-1, K-2)	Analysis of metals and alloys for oxygen under industrial conditions	Oxygen determination threshold $3 \cdot 10^{-4}$ %; analysis takes not more than 5 min to complete; error at contents >0.01% not greater than 10% relative; neutron yield $6 \cdot 10^8$ neutrons/sec; floor area 25 m^2
Subsystem for single-element activation analysis, KOA-1-01 (Gerakl-1)	Single-element analysis under laboratory conditions	Specimens accepted if shaped cylindrically · pneumatic ducts of round and rectangular cross section; analysis sensitivity (at 10^{10} neutrons/sec) 200 pulses per mg oxygen; 400 pulses per mg nitrogen; instrumental error < 1%; floor area ~50 m^2
Arrangement for determinations in slurry stream (NAR-2)	Analysis of slurry in process stream	Range of measured concentrations: 2 to 30 mg /liter for indium; 5 to 20 g/liter for cadmium; yield of Pu–Be source $5 \cdot 10^6$ neutrons/sec
NAR-3 facility	Automatic continuous determination of one element in slurry stream (fluorine, selenium)	Fluorine detection threshold 5 g/liter; selenium detection threshold 0.2 g/liter; range of concentrations 10 to 400 g/liter for fluorine, 0.5 to 35 g/liter for selenium; error ±10% for both fluorine and selenium; Pu–Be source $5 \cdot 10^6$ neutrons/sec
Set of equipment for multicomponent activation analysis KAMA 1-01 (Gerakl-2)	Activation analysis under laboratory conditions	Limiting load for scintillation spectrometer 10^5 pulses/sec; for semiconductor counter $3 \cdot 10^3$ pulses/sec; control device allows five exposures lasting from 1 sec to 1 h; transport device allows displacement of specimens weighing 50 g at speed of 10 m/sec
Standard activation analysis laboratory with IIN-3 reactor	Activation analysis	Composition IIN-3M pulsed reactor; control room with pneumatic shuttle system; set of measuring equipment
Razmnozhitel'-1 facility for neutron activation analysis	Analysis of technological samples and geological specimens under stationary laboratory conditions	Neutron source: PS-1; transport system consists of five pneumatic shuttles 12 mm, 28 mm, and 50 mm in diameter; floor space required 60 to 70 m^2
Luch set of equipment	Multicomponent analysis of specimens of rock, ores, and other materials	Radiation source: betatron (or microtron); specimens weighing 50 to 300 g; transport speed 5 m/sec; peak load on equipment 10^5 pulses/sec
Element pneumatic shuttle system	Activation analysis (systems of different grades of complexity can be custom-engineered)	Shuttle trunk line 12 mm and 28 mm in diameter; single-conduit and twin-conduit systems

beryllum, zirconium, hard alloys, refractory metals, etc.) under the conditions prevailing in scientific research laboratories and in-plant laboratories, and also directly in production departments of factories and other enterprises. The NGI-5 portable neutron generator with its sealed-in tube operates reliably and is easy to maintain. The facility is fully automated, and can be used to complete an analysis of metal specimens for oxygen, with a sensitivity to $3 \cdot 10^{-4}$%, within a space of 1 to 5 min. The K-1 facility with its single-channel γ-ray spectrometer can be used in all cases where analysis based on a single individual line in the γ-ray spectrum will not be interfered with by isotopes of closely similar energy or emitting harder γ-radiation.

The K-2 facility (a modification of the K-1 model) can be used to measure activity on the basis of $\gamma-\gamma$-coincidences. The facility is provided with BS-1 and BS-6 coincidence circuits (BK2-10 in the LPRA system) for that purpose. The use of the coincidence spectrometer broadens the range of applications of the facility, so that analysis based on annihilation radiation or on γ-photons emitted in cascade transitions can be carried out under favorable conditions.

The KOA-1-01 Set of Instruments for Single-Element Activation Analysis. This is based around the NG-150-I generator with its continuous evacuation features. The measuring part of the facility includes high-speed electronic logic circuitry for work with samples of relatively high activity level. In contrast to the K-1 facility, the automatic data processor in the KOA-1-01 system is capable of making oxygen determinations against a varying background level. That special feature of the facility can be exploited to advantage, in particular, for analyzing materials for oxygen where activation of the matrix would mask the emission of oxygen when a single-channel pulse-height analyzer is employed.

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The KAMA-1-01 set of equipment is designed for multicomponent activation analysis of specimens investigated under laboratory conditions. The measuring equipment can be used in precision measurements of γ-ray and β-ray emissions from activated specimens, through the use of single-detector and multidetector scintillation spectrometers and PPD [semiconductor detector] spectrometers. The electronic circuitry of the recording equipment in this set incorporates stabilized electronic circuitry for the scintillation spectrometers, high-precision circuitry for the PPD-spectrometer, time gates and amplitude gates, data storage modules, a digital printout module, and a data readout for display of data on punched tape, as part of the interfacing equipment with a digital computer.

The Luch set of equipment is designed for semiautomatic multicomponent analysis of specimens of various substances by γ-activation and other photonuclear methods, when the specimens to be analyzed are irradiated by radiation from betatrons, microtrons, and linear accelerators. The recording equipment can be used to perform pulse-height analyses, group amplitude-time analyses and group time analyses, and to set up operating conditions with broad windows. The set also features stabilization and monitoring systems. Analysis is handled by a program that can be modified or substituted.

The following techniques of activation analysis of the ultimate composition (by elements) of the test material without taking unit samples are available: 1) continuous methods of analysis or of monitoring the flow of products on a production line or production stream (or with some of the material to be analyzed shunted off to a bypass line); 2) discrete methods of analysis or of monitoring of the low of products in boxes or on pallets, or in their naturally occurring sites (in the case of minerals) without taking samples.

Both of these directions are being developed to some extent in the Soviet Union.

Neutron activation analysis of slurries in a process stream has been investigated most thoroughly. That research has provided a basis for the design and fabrication of the first neutron activation analysis facilities for carrying out analysis under industrial conditions. Those facilities are designed for continuous automatic determinations of individual elements in a process stream and can be used to sense the composition of materials in an automated process control system.

Activation analysis of slurries in a process stream is carried out in the following pattern: continuous sampling of the slurry, irradiation of the slurry in an activation chamber, and continuous measurement of the induced activity in the chamber with a radiation detector. The neutron sources employed are long-lived isotope sources, in some instances neutron generators.

Because of the differences in the chemical composition and in the physicochemical properties of process slurries, as well as special features of technological processes in each specific case, the facilities are developed and fabricated to individual custom order as a rule. In particular, facilities meeting that description include the NAR-2 and NAR-3 systems designed for automatic continuous determinations of the concentration of a single element in a process slurry stream by neutron activation techniques.

As experience accumulates in this new and highly promising area of applications of the neutron activation analysis method on an industrial scale, modular general-purpose equipment suitable for composing sets and facilities for a variety of applications and purposes will become available.

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ACTIVATION ANALYSIS IN THE INSTITUTE OF NUCLEAR PHYSICS OF THE UZBEK SSR ACADEMY OF SCIENCES

U. G. Gulyamov

The activation analysis division at the Institute of Nuclear Physics of the Academy of Sciences of the Uzbek SSR [IYaF AN UzSSR] was organized in 1960. The division was faced with the problem of developing an activation analysis procedure to meet the needs of the national economy in the Central Asian area. The functions of the USSR's leading institute for reactor-based activation analysis were entrusted to the IYaF AN UzSSR in 1962. The I, II, and III All-Union coordination conferences on activation analysis were held in Tashkent.

At the present time, the division comprises a large institution with a staff of over 100. The staff has at its disposal a nuclear reactor whose rating was increased to 11 MW after being redesigned, two neutron generators, a cyclotron, isotope neutron sources (Sb–Be and Po–Be), sophisticated pulse-height analyzers, electronic equipment, several germanium–lithium detectors, etc. A computer whose function will be to simplify the procedure followed in processing experimental results is now being adjusted.

The entire arsenal of modern activation analysis is being used generously in order to determine the gross contents of the elements in different matrices. The procedures worked out at the Institute encompass practically all of the elements in the periodic table. Several procedures have been worked out for analyzing rocks, ores, and minerals.

Analysis of biological specimens is undergoing extensive development. Over 80 procedures for determining 35 elements in both instrumental and radiochemical variants are counted. Work is being done jointly with other institutes on the study of the role played by chemical elements in the problem of verticilliaceous wilt.

Procedures for analyzing boron and boron compounds, germanium, silicon, highly activated intermetallic compounds, some refractory and high-melting metals and alloys, have been developed for pure materials. Procedures for determining nitrogen, oxygen, and carbon in tungsten, molybdenum, and silicon were found by employing accelerated charged particles.

Methods for investigating the composition of natural waters and using stable isotopes (with subsequent activation) and radioactive isotopes for the study of the parameters of the flow of underground waters have been worked out. Results of that work have found applications in geochemistry, in hydrochemical prospecting for minerals, and in engineering hydrogeology, specifically in studies of water seepage at one of the major Central Asian water reservoirs.

Close attention is being given to the utilization of activation analysis under industrial production conditions. Facilities for determinations of fluorite in ore concentrations, or using conventional structural materials common in industry, have been developed. Activation analysis is used to study the composition of technological products and in order to solve various technical problems.

Possibilities of utilizing isotope neutron sources have been under investigation in recent years. A high-level Sb–Be source has been developed. Work is being carried out on the use of Po–Be sources in industry and in agriculture.

Satisfaction of the needs of the gold mining industry is being given high priority. Over 18,000 analyses have been carried out within the framework of investigations of the applicability of biogeochemical prospecting

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of gold ore deposits, and these analyses have provided a basis for discernment of two anomalies indicative of the presence of gold.

A suitable procedure has been worked out for analysis of gold ores, and a semiautomatic facility with an anticipated capacity of over 100,000 analyses a year has been designed. A facility using an isotope neutron source has been developed and is now being introduced into routine service, and a procedure for preliminary concentration of gold as ore for determinations. Autoradiographic techniques and techniques for studying tracks in dielectrics are being used to investigate the distribution and forms of occurrence of chemical elements. Accessible forms of chemical elements in soils, protein-bound forms of elements in biological material, the distribution of elements in peptides, in nucleic acids, and in the subcellular structures, etc., are being studied via preprocessing of specimens.

An especially intriguing and timely area of application of preprocessing of specimens is the determination of pesticides. While pesticides containing arsenic or mercury can be determined, in principle, and should be determined, by the increase in the gross contents of those elements, a fairly complicated and reliable procedure for isolating the pesticide form of such elements as bromine, chlorine, sulfur, or phosphorus is required in order to make determinations on pesticides containing the elements mentioned.

The division is working on theoretical topics in activation analysis, as well as topics related to improving the reliability of the analytical information, without which correct planning, taking of samples, and interpretation of the results, would be impossible.

The division is carrying out analyses in one form or another for more than 40 organizations in the Tashkent area and in other cities in the Soviet Union. Several collections of articles and monographs have been published, as well as many individual articles. The commissioning of an electronic computer, provision of new electronic equipment for physics research and particle detectors, the use of a high-capacity radiochemical facility, an increase in the power level of the nuclear reactor, and other measures are making it possible to further expand and deepen the work on activation analysis.

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CONFERENCES

SESSION OF THE SCIENTIFIC COUNCIL ON THE TOPIC "PLASMA PHYSICS" OF THE USSR ACADEMY OF SCIENCES

M. S. Rabinovich

A session of the scientific council on the topic "plasma physics" was held in Moscow in April, 1972. Trends in the development of plasma physics, and major achievements in that field over the past five years, were analyzed at the session.

Over 400 scientists from all the research centers of the nation were present. Detailed review reports were presented as well as the scientific council's 1971 report.

The course of the recent years in this field was summarized as a continuous enhancement of the role of plasma physics in science and in industry. It was considered typical that the process took place not so much through direct expansion of research, but rather through the penetration of plasma physics into other fields.

In recent years, plasma physics has found applications in quantum electronics, in space physics, in accelerator engineering, in recording of fast particles, and new trends have appeared in electronics (plasma electronics), chemistry (plasma chemistry), and in several other branches of new technology.

Research on the physics and engineering of hot plasma presently leads the field. This is due not so much to the importance of applications of hot plasma to controlled thermonuclear fusion as to the comparative clarity of the physical situation, and the higher level of development of theory, in this area. Consequently, one of the most significant achievements is the development of the theory of nonlinear processes and turbulence. Even though we of course still have a long way to go in working out nonlinear theory, the mathematical groundwork put together at the present time is capable of predicting the behavior of plasma in a number of situations. For example, success has been registered in describing the anomalous behavior of plasma through which strong current has been passed. Processes involving interactions of beams of charged particles, including ultrahigh-power relativistic beams, with plasma have been studied. Explanations have been forthcoming for a number of astrophysical phenomena: the fundamentals of the control of instabilities have been laid down. The theory is now capable of describing transport processes and oscillatory processes not only in such simple situations as one-dimensional models, but also in intricate toroidal systems such as tokamak machines and stellarators; the theory is being applied effectively to explanation of phenomena occurring in the atmosphere and in the ionosphere. B. B. Kadomtsev reported in great detail on the theory of plasma physics.

In recent years, experimental research using thermonuclear machines such as tokamak machines, in work led by L. A. Artsimovich, has attracted special attention. A stable plasma with record parameters (densities to $3 \cdot 10^{13}$ to $5 \cdot 10^{13}$ cm^{-3}, energy lifetime of 10 to 15 msec, electron temperature to $1.5 \cdot 10^3$ eV, ion temperature to 700 eV) has actually been produced in tokamak machines. There is no question that work in that direction will hold first place for some time to come. Ion temperatures to 3 keV with Lawson parameters $n\tau = 3 \cdot 10^{12}$ to $5 \cdot 10^{12}$ are apparently expected in tokamak machines in the immediate future. The successful completion of this research program will probably pave the way for the next decisive step on the road to a physical thermonuclear reaction.

Work on stellarator systems is being continued: they are being studied at the Physics and Engineering Institute of the Academy of Sciences of the Ukrainian SSR and the P. N. Lebedev Physics Institute of the

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Academy of Sciences of the USSR (FIAN). There exists one point of view to the effect that the relative lack of success shown by stellarator systems is due to the small poloidal magnetic field. This problem is taken into account in newly designed stellarator systems. For example, the plasma confinement time obtained with the Uragan-1M machine is commensurate with the confinement time in tokamak machines of equivalent dimensions. Results of experiments performed at FIAN and at Culham (Britain) show that the lifetime of particles in stellarators is close to the classic lifetime.

Confinement of plasma of density 10^{12} to 10^{13} cm^{-3} with an ion temperature of the order of 0.5 keV has been studied in open-ended traps. Methods for stabilizing a plasma by feedback have been developed. But the future of open-ended systems appears to be wrapped up with the effectiveness of the energy recovery system. In one way or another, traps are inevitable features of the thermonuclear research program. A report by I. N. Golovin dwelt in detail on open traps.

The combination of methods developing for heating plasma with concrete existing systems is fundamental in nature. In other words, the period of simulation experiments in plasma heating is coming to an end.

The most important methods for heating plasma are:

1. Injection of fast neutral particles. Injection of fast neutrals appears to offer great promise.
2. Turbulent heating. This method has undergone extensive development in the past decade, but is obviously not being exploited to its full potentialities for heating plasma in thermonuclear machines.
3. Microwave heating techniques. These techniques appear to be basic and are being developed with particular success at the Physics and Engineering Institute of the Academy of Sciences of the Ukrainian SSR (FTI AN UkrSSR) and at the I. V. Kurchatov Institute of Atomic Energy (IAÉ). Heating efficiency is 30 to 50% under optimum conditions.

We should also mention the linear method of transforming tranverse waves into strongly attenuating longitudinal waves, which was developed at the A. F. Ioffe Physics and Engineering Institute of the Academy of Sciences of the USSR, and the method of nonlinear anomalous absorption of microwaves developed at FIAN.

V. E. Golant reported on microwave methods of heating plasma.

Plasma accelerators are meeting with great acceptance in a variety of engineering applications, including controlled thermonuclear fusion and astrophysical research. The discussion here centers around accelerators in the 10 to 100 keV energy range, or somewhat higher, at currents ranging from several amperes to several kiloamperes. The machines will have to be redesigned and have fninishing touches applied to them, and their performance properties will have to be improved, with searches made for new accelerator designs and layouts, in order to expedite even wider acceptance of the machines. That will require a more detailed physical investigation of flux parameters.

Despite the colossal amount of work that has been done on coordination of research by the plasma accelerators section, the outlook for utilization of high-energy plasma streams in technology is not being investigated currently in the way it should be, unfortunately, and plasma accelerators are not being developed for a broad range of technological tasks. This is explainable to a certain extent in terms of the inadequate liaisons between specialists in different branches of science and industry. A report by A. I. Morozov went into some detail on plasma accelerators and related work.

Here we should mention the introduction of findings of plasma physics into accelerator engineering. In essence, collective plasma phenomena are encountered in all high-current systems. Those phenomena act to seriously limit current in storage systems, and in colliding-beam accelerators. One achievement is the development of high-energy collective accelerators by V. I. Veksler. The council on plasma physics will take part in organizing a conference on collective methods of particle acceleration to be held in Dubna September 27-30, 1972.

Investigations of fast processes and of the theta-pinch, and plasma focus, have been carried out in the USSR at the Sukhumi Physics and Engineering Institute and at the I. V. Kurchatov Institute of Atomic Energy, but not on a very broad scale to date. However, this direction of work should be intensified substantially. Here a lot will depend onthe development of the theory of high-density plasma ($\beta \approx 1$) and concomitant engineering advances. E. P. Velikhov discussed fast processes in his report.

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D. D. Ryutov reported on some new proposals for confinement and generation of high-density plasma; Ryutov reported in his own name and in the name of G. I. Budker.

The plasma electronics research program initiated by FTI AN UkrSSR has undergone considerable development. The major advances in that direction are intimately related to the development of high-current pulsed relativistic electron accelerators. Consequently, plasma electronics becomes relativistic. Institutes working on this problem also include FIAN, the I. V. Kurchatov IAÉ, and the Institute of Nuclear Physics of the Siberian Division of the USSR Academy of Sciences [IYaF SO AN SSSR].

The most important applications of plasma electronics are:

1) development of methods for heating plasma, and possibly the development of a pulsed thermonuclear reactor in the remote future;

2) development of microwave oscillators;

3) development of new collective methods of particle acceleration.

A detailed report on plasma electronics was delivered by Ya. B. Fainberg. The principal achievements on record in this direction are:

1) the development of high-current accelerators;

2) the development of a theory of collective interaction of relativistic beams and plasma, a theory of limiting currents, gas focusing, a theory of compensation of the self-magnetic field by a beam of electrons in a plasma;

3) development of theory and experimental work on control of beam instabilities and transformation of waves.

Experiments on coherent interaction between modulated electron beams and plasma are of special interest.

R. Z. Sagdeev reported on plasma physics and cosmic phenomena.

As an example illustrating the uses of plasma physics in the study of cosmic phenomena, we might point out that a broad range of interesting phenomena, including the power-law dependence of the energy spectrum of fast particles, have yielded to explanation on the basis of the nonlinear theory of plasma turbulence. Of course, that spectrum is also observed in cosmic rays, and in relativistic electrons as well. Radio bursts from the sun have been calculated (FIAN), and other related advances have been reported.

Magnetohydrodynamical models designed to explain the nature of the chromosphere, of prominences, of radio sources above sunspots, etc., have been constructed (Shternberg State Astronomical Institute).

Ya. B. Zel'dovich's report on a model of the hot universe met with keen interest.

P. L. Kapitsa gave an account of some completely unanticipated properties exhibited by a free plasma pinch in a radio-frequency field. The unusually high parameters obtained for the plasma, and the subtle experimental research techniques put to work, give good reason for the view that we are dealing here with new properties, still obscure in many respects, of a high-density high-temperature plasma.

The next session of the scientific council on the problem of plasma physics will be held in March, 1973.

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FIRST ALL-UNION RADIOGEOCHEMICAL CONFERENCE

N. P. Ermolaev

The first All-Union conference on the radioactivity of rocks and of the hydrosphere was held in Novosibirsk, May 15-19, 1972. The conference drew up a balance sheet on the knowledge accumulated in the field over decades, and sketched out the cardinal directions of radiogeochemical research in the future. Many prominent scientists in the country took part in organizing and expediting the conference.

A total of 47 reports devoted to the behavior of radioactive elements in exogenetic, magmatic, metamorphic, and hydrothermal processes, and also to procedures for radiogeochemical mapping of the territory of the USSR, and to determinations of uranium, radium, and thorium in geological objects, were heard; the reports also dealt with how to utilize data on concentrations of radioelements in the allied sciences of geochemistry and geology.

A historical survey of research on the geochemistry of the radioelements (L. V. Komlev) formulated the major problems in radiogeology which are being developed as work on the creative legacy bequeathed by Joly, Clark, and Vernadskii. Special attention was given to the problems of geochronology and the earth's heat budget. The use of methods of lead isotopy (S. F. Karpenko) makes it possible not only to single out districts that are promising in ore content, but also to locate ore-productive strata adjacent to local concentrations of radioelements. The study of geochemical lead anomalies in the study of ore sources and the genesis of ore occurrences opens up new perspectives for investigation of lead–zinc deposits (A. A. Tychinskii, L. D. Shipilov, etc.), and also for investigations of the dynamics of the formation of crusts of weathering (V. I. Balabanov). The use of data on the radiogeochemistry of rocks, particularly data referable to deeply metamorphized sediments and mantle products, is helpful in analyzing thermal fluxes within the earth's crust (E. A. Lyubimova). The study of the evolution of a seat of local heating shows that redistribution of naturally occurring radioelements is a real factor in the generation of a thermal front. The dynamical model of the zone melting mechanism is entirely applicable to the explanation of natural processes in this context.

Among the other general topics in radiogeology dealt with, analysis of uranium and thorium contents in the mineral matter comprising the earth's crust at different "levels of organization" was given special attention (A. A. Smyslov). The study of radiogeochemical features at the lower (mineral) level revealed a marked differentiation of the concentrations of uranium and thorium (differences as great as five orders of magnitude in the average concentrations of the elements). As the level of organization increases (rocks → geological formations → distinct layers of the earth's crust), the nonuniformity in the distribution of uranium and thorium becomes less conspicuous. The average contents of the two radioelements does not differ by more than one order of magnitude at the higher levels. A direct correlation is established between the radioelements and certain petrogenic elements.

Differences in clarks, in the analysis of geochemical migration, interfered with comparisons of the absolute contents of elements in different geochemical systems. It would be better advised in such cases to compare the clarks of the concentrations (A. I. Perel'man). Comparison of the clarks of the concentrations, in the context of hypergenetic geochemistry of uranium, supports the inference that uranium is an element with conspicuous "hydrophilic" properties (the high-contrast and energetic aqueous migration is quite typical) and modest "biophilic" properties (uranium is not concentrated by living matter).

A review report on the geochemistry of uranium in the sedimentation process (M. N. Al'tgauzen) surveyed various concepts on the conditions governing migration and sedimentation of uranium in conglomerates, in mottled sand-clayey sediments, in coals, in bituminous rocks, in phosphate rocks, etc. Directly

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opposed concepts on uranium sources, and on the time and methods of accumulation of uranium sources, were pointed out. The discrepancies are due both to problems in the study of the natural objects and to inadequate development of experimental physicochemical research. In addition, little attention has been given to theoretical analysis of the conditions governing the joint migration and accumulation of elements accompanying uranium in these processes.

Carboniferous sedimentary formations as possible concentrators of uranium and other rare elements were the subject of an extended discussion. Enhanced concentrations, including ore concentrations, of uranium, germanium, molybdenum, beryllium, in deposits of coal-bearing formations are disparate in nature: sedimentary-diagenetic, epigenetic, polygenic (V. I. Danchev, N. P. Strelyanov, G. Ya. Ostrovskaya, et al.). The criteria for syngenetic behavior on the part of uranium mineralization in coals can be the spatial affinity with facies zones of ancient peat bogs, accumulations of vegetable remains in alluvial flood-plain deposits, and the like. The stratified and concretionary textures of the ores, the position of ore pebbles within intraformational nonconformities, etc., provide evidence of the formation of ore concentrations at the stage of diagenesis. Finally, criteria for the epigenetic genesis of uranium concentrations are provided by the confinement of uranium concentrations to zones of tectonic dislocations, the ore replacement textures, the ore-controlling role played by epigenetic zonation. A detailed phase analysis of organic matter and uranium mineralization (V. A. Uspenskii et al.) shows that heavy bitumens (asphaltenes, kerogens) in products of epigenesis cement the earlier secretions of uraniferous minerals per se, i.e., they are formations of different ages.

A pronounced dependence of the contents of uranium and thorium, and of the thorium/uranium ratio, on the lithological composition of the rock species and on their facies adherence and affinities, was brought to light (G. M. Shor, V. P. Vorob'ev) in an analysis of the distribution of radioactive elements in sediments of young mantles (Mesocenozoic age) on an ancient folded foundation. A lowering of the values of the radiogeochemical characteristics was established in the series terrigenous → terrigenous-carbonate → carbonate rocks, and in the direction of the succession of continental sedimentation conditions by marine sedimentation conditions. The uranium concentrations are determined to a considerable extent by the oxidation—reduction properties of the rock species.

An investigation of modern marine sedimentation on columns of red clays, foraminiferous, diatomaceous, radiolarian, and terrigenous—authigenous sediments, iron–manganese concentrations and carbonate concretions (Yu. V. Kuznetsov, V. K. Legin, et al.) made it possible to discern primary and secondary physicochemical processes at work, predetermining the relationship between the concentrations of uranium, ionium, radium, and thorium in a vertical core section. Conversion of the concentration of radioelements in sediments of different composition to the level of comparison makes it possible to use the ionium/radium ratio to successful advantage in investigating age and dynamics of sedimentation.

In a summary report on the geochemistry of the radioelements in the magmatic process (A. I. Tugarinov), some basic concepts regarding the role of magmas in mineralization were formulated. It was emphasized that the constancy of the thorium/uranium ratio in various phases of intrusive rocks proves the strength of the bond between the radioelements and the melt, and argues against the view that the radioelements are washed out of the melt with the fluids. However, the process of felsitization and perlitization of volcanic glass in liparitic formations is accompanied by liberation of a portion of the uranium present, and this is recorded by the change in the thorium/uranium ratio. The "migrational activity" of the radioelements in the magmatic process increases in the course of geological time, i.e., the role played by the mobile form of uranium and thorium is enhanced in younger intrusives. This regularity agrees, in the case of grainitoids, with the data on lead–uranium and lead–thorium isotopy. These ratios are characterized by their marked constant level in microclines whose age dates back three billion years. The spread in the ratios of the value sets in at the age of two billion years and increases from then on. Intrusions enriched or depleted in Pb^{206} and Pb^{207} make their appearance. That trend corresponds to concepts on the minimal differentiation of the earth's crust in which granitoids are brought into being, a full three billion years ago, when there were still no local concentrations of uranium, thorium, lead in specific sediments. The differentiation process became initiated in the early Protozoic (2.6 to 2 billion years ago), when the first carbonate-bearing strata, jaspilites, etc., made their appearance. Granitoids shaping up in such variegated strata inherited the radioactivity of the strata, as reflected in the deviations of the leads from the average evolutionary curve.

The effect of subcrustal hearths begins to be felt as intrusives of basic composition appear. But the relative import of those two sources of radioactivity in the melts (palingenetic and mantle sources) cannot

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be traced further back in a consistent manner. A variant solution to the problem has been proposed on the basis of a comparative analysis of the behavior of uranium and thorium in volcanic and plutonic magmatism processes (V. P. Kovalev). Intrusive and effusive derivatives belonging to two generations of magmas differ conspicuously in their radiogeochemical characteristics and have a mantle origin (in the former case) and a crustal origin (in the latter case).

Additonal characteristics of alkaline magmas of the sodium and potassium series can be obtained on the basis of data referable to concentrations and ratios of uranium and thorium, and alkaline–olivine–basalt melts and tholeiite–basalt melts can be successfully separated on the same basis (V. I. Gerasimovskii). The content of radioelements in such magmas is determined by the conditions under which the melts are generated within the confines of the upper mantle, but not by their interaction with the materials comprising the earth's crust.

A survey paper on the geochemistry of the radioelements in the metamorphic process (Ya. N. Belevtsev) emphasized the decisive role played by the redistribution of matter in the formation of ore concentrates. The differentiation of uranium and thorium, which predetermines the appearance both of metamorphogenetic deposits or of melts of enhanced radioactivity (in the case of ultrametamorphism) and the yield of radioelements in hydrothermal-metasomatic processes, takes place in the course of progressive metamorphism and regressive metamorphism of rock species.

The mechanisms at work in the redistribution of the radioelements in response to rises in the temperatures and pressures, and the involvement of the radioelements in geochemical migration, are analyzed on the basis of currently held concepts in the theory of chemical sedimentation and recrystallization of matter (N. P. Ermolaev). For example, blastesis occurs when temporary oversaturations relative to macrocomponents occur in film solutions, and when trace impurities of uranium and thorium get into a solution that is not saturated with respect to uranium and thorium. The process by which the carrier mineral gets rid of trace impurities of the radioelements on its own is aided by the processes of polymorphic transformations undergone by the carrier mineral, by the variation of the impurity distribution function in the system solution–sediment with increasing temperature, and by processes of desorption in the water–carbonate phase.

A survey report on the geochemistry of the radioelements in hydrothermal-metasomatic processes (G. B. Naumov) points out the exceptionally high mobility of uranium, and of thorium to a lesser extent, over a wide range of parameters of the medium. However, the way research is preponderantly localized within the confines of ore-bearing areas restricts opportunities for working out complete and valid concepts on the balance of the radioelements in postmagmatic processes. Reconstruction of the temperatures, pressures, and concentrations in solutions in which migration and sedimentation of uranium took place supports the view that the deposition of pitchblendes under hydrothermal conditions took place principally within the temperature range from 250 to 50°C, whereas the temperature range from 380 to 200°C is the most favorable one for the formation of uraninites from Precambrian metasomatites. The pressure generated in hydrothermal systems could be not only less, but also much greater, than the hydrostatic pressure and lithostatic pressure, as evidence of the possible formation of ore-bearing solutions in deeper-lying portions of the earth's crust below the actual ore emplacement strata. The composition of high-temperature solutions has not been ascertained precisely. In the case of medium-temperature and high-temperature conditions, however, the concentrations of the components of uraniferous solutions have been determined reliably enough. That makes it possible to analyze the equilibrium conditions of the mineral phases, and to estimate the scale of the process under concrete sets of geological conditions. A rise in the temperature shifts the peak solubility of pitchblende into the range of higher pH values of the solutions, which is responsible for the type of high-temperature associations of pitchblendes actually observed. When temperatures are high but alkalinity is moderate, the typical carbonate form of uranium transport encountered at low temperatures may have less significance, yielding before other compounds possible fluorides and phosphates.

Hydrothermal metamorphism of rocks in uranium mineralization and thorium mineralization over significant areas was analyzed for the first time, making it possible to discuss those processes in relation to the geological features of an entire region (E. V. Plyushchev). Practically important zones of quartz–hydromica associations in regions where acid components were found to be washed out are being mapped, as well as zones featuring the development of riebeckite–albite and chlorite–albite associations.

Reports devoted to procedures and results in radiogeochemical mapping and demarcation of concrete geological provinces held an important place in the proceedings of the conference (V. K. Titov, A. S. Mitropol'skii, D. K. Osipov, R. S. Zhuravlev, Yu. V. Il'inskii, A. D. Nozhkin, F. I. Zhukov, et al.). The

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special features of the radiogeochemistry of rock species depend on the geological structure of the distinct regions and on their position in the history of geological development. That dependence is reflected in the concentrations of uranium and thorium, which vary widely in sedimentary and magmatic species of rock of different composition and origin, and also in the distribution pattern of the radioelements in metamorphic and ultrametamorphic rock species formed among stratified deposits.

Special attention was given to methods for analyzing radioelements present in geological objects. The requirements imposed in geochemical studies on the metrological parameters of the analytical techniques employed, and the potentialities of those techniques in geochemical investigations carried out on the radioactive elements, were discussed (B. Ya. Yufa), and the outlook for the development of sophisticated techniques for making determinations of trace quantities of uranium and thorium in rocks and minerals also came under discussion (A. A. Nemodruk).

Methods of field γ-ray spectrometry and laboratory γ-ray spectrometry (L. V. Matveev et al., F. P. Krendelev et al., O. P. Sobornov et al.), and analysis of radioelements in mineral phases by fission-fragment diffraction (I. G. Berzina et al.) have now gained wide acceptance in the solution of geochemical problems. Problems of reliability, rapidity, and sensitivity of analysis of natural radioactivity in the lithosphere and in the hydrosphere, were reflected in the resolutions adopted by the conference.

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SPECTROMETRIC METHODS OF RADIOACTIVE CONTAMINATION ANALYSIS OF THE NATURAL ENVIRONMENT

A. N. Silant'ev

As a result of nuclear weapons tests using nuclear explosions for useful purposes, and of work in atomic plants, radioactive products enter the natural environment. Falling into the atmosphere or waters, they spread to significant distances from their place of origin. Because of this, the concentration of radioactive products is greatly decreased, but at the same time the area of contamination is significantly increased. Thus, the radioactive products penetrating to the upper troposphere are, in the course of a month, able to mix fairly uniformly with the tropospheric atmosphere of that hemisphere in which the test was conducted.

In connection with the possibility of transport of the radioactive products to great distances it is necessary to systematically monitor their content in the natural environment and to develop the laws of formation of these products. This can be performed with the aid of radioisotopic analysis of selected samples. Mass analysis of radioisotopic samples of the natural environment is more easily conducted with the aid of radiospectrometric methods of investigation, the characteristics of which include the fact that such analysis can be performed on specimens with low specific activities. This in turn leads to specific features not only in the conduct of the spectrometric analysis but also in the processing of the results.

At the present time the monitoring of radioactive contamination of the natural environment occupies the attention of many specialists. In connection with the necessity for interchange of test results meetings were held on March 27-31 at the Institute of Experimental Meteorology in Obinsk on methods of analysis of radioactive contamination of the natural environment.

Fifty-three papers were heard. The first group of papers was devoted to the question of γ-spectrometric analysis of the natural environment with the aid of scintillator γ-spectrometers. The papers dealt with the most varied aspects of γ-spectrometric analysis. In them were considered the use of γ-spectrometers with solid angles approaching 4π, low-background γ-spectrometers with anticoincidence shielding, selection of optimum conditions of measurement, and operation at underground locations in order to reduce the background level.

Several papers were presented on direct methods of spectrometric analysis of soil surface, by use of results of which corrections can be made to the measurement program.

Also considered were methods of processing the obtained data: statistical accuracy of results, conditions for the development of photopeaks in the experimental spectra, methods for estimating the values of self-absorption in γ-spectrometric analysis of soil samples. Particularly detailed was the treatment of methods of processing the obtained data with the help of computers, not only by the method of the direct introduction into the machine of punched tape with coded spectra, but also by the method where the obtained results first undergo preliminary processing. Processing of the obtained spectrum was considered by the method of intervals as well as by the method of least squares. Also considered in these papers were the problems of increasing the accuracy of the analytical methods, standardization of γ-spectrometric methods, techniques of calibrating scintillator spectrometers, and automation and combination of measuring apparatus into the complex.

In the second group of papers consideration was given to the use of semiconducting detectors. The possibility was demonstrated of their use for the measurement of γ-radiation of samples with specific

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activities corresponding to that of samples of the natural environment, for the direct γ-spectrometric analysis of surface soil.

Methods were considered for processing in computers of the results obtained with the aid of semiconductor detectors used for γ-spectrometric analysis of samples of the natural environment.

The third group of papers considered the β-spectrometric analysis of the natural environment. Methods were considered for the β-spectrometric analysis of radioactive mixtures. The influence of thickness of test samples and measurement geometries on the calculation results was discussed. The influence of back-scattering of β-radiations on obtained results was analyzed. Methods for increasing the sensitivities of β-spectrometric methods were considered. In several papers methods were considered for direct β-spectrometric analysis of soil cover.

In a series of reports there were discussions of the use of coincidence methods, which are used for the determination of the absolute activities of specimens, analysis of complex mixtures, and the separation out of γ-radiation of separate isotopes in an intense γ-background. Also heard were papers on the stabilization of the amplifier circuit of a spectrometer and the selection of diameters for photomulitpliers and scintillators.

In conclusion, it should be noted that the papers presented at the conference evoked strong interest, and the very fact of the holding of such a conference is timely and useful.

It is proposed that the material of the conference be published in 1973.

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EUROPE'S FIRST NUCLEAR PHYSICS CONFERENCE

G. M. Ter-Akop'yan

The first All-Europe conference on nuclear physics was held at Aix-en-Provence (France) June 26 through July 1, 1972. This was the first conference on that topic organized by the European Physics Society.

The conference agenda was restricted to three urgent topics in nuclear physics: the physics of fission, the physics of heavy ions, and nuclear physics at energies above 100 MeV. All of the topics were discussed at the morning plenary sessions, at which 15 review papers were presented. Sessions of three panels on the three directions of research discussed took place in parallel during the evenings. Brief reports lasting 10-15 min were heard at the panel sessions: 30-odd reports on the first topic, 80 reports on the second topic, and 55 reports on the third.

The conference attracted the attention of a large number of specialists not only from European countries, but in fact from all scientific research centers throughout the world that are engaged in nuclear physics research. About 570 scientists took part in the conference.

Shell effects received a good deal of attention in the discussion. A report by R. Balian (France) was devoted to shell effects. The topic was also touched upon in a report by K. Dietrich (West Germany). No fundamentally new findings in theory, at least as compared to the papers authored by V. M. Strutinskii et al. (1967-1970), came to light. Some new and interesting data were obtained in an experiment in which the properties of spontaneously fissioning isomers were investigated. Results arrived at by a team of West German researchers (H. Specht et al.) in observations of conversion electrons resulting from the decay of levels of the rotational band in the second potential well (transitions $8^+ - 6^+$, $6^+ - 4^+$, and $4^+ - 2^+$) in coincidence with fragments of the spontaneously fissioning isomer Pu^{240} are included among such data. The value of the rotational constant $\hbar^2/2J = 3.33$ keV obtained from the experimental data is far below the value obtained for the ground state (7.16 keV).

Data on correlations between the number of fission neutrons and the mass and charge of fission fragments, and with the γ-photon yield and the parameters of fission resonances, were reported in some of the papers, principally those submitted by French authors. Those results can prove useful, when filled out in greater detail subsequently, for obtaining information on the potential energy and the viscosity of the fissioning nucleus.

All of the topics that have now become traditional in the area were of course included under the heading of the physics of heavy ions: transfer reactions, nuclear spectroscopy in direct reactions, the state of nuclei with large angular momentum, etc. These topics were also dealt with in the overwhelming majority of the reports presented at panel sessions, as well as in review papers presented by H. Morinagi (West Germany), G. Morrison and M. Beranger (USA). But substantially new results in heavy-ion physics would have to be anticipated along another path. Appreciable progress has been made in recent years in the acceleration of very heavy ions (such as xenon and uranium). A beam of 900 MeV xenon ions with a beam intensity of 10^{10} to 10^{11} particles has been generated at Dubna. The conference participants manifested keen interest in a report by G. N. Flerov (USSR) on work done with this beam with the object of synthesizing ultraheavy elements. The study of nuclear reactions on a xenon beam at Dubna is yielding valuable information on the role played by direct processes in fusion reactions and the role played by friction in the process of fusion of two heavy nuclei (such as xenon and tin). The findings from the Dubna experiments indicate that fission fragments of a compound system obtained by irradiating uranium with xenon will form as nuclides with a cross section greater than 100 mbarn. Searches are underway to find ultraheavy elements among those fission fragments. Some encouraging results have been obtained.

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Pessimistic conclusions on the formation of compound nuclei in reactions involving very heavy ions were drawn in reports by a French team from Orsay (M. Lefor). The Orsay team obtained a very low limit (below 10 mbarn) for the probability that a "classical" fissioning compound nucleus would form in the reaction Th^{232} + Kr. From this, the authors inferred a lack of prospects for the fission reaction in the synthesis of ultraheavy elements. The same conclusion was reached in a review paper presented by W. Swiatecki (USA) and in a report by F. Plazil (USA) on the basis of a discussion of the behavior of a compound nucleus with a large angular momentum. Apparently, however, the formation of a "classical" compound nucleus is not obligatory if what we seek to establish is statistical equilibrium with respect to the charge and mass of fission fragments. Data in Dubna experiments have supported precisely that view.

Beams of heavy ions (xenon, uranium) make it possible to broaden the range of objects studied in nuclear physics substantially. In addition to systematic studies of the properties of compound nuclei such that $Z > 100$, and in addition to work on the synthesis of ultraheavy elements, there is great interest in investigations of the atomic properties of very heavy nuclei near which exceptionally strong electric fields are observed. Two panel reports dealt with analysis of this last topic. Some of the results on the study of x-radiation emitted by a compound atom (more precisely a quasimolecule) I + Au at iodine ion energies from 10 to 60 MeV were reported on by P. Armbruster (West Germany).

The study of nuclear reactions involving heavy ions such as xenon calls for a new approach in the theoretical description of the fusion process. The basis for the elaboration of any such new theory would seem to be concepts that have been yielding good results in recent years in the study of the physics of fission. A review report by W. Swiatecki (USA) was devoted to a discussion of the principal traits of the future theory shaping up.

The conference offered confirmation of the fact that high-energy nuclear physics now constitutes a fully formed area of research on its own. The use of high-energy particles in the physics of the nucleus has already produced some important results bearing both on the characteristics of specific nuclides and on the general properties of nuclear matter. There was great interest shown in reports on new research findings relating to elastic, inelastic, and quasielastic scattering of hadrons on nuclei. The Thyrion group working at Saclay on the Saturn synchrotron submitted spectra and differential scattering cross sections of 1 GeV protons scattered on C^{12}, Ni^{58}, Pb^{208} nuclei, and measured with a custom-engineering magnetic spectrometer. The high resolution (±135 keV, a record at this writing) attained in their work made it possible to reliably separate the transitions into distinct excited states of the nucleus. That possibility opened up a whole broad new field of activity in the area of relativistic nuclear spectroscopy for the group.

It was shown that the trend toward spectroscopic precision in measurements in high-energy nuclear physics is one of the principal trends in the present-day development of nuclear physics. Another salient trend is related to efforts to achieve as complete a kinematic analysis as possible of the reactions accompanied by decay of the nucleus or by the production of new particles. The coincidence method is coming into steadily greater use, and applications of coincidence techniques under various sets of experimental geometry conditions were widely discussed at the conference. In particular, keen interest was shown in a report by G. A. Leksin (ITÉF [Inst. Theoret. Expt. Phys.], USSR) on the use of the method of quasielastic kinematics proposed by V. V. Balashov by the Leksin group in studies of pion–nucleon interactions.

Research in high-energy nuclear physics, situated on the borderline between the physics of the nucleus and the physics of elementary particles, brings those two fields closer together in practice. Science has now gone far enough to broach the question of the role of excited (isobaric) states of the nucleon in the formation of the structure of the nucleus, and in the progress of various nuclear reactions. Two review papers dealt with that problem: M. Danos (USA) and M. Reaux (France). The topic spurred a particularly lively discussion in connection with the inverse proton–deuteron scattering reaction.

The proceedings of the conference will be published in two volumes. The second volume, with abstracts of the panel reports, was distributed to the conference participants. The first volume, which contains the review reports and the ensuing discussion, will appear in September or October.

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MEETING OF THE INTERNATIONAL WORKING GROUP ON NUCLEAR DATA

G. Rudakov

A meeting of the First International Working Group took place in Vienna on March 17, 1972 on the compilation, evaluation, and dissemination of nuclear data, the structure of the nucleus, and nuclear reactions (for brevity we will henceforth designate these as "nonneutronic nuclear data"). The meeting was called within the framework of the MAGATE. In attendance were more than twenty representatives from fourteen countries.

A question has been raised by certain organizations and individuals in the past year on the effectiveness of the utilization of nonneutronic nuclear data. These data include essentially all the information on the structure of the nucleus, nuclear radiation, and nuclear reactions, and are widely used for scientific and applied purposes. However, it is necessary for such purposes that the literature be in the form of tables of isotopes, decay schemes, cross section atlases etc. These are published infrequently and with no regularity. Especially inadequate is the matter of obtaining analyzed recommended data.

The purpose of the meeting was, firstly, the consideration of the current status in the area of collection, compilation, and evaluation of nonneutron nuclear data, and secondly, the determination of the principal areas of their utilization, principally for applied purposes, and thirdly, the development of recommendations serving to improve the efficacy of the work of the compilers and analysts of the nonneutron nuclear data.

Brief reports heard on the work of compilation and evaluation of nuclear data indicated that such work is in progress in many countries. The principal difficulty in this regard is the enormous volume of material that it is necessary to process and the relatively small number of persons engaged in this task.

Very useful work is being performed at Oak Ridge (USA), where a full bibliography is being compiled on work at low and medium energies, with brief annotations for each work. It is obvious that such a bibliography will substantially lighten the labor of compilers and analysts.

The principal areas of utilization of the nonneutron nuclear data were considered. It was noted that the data are widely used in reactor construction, analysis of shielding, the investigation of thermonuclear reactions, in activation analysis, and in other nuclear physics methods of determining element and isotopic composition of materials, in preparation of artificial radioactive isotopes and their use in the most varied areas of science and technology. Also noted was the necessity of establishing some form of communication between the users of nonneutron nuclear data on the one hand and their complements, the analysts and producers on the other. Such communication can even now answer many user questions and permit the establishment of lists of the most important uses of nonneutron nuclear data, which will be a guide for the activities of compilers and analysts.

The recommendation of the meeting on the improvement of the effectiveness of the work of compilation and evaluation of nonneutron nuclear data concludes essentially with the following: it is recommended that there be much tighter international cooperation in this area. This cooperation could be expressed in a division of labor between the various groups of compilers and analysts in the development of common standards for recording and storage of information (especially as regards to methods of machine recording and storage). An appeal was made to editors and publishers of scientific journals to pay more attention to the form of the material by the authors of scientific articles. The articles must give the worked-out

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information about the material in their presentation, from which it would be easy to evaluate the reliability of the obtained data.

The second conference of the International Working Group on nonneutron nuclear data is planned for March, 1973.

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RADIATION IN THE WORLD AROUND US

A. M. Kuzin

The UNO science committee on radiation effects completed its sixth report to the UNO General Assembly on March 24, 1972. The report provided an exhaustive rundown on the effects produced by all radiation sources on the population of our planet.

The committee discussed and reviewed the average exposure to radiation of critical tissues of the human body (gonads, bone marrow and cells lining the osteolar canals) due to the natural radioactivity of our environment, on the basis of the latest available data. It is generally known that this natural radiation is made up of secondary cosmic rays (neutrons, mesons, electrons) emitted by C^{14} and by tritium formed in the upper-lying layers of the atmosphere, radiation emitted by the isotope K^{40} and deposited in the tissues of the human organism, and emissions by uranium, radium, and thorium scattered in the earth's crust and producing the external γ-irradiation, as well as partially gaining entry to the human organism via ingested foodstuffs, and finally the gaseous Rn^{222} and Rn^{220} and their decay products in the earth's ground atmosphere.

Exhalations of Rn^{222}, Rn^{220}, and their short-lived daughters cause additional exposure to the basal cells in the tracheobronchial tree, in the dose range from 0.055 to 0.2 rad/year, attaining a level of 0.5 rad in areas enriched with uranium or radium.

The population is exposed to dosages of 1 to 8 rad/year in some populated regions (the state of Kerala in India; Guarapari, Araxa, and Tapira in Brazil) situated on monazite sands with a heightened content of uranium and thorium.

The exposure increases depending on the altitude (contribution by cosmic radiation). Supersonic flights during which passengers and crew were at altitudes of 20 km were discussed as a special topic. If we proceed from the assumption that the crew will be spending 600 hours per year up in the air (as much as is currently often the case in jet aircraft flight), they will be exposed to an additional 0.4 rad/year. The passengers will not be exposed to more intense radiation than they are now in jet planes, since the increase in the rate of exposure will be compensated by the speed of flight, i.e., by the shortening of the exposure time.

The degree of exposure suffered by the population as a consequence of atmospheric and ground-level nuclear explosions was estimated. It was pointed out that contamination of the atmosphere by Sr^{90} and Cs^{137} diminished sharply starting with 1963 and continuing through 1967. But the decline came to a halt in 1967, and the 1967 level has been continued since (see Fig. 1) as a consequence of nuclear explosions set off in continental Asia, in Africa, and in the Pacific Ocean.

Whereas it was Sr^{90} that made the major contribution to exposure to the human global population during 1961-1963, at the present time the role of Sr^{90} in irradiation of the bone marrow and bone cells of humans has decreased appreciably because of absorption of Sr^{90} in the soil and the low coefficients of uptake from the soil to plants. The relative contribution made by Cs^{137} as a source of internal and external radiation exposure to humans resulting from nuclear weapons tests therefore increased.

The weighted-average absorbed dose calculated for the entire exposed population (dose commitments) due to the 1955-1971 nuclear explosions runs to ~0.2 rad by the year 2000, according to the committee's calculations. It must be stressed that the figure does not take into account continuing nuclear weapons tests, and may have to be scaled up if those tests are not discontinued altogether.

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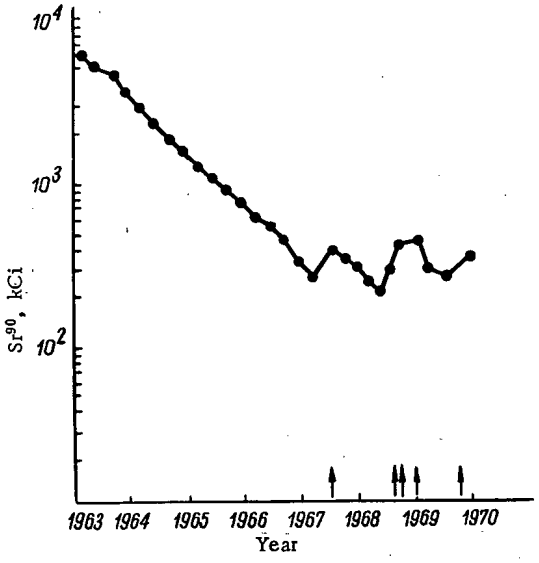

Fig. 1. Total Sr^{90} activity in the atmosphere (arrows indicate time of experimental atmospheric explosions).

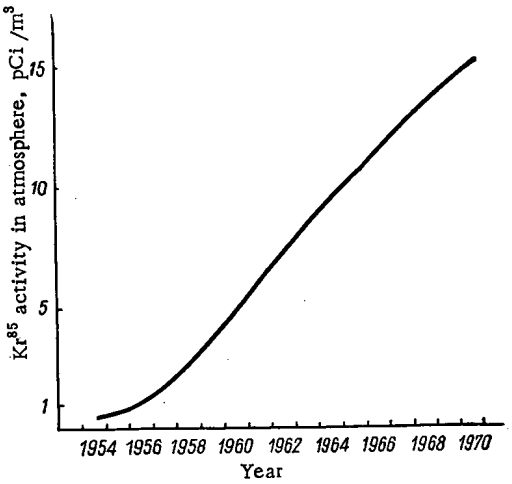

Fig. 2. Kr^{85} activity in air samples taken in the northern hemisphere.

Another point to stress is that the averaged dose does not reflect the true degree of exposure to which the population is subject in some major regions of the globe, where that dose may differ substantially from the figures cited (northern and southern hemispheres, northern areas of tundra, etc.). For example, the Cs^{137} content in the human organism can vary considerably depending on the special features of the nutrition and food chains involved. The report took note of the fact that, in view of those factors, the Cs^{137} content levels in the organism of people populating the subartic zone will be one or two orders of magnitude higher than the levels in the organism of people inhabiting the temperate latitudes.

The committee launched into a careful discussion, the first of its kind, on the effect of nuclear power station construction programs. The basic contribution made to the global exposure of the population was that made by gaseous wastes vented to the atmosphere, more precisely Kr^{85} and tritium, the concentration of which in the atmosphere increases year by year (Fig. 2).

The committee proceeded, in its calculations, on the basis of the assumption that generation of electric power at nuclear power stations will increase from 22 million kW(e) in 1970 to 4,300 million kW(e) by the year 2000. That will result in an increase in tritium in the atmosphere from 1 to 720 MCi, in that time, and an increase in Kr^{85} from 16 to 10,5000 MCi.

Calculations of the exposure to the human organism during that period yielded a weighted-average absorbed dose of 1.3 rad, which accounts for not more than 2% of the yearly dose due to natural radiation.

The calculations show, quite evidently, that the peaceful utilization of nuclear power will not lead to levels of global radioactive contamination of our planet that would be dangerous to humanity. But the committee pointed out the possibility of local radioactive contamination of the environment near nuclear power plants, a problem that calls for careful public-health controls and inspection.

Investigations have shown that the contribution to the total exposure of the population made by medical radiation facilities is the major one at the present time, amounting to 50% of the yearly dose due to natural sources of radiation in the advanced countries. Improvements in radiation equipment and more efficient and carefully thought-out use of radiation equipment in diagnostic research may reduce that figure to the level of 20%.

The report goes into detail on cases of professional irradiation of small groups of people (workers in uranium mines, radiographists, x-ray technicians and roentgenologists, workers in the uranium industry, etc.), as well as the effect of such radiation sources as watches with a luminous dial, color television sets, ceramics glazed with uranium additives, building materials containing various radioactive isotopes, and so forth.

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The committee undertook, for the first time, to evaluate the effect of nuclear explosions (both underground explosions and crater explosions) around the world on the exposure experienced by the global population. Several projects involving such test explosions brought about with the object of generating gas, digging out canals, etc., were studied. The temporary radioactive hazard in the neighborhood of the explosions, and the comparatively small contribution the explosions made to the overall exposure suffered by the population of the planet, were taken note of. For instance, an experimental underground explosion engineered in geological formations of natural gas at Gasbuggy (USA) was analyzed. Analysis of the gas released showed contamination of the material by tritium, C^{14}, and Kr^{85}. They calculated what effect that gas would have on the exposure of the population of Los Angeles (7 million) if the gas were used in the gas lines for domestic use immediately after the underground explosion was touched off. The figures arrived at were approximately 0.02 mrad/organism. The major contribution to the irradiation level would be that made by tritium, whose content can be reduced by modifying the design of the nuclear charges in future work involving explosive stimulation of natural gas deposits.

The effect of different sources on the exposure experienced by the population can be expressed in percentages of the natural average exposure, if we assign the latter a value of 100:

Natural exposure	100%
Medical irradiations	20-50%
Irradiation due to nuclear explosions (during 1970)	3-6%
Irradiation due to power plants (by the year 2000)	2%
Professional exposures	<1%
Irradiation due to other miscellaneous sources	<0.1%

It should be stressed that here we are dealing with averages for the entire global population of the earth. That means that the figures for different groups in the population in particular regions of the globe may deviate from those cited in the report.

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SECOND EUROPEAN CONFERENCE ON RADIATION SHIELDING

P. V. Ramzaev

The second European congress on radiation shielding, organized under the auspices of the Physics Society of the Hungarian Peoples Republic and supported by the International Radiation Shielding Association (IRSA), was held in Budapest May 3-5, 1972. About 300 scientists from 25 countries in Europe and from other continents (USA, Canada, Australia, Japan), including 21 persons from the Soviet Union, were in attendance.

Most of the reports were particularistic in nature, and were devoted to detailed treatments of special topics in radiation safety pertaining to internal exposure to radioactive isotopes. The list of those topics is quite varied: mathematical and technical aspects of internal dosimetry; the metabolsim of radioisotopes of some elements (tritium, carbon, fluorine, iron, strontium, cesium, cerium, polonium, lead, radium, plutonium, etc.); biological effects of isotopes (particularly radon daughters in uranium mines); deactivation, speeding up removal of isotopes; measures for shielding the population and persons in production work; validation of the limiting tolerance dose for exposures.

In his introductory report, the president of the IRSA, W. Marley (Britain), cited reference data on the carcinogenic effects of osteotropic isotopes on dogs. More frequent occurrence of tumors is observed at doses from 1000 rad up; the maximum yield (to 60-70%) was recorded at doses on the order of 10,000 rad. Any further increase in dosage (in the range of 10^5 rad) reduces the frequency of occurrence of tumors abruptly. The carcinogenic effect of the isotopes, at the same dosages, increases in the sequence Sr^{90}, Ra^{226}, Pu^{239}. According to W. Marley's calculations, the hazard due to Cs^{137} from radioactive global fallout is 15 times greater than the hazard due to Sr^{90}.

A discussion was prompted by a report by K. Morgan (USA) on a USAEC decision to institute new rules lowering the limiting tolerance dose for individual exposure in populations living in areas where radioactive wastes are vented to the atmosphere by 100 times (from 500 to 5 mrem/year), and lowering the tolerance dose level from 170 to 1 mrem/year for large groups in the population. The new limiting tolerance doses amount to at most 1-5% of natural background, the amplitude of fluctuations in which is ±10%. To monitor such small doses, K. Morgan suggested the use of germanium–lithium spectrometers, taking counts in foils, using counters with thin scintillators, etc.

W. Snyder (USA) justified the need for studying the microdistribution of radioisotopes throughout the organism, without which, in his opinion, calculations of absorbed doses would be extremely imprecise.

Analysis of the dose–effect relationship through studies of uranium miners (from a sample population of 3366 miners in the USA over the 1950-1968 period, with 70 cases of lung cancer incidence instead of 12 as presupposed) enabled several authors to validate an assignment of 30 pCi/liter for the limiting tolerance dose in radon exposure.

While accidents involving nuclear facilities are among events of lesser probability (10^{-4} to 10^{-9}), the extraordinary situations caused by contamination of worksites and of personnel handling radioactive materials in research institutions are a fairly frequent occurrence. For example, 58 such accidents and spills were recorded in the period from 1957 through 1970 in a research institute in Czechoslovakia. The survey and study of these accidents and spills provided material for elaborating public-health regulations.

The leader of the Soviet delegation, P. V. Ramzaev, announced the adherence of the radiation hygiene health physics section of the All-Union society of public health specialists and physicians to the IRSA

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organization. This report was approved by the congress, and was greeted by welcoming remarks on the part of the leaders of the delegations sent by several other countries.

The third congress on radiation protection will be held in September 1973, in the USA. Preparations for that congress are already underway. The proceedings of the second congress will be published in 1972.

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COMMISSIONING OF THE RF SEPARATOR AND FAST BEAM EXTRACTION SYSTEMS AT THE SERPUKHOV ACCELERATOR

A. V. Zhakovskii

On June 8, 1972, an official ceremony at the Institute of High-Energy Physics [IFVÉ] marked the commissioning of systems built under a contract concluded between the European Nuclear Research Or-

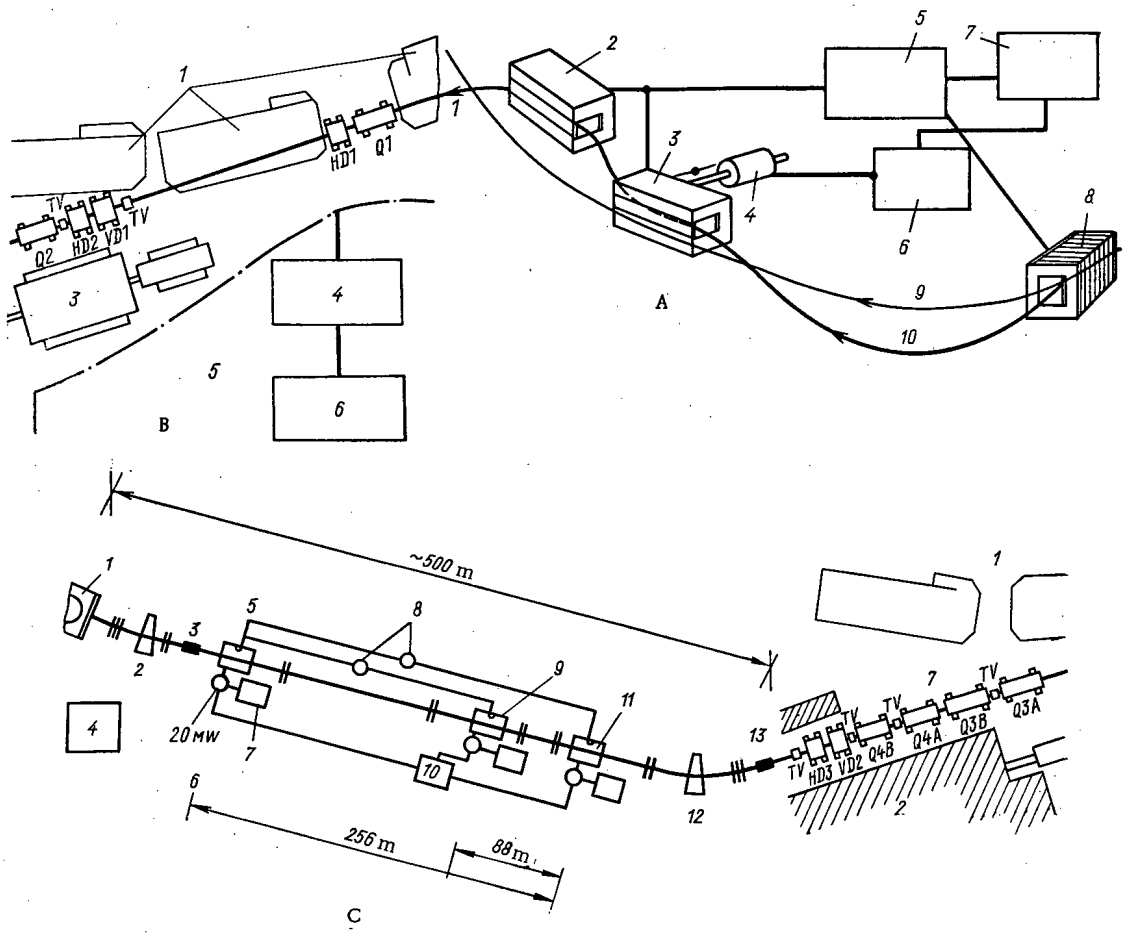

Fig. 1. Diagram of systems for production of separated beams. A) Fast beam extraction system: 1) extraction port; 2) fixed septum magnet; 3) movable septum magnet; 4) hydraulic power cylinder; 5) power supplies; 6) pumphouse for hydraulic system; 7) control panel; 8) shock magnet; 9) undistorted orbit; 10) deflected beam; B) beam transport: 1) accelerator; 2) shielding; 3) channel No. 4; 4) power supplies; 5) beam extraction building; 6) control panel; 7) lens triplet; HD) horizontal deflector; VD) vertical deflector; Q) lenses; TV) television screen; C) separated beam and RF beam separator: 1) Mirabel bubble chamber; 2) second momentum analyzer; 3) beam shutter; 4) control panel; 5) deflector; 6) klystron; 7) modulator; 8) phase control system; 9) deflector 2; 10) amplifier; 11) deflector 1; 12) first momentum analyzer; 13) target.

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ganization (a CERN affiliate) and the USSR State Committee on the Peaceful Uses of Atomic Energy [GKIAÉ] on scientific and technical collaboration. The agreement, concluded in July 1967, envisaged development and fabrication of equipment for a RF beam separator system and a fast proton beam extraction system, on the basis of CERN efforts, for the Serpukhov particle accelerator. That equipment was designed for the beams of separated particles ($K^{\pm}$-mesons, antiprotons, etc.) designed for bubble chambers, and in the first instance for the French Mirabel liquid-hydrogen bubble chamber, in a project sponsored jointly with IFVÉ.

All of the equipment for the systems was transferred from CERN in late 1971 and early 1972 and installed at IFVÉ by Soviet and foreign specialists. The first extraction of a beam with the aid of the fast extraction system was completed on February 5, 1972. The separate beams of K-mesons of 32 GeV/c momentum were first obtained in April, 1972.

The chairman of the USSR State Committee on the Peaceful Uses of Atomic Energy, A. M. Petros'yants, was present at the commissioning ceremony, along with Academician M. A. Markov, secretary of the Division of Nuclear Physics of the USSR Academy of Sciences, the manager of IFVÉ A. A. Logunov, the General Director of CERN W. Entschke, Professor H. Schopper, Dr. I. Goldschmidt-Clermont, administrative director of CERN D. Hampton, and various other official personages. During the ceremony, the document attesting to the satisfactory performance of the fast beam extraction system and of the separated beam system was signed. The document was signed by A. M. Petros'yants on behalf of the Soviet scientists, and by W. Entschke on behalf of CERN.

Figure 1 shows a diagram of the systems designed to achieve separated beams of particles. It was prepared by CERN colleagues for the official ceremony, and provides a lucid graphical picture of the make-up of the system basic equipment at IFVÉ.

A general description of the separated beam channel can be found in an article by A. Bertheleau and R. M. Sulyaev (Atomnaya Énergiya, Vol. 32, No. 5, 371 (1972)), with more detailed coverage in the CERN periodical Curier, Vol. 11, 212 (1971).

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New Books

N. P. Mel'nikov, Konstruktivnye Formy i Metody Rascheta Yadernykh Reaktorov [Nuclear reactor design forms and methods], 2nd edition, Atomizdat, Moscow, 1972.

This book, the first edition of which appeared in print in 1963, analyzes and generalizes Soviet and foreign experience in the design, fabrication, and operation of nuclear plants and facilities.

The book is supplemented in this edition with a description of new materials employed in reactor design for structures doing service at high temperatures and high pressures. Methods of designing of components for strength to withstand thermal fatigue, low fatigue cycles, etc., are cited. The volume of reference material on methods for the design of individual components and subsystems has been expanded.

The book is intended for designers and production experts working in the field of reactor design and nuclear equipment design.

R. R. Ionaitis and V. N. Stobetskii, Gidravlika SUZ Yadernykh Reaktorov [Hydraulics of nuclear reactor control rod systems], Atomizdat, Moscow, 1972.

This book is a first experiment in a consistent presentation of the theory, experimental results, design, and rational construction of the hydraulic flow systems in nuclear reactor control and protection systems. It contains some original results on the hydraulics of reactor control and protection systems. The authors discuss various cases of motion of control rods, and cite results of specially staged experiments in investigations of individual devices and of reactor control and protection systems as a whole. A procedure for design is presented with appropriate formulas and graphs. Light is shed on experience accumulated in the design, adjustment, and operation of the hydraulic part of nuclear reactor control and protection systems.

The book is intended for research scientists, design engineers, and designers specializing in this field. It will also prove useful to workers handling the operation of reactor control and protection systems, as well as to graduate and undergraduate students and college instructors in the field.

Fizika i Tekhnika Nizkotemperaturnoi Plazmy [Physics and engineering of low-temperature plasma], Atomizdat, Moscow, 1972.

This book is devoted to research on low-temperature plasma generated in high-frequency induction type plasmotrons. The physical properties of low-temperature plasma, the thermodynamics and transport properties of low-temperature plasma, are elucidated in detailed treatments. The optical, thermal-physics, and gas-dynamic techniques required for plasma research are presented exhaustively. Results of theoretical calculations of the parameters of an induction plasma, thermodynamic equilibrium in a high-pressure induction plasma, and the results of an experimental investigation of an induction plasma, are of great scientific interest. Designs of high-frequency induction plasmotrons and of power sources (vacuum-tube generators for induction plasmotrons) are described.

The book will be of interest to specialists studying the properties of low-temperature plasma, and various applications of low-temperature plasma, and also to senior undergraduate and graduate students specializing in this field.

M. N. Nikolaev and N. O. Bazaz'yants, Anizotropiya Uprugogo Rasseyaniya Neitronov [Anisotropy of elastic neutron scattering], Atomizdat, Moscow, 1972.

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Results and a critical review of all data published to date on angular distributions of elastically scattered neutrons are presented. The available experimental and theoretical information is discussed, as well as the compatibility of the data reported by different authors; the possible causes of discrepancies in the data are discussed. The data for energies up to 15 MeV are presented graphically. The basic characteristics of the experimental procedures followed are cited, and the bibliography presented on the topic is practically exhaustive.

The book will be of interest to specialists in nuclear physics, and to reactor physicists.

I. N. Slivkov, Elektroizolyatsiya i Razryad v Vakuume [Electrical insulation and vacuum discharges], Atomizdat, Moscow, 1972.

This book, whose author is familiar to our readers from the earlier monograph entitled Elektricheskii Proboi i Razryad v Vakuume [Electrical breakdown and discharge in vacuum] (Atomizdat, Moscow, 1966), discusses processes taking place in the vacuum gap both in the prebreakdown region and in breakdown. Experimental data on the topics are systematized, information on vacuum electrical insulation widely used in various instruments and facilities, and an independent discharge in a vacuum, are reviewed.

The book is written for engineers and research scientists working in physical electronics and experimental physics, and may also constitute a useful supplement to college courses on physical electronics or on electrical phenomena in gases and in vacuum.

S. A. Pan'kov, Remont i Nastroika Elektronnykh Priborov Yadernoi Fiziki [Repair and adjustment of nuclear physics research electronic instrumentation], Atomizdat, Moscow, 1972.

The repair, adjustment, and checkout of nuclear physics electronic devices manufactured by Soviet industry are discussed in this text. Methods for locating and eliminating the most frequently encountered malfunctions are described. Circuitry and schematics of individual modules and subsystems of instruments are presented, to illustrate likely malfunctions and defects.

The book is written for specialists engaged in the maintenance, repair, and adjustment of electronic equipment, and familiar with electronics at the level of the middle technical radio and electronics technician courses, and may also prove useful to a broad range of workers concerned with the operation of electronic equipment.

Ekspluatatsiya i Remont Apparatury dlya Izmereniya Ioniziruyushchikh Izluchenii. Vyp. 1. Mnogokanal'nye Sistemy Radiatsionnogo Kontrolya [Operation and repair of equipment for measuring ionizing radiations. No. 1. Multichannel radiation monitoring systems], Atomizdat, Moscow, 1972.

This issue inaugurates a series of publications on the operation, repair, and maintenance of equipment for measuring ionizing radiations. The issue is devoted to multichannel radiation monitoring systems which can be employed to monitor objects in different rooms. Concise reference data on multichannel radiation monitoring systems are cited, with the conditions and rules governing their operation. Standard circuit diagrams and schematics are presented, along with the basic parameters of the modules or functional units incorporated in the system. The adjustment and maintenance of the monitoring systems are treated in detailed fashion. Designs and diagrams of special-purpose measuring instruments and process instruments are presented, with attention centered on adjustment, regulation, and checkout.

The book is written for workers engaged in monitoring and maintenance of dosimetric equipment, and also for workers concerned with the operation of such equipment.

N. P. Konopleva and V. N. Popov, Kalibrovochnye Polya [Calibration (gage) fields], Atomizdat, Moscow, 1972.

A broad range of mathematical topics pertaining to attempts to construct a unified theory of different interactions of elementary particles on the basis of the calibration field concept is discussed. The calibration field concept can embrace both strong and weak interactions, and electromagnetic and gravitational interactions of elementary particles. This unique approach to different interactions opens the way for a new approach to earlier attempts to describe electromagnetic and gravitational fields, and also to the Einsteinian general theory of relativity.

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The book is written for research scientists, graduate students, and senior undergraduates majoring in physics and mathematics. It may also prove useful to readers interested in the development of the principles of relativity and symmetry in the theory of elementary particles and in modern quantum field theory.

V. A. Nevskii, A. I. Ginzburg, P. S. Kozlova, et al., Geologiya Postmagmaticheskikh Torievo-Redkometal'nykh Mestorozhdenii [Geology of postmagnetic thorium and rare earth occurrences], Atomizdat, Moscow, 1972.

The text offers a genetic classification of the basic types of postmagmatic thorium and rare earth occurrences, and discusses the patterns of spatial arrangement of those occurrences and the geological conditions of their formation. The spatial and genetic relationships between those occurrences and alkaline and alkalified rocks of different formations is demonstrated. The most important geochemical features of rare earths, thorium, uranium, and other elements that are responsible for those elements occurring in combination in desposits are described; the most important types of pneumatic-hydrothermal, high-temperature, medium-temperature, and low-temperature hydrothermal thoriferous and rare earth occurrences are described in expanded form; a comparative estimate is given of the industrial significance of various types of thoriferous and rare earth deposits.

The book is written for a broad range of geologists involved in exploration and exploitation of thorium and rare earth occurrences, and also for seniors at college level majoring in related fields.

V. L. Shashkin, Oprobovanie Radioaktivnykh Rud po Gamma-Izlucheniyu [Sampling of radioactive ores by γ-radiation], Atomizdat, Moscow, 1972.

The book deals with sampling of uraniferous and thoriferous ores in place (by γ-ray logging and γ-ray sampling of mine workings).

The physical fundamentals of the methods involved, the radiological characteristics of radioactive ores, and procedures followed in making determinations, are discussed. Close attention is given to estimates of the effect of radiological characteristics of uranium ore (emanations and breakdowns in the radioactive equilibrium between uranium and radium). Methods for separate determinations of uranium and thorium with the aid of spectral γ-ray logging are also described.

The book is intended for engineering geophysicists and geologists engaged in prospecting, exploration, and exploitation of deposits of uraniferous and thoriferous ores. It can also be useful to students as an auxiliary training text in the study of exploration radiometry.

I. I. Kreindlin, R. A. Markova, and L. M. Paska, Pribory dlya Radiometricheskogo Obogashcheniya Rud [Instruments for radiometric beneficiation of ores], Atomizdat, Moscow, 1972.

The fundamentals of the theory behind the design of instruments for radiometric beneficiation of ores, the functional design of ore-sorting radiometers, radiometers for express analysis of ore, and process control, monitoring, and automation instrumentation in ore beneficiation, are presented in this book. The book is based on data that have been reported in the literature, as well as on the results of the many years of experience the authors have had in the design of radiometric equipment to aid ore beneficiation. Close attention is given to instruments which improve the efficiency of the ore separation process, or which facilitate automatic monitoring and regulation of the ore beneficiation process.

The book will be of interest to specialists working in the field of mining and processing of radioactive ores, and especially to those persons engaged in the design of electronic equipment for beneficiation of mineral ores, and the use and maintenance of such equipment. The text will also be useful to students at college level majoring in related fields.

B. G. Egiazarov, L. A. Korytko, and O. P. Sel'dyakov, Izmeritel'naya Tekhnika v Instumental'nom Neitronnoaktivatsionnom Analize [Measuring equipment in instrumental neutron activation analysis], Atomizdat, Moscow, 1972.

The development and applications of instruments and facilities for analyzing the composition of matter by neutron techniques are discussed. A detailed presentation of data on the design of neutron instruments, based on various processes involving interaction between neutrons and matter, is presented. Neutron emitters (isotope sources, neutron generators using accelerating tubes, neutron mulitpliers, etc.) are

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described. Attention is centered on the development of portable low-cost neutron generators. Instruments and methods for measuring neutron flux (monitors), and equipment useful in studying inelastically scattered neutrons and radiative capture, are discussed in the text.

The book is intended for specialists working in the area of applied nuclear physics, and also for those interested in sophisticated techniques and instruments used in analyzing the composition of matter.

G. M. Fradkin and V. M. Kodyukov, Radioizotopnye Istochniki Elektricheskoi Energii [Radioisotope sources of electrical power], Atomizdat, Moscow, 1972.

The recent steadily broadening acceptance of isotope sources of electric power combining the achievements of nuclear physics and direct energy conversion techniques in science and industry is a topic of current interest.

The basic operating principles of isotope current sources are presented, methods for fashioning radioactive isotope sources of heat energy (isotope thermal units), the requirements to be imposed on such devices, are presented, along with the radiation physics characteristics of such devices, designs of thermoelectric direct converters exhibiting unique engineering parameters, and useful as components in various devices and electric power plants.

The material is based on experience in the development and design of Soviet isotope sources of electrical energy, of types Beta-1, Beta-2, Angara, etc.

The book will be useful to a wide readership interested in promising methods of direct conversion of heat energy to electrical energy.

A. M. Shalaev, Radiatsionno-stimulirovannaya Diffuziya v Metallakh [Radiation-stimulated diffusion in metals], Atomizdat, Moscow, 1972.

Theoretical and experimental material on the effects of ionizing radiation on the diffusion mechanism in metals, which is of major practical importance in reactor design work, is reviewed. The effect of irradiation on the rates of diffusion processes, and on the formation of the structure of metallic materials, is discussed. The important role played by excess point defects in stimulating diffusion at low temperatures is demonstrated.

The book will be of great interest both to students in physics and engineering departments of colleges, and to research scientists and engineers involved in radiation materials studies.

M. F. Romantsev and V. A. Larin, Radiatsionnoi Ekislenie Organicheskikh Veshchestv [Radiative oxidation of organic materials], Atomizdat, Moscow, 1972.

This monograph surveys results of research on processes involving oxidation of organic materials and occurring in response to the effects of ionizing radiations. The underlying mechanism and general pattern of radiolysis of various classes of organic compounds, including structural materials, lubricants, and products of nuclear fuel reprocessing, are discussed.

The book is written for chemists, biologists, and other specialists, working in the field of practical and theoretical radiation chemistry, and also for students at college level majoring in those areas.

V. A. Smolyak and V. I. Vasilenko, Radioizotopnyi Kontrol' i Avtomatika v Chernoi Metallurgii [Radioisotope monitoring and automatic control in the iron and steel industry], Atomizdat, Moscow, 1972.

The development, implementation, and operation of radioisotope monitoring, measuring, and control instrumentation, equipment, and devices for automatic alarm annunciation and safety interlocks in the iron and steel industry are discussed in this text.

The design, operating principles, diagrams, basic characteristics, and methods for calculating the adjustment parameters, of radioisotope instruments and process-regulating equipment for certain metallurgical production units and processes are described. Specific examples of radioisotope process monitoring and control devices and devices for automation of production operations and technological processes in the basic steps of metallurgical work, as well as engineering cost and production cost questions and radiation safety, are discussed in the text.

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The book is written for engineers and technicians in basic production departments, for process monitoring and control instrumentation services, for isotope laboratories in metallurgical industry enterprises, and can be useful to students in colleges and technical colleges.

L. A. Pertsov, Ioniziruyushchie Izlucheniya Biosfery [Ionizing radiations in the biosphere], Atomizdat, Moscow, 1972.

The basic regularities in the formation of natural radiation loads affecting the vital metabolism of all plant and animal organisms are discussed. The reasons for the fluctuations in natural radiation loads are demonstrated. The effect of current technical progress and intense urbanization on shifts in the components of the radiation field of the biosphere are discussed. Indices of the radioactivity of components of the external environment, of plant tissues, of animal tissues, and of human tissues, are cited. The properties of various radionuclides, their distribution and migration in the troposphere, atmosphere, hydrosphere, and pedosphere as a function of the physical and chemical properties of the radionuclides, of special features of the landscape, climate, meteorological conditions, etc., are described in detail. Quantitative and qualitative estimates are given of the degree of hazard presented by probable unmonitored incorporations of radioactive mixtures into the external environment.

The book is written for college instructors, research scientists, health physicists and public health physicians, and engineers.

Sovremennye Problemy Radiobiologii [Current topics in radiobiology], under general editorship of Corresponding Member of the USSR Academy of Sciences A. M. Kuzin. Volume III, Molekulyarnaya Radiobiologiya [Molecular radiobiology], edited by N. B. Strazhevskaya, Atomizdat, Moscow, 1972.

This is the third volume in the series Current topics in radiobiology, the first volume having appeared in 1970, the second volume in 1971.

The third volume goes into the present status of the most urgent topics in molecular radiobiology. The latest data on the structural–functional organization of chromosomes, on impairment of structure and function of deoxyribonucleic acid in the cell, on the mechanism involved in effects of ionizing radiation on the protein-synthesizing system of the cell and on membranes, are cited.

Current concepts of radiation-chemical transformations of aqueous solutions of DNA, proteins, and carbohydrates are elucidated. Special attention is directed to such theoretically and practically important topics as the molecular mechanisms underlying the protection and recovery of biomolecules.

The book is written for a broad range of specialists in the fields of radiobiology, ecology, cytology, biochemistry, radiochemistry and radiation chemistry, and also for students at college level majoring in those fields.

A. A. Makarenya, D. I. Mendeleev i Fiziko-Khimicheskie Nauki ot D. Dal'tona do N. Bora [D. I. Mendeleev and the physicochemical sciences from J. Dalton to N. Bohr], Atomizdat, Moscow, 1972.

This book is written by the director of the D. I. Mendeleev Museum and Science Archives. The monograph offers a brief account of the basic stages in the life of D. I. Mendeleev and of his scientific activities. Attention is centered on clarifying the contribution made by D. I Mendeleev to the science of matter, as it affected the entire subsequent development of theoretical natural science (studies of the elements, of valency, of periodicity, etc.). Special features of the scientific creativity of D. I. Mendeleev are demonstrated (by drawing upon archival materials).

The book is intended for a broad range of readers, but is addressed principally to those interested in the history and methodology of science, and in the psychology of scientific creativity.

Vychislitel'nye Metody v Fizike Reaktorov [Computational methods in reactor physics], collection of articles edited by H. Greenspan, K. Kelber, D. Okrent. Translated from the English, Atomizdat, Moscow, 1972.

The book comprises a collection of review articles on the principal topics in the development, algorithmization, and realization of numerical methods for solving applied reactor physics problems by computer. Each of the review articles was written by a leading specialist on the method in question. Five of

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the eight chapters are devoted to stationary processes in nuclear reactors. The diffusion approximation for one-dimensional, two-dimensional, and three-dimensional problems, the method of discrete ordinates, and the method of spherical harmonics, are presented. Transients in nuclear reactors are described, and the special features of computer programs designed to realize particular analytical and numerical methods are pointed out. The solution of problems involving rapid introduction of high positive reactivity into the reactor is presented. Processes accompanying a hypothetical nuclear accident at a reactor facility, and resulting in the destruction of the reactor, are investigated.

The book is written for specialists engaged in nuclear reactor calculations and design work; it will also be useful to designers of reactor physics computing techniques, and to those interested in devising computer software for reactor physics problems.

W. Lock and D. Mizday, Fizika Chastits Promezhutochnykh Énergii [Physics of particles of intermediate energies], translated from the English, Atomizdat, Moscow, 1972.

This book comprises an expanded and revised edition, supplemented by more recent data, of the monograph Nuclear Physics of High-Energy Particles published in 1962.

Results of experimental and theoretical investigations of nuclear interactions involving particles of intermediate energies (up to 10^9 eV) are reviewed and systematized. Attention is focused on a description of accelerator experiments. Concise information is also cited on current experimental techniques in use in this branch of physics.

The book is written for a broad range of readers including physicists, research scientists, college instructors, and senior undergraduate physics majors.

Rukovodstvo po Radiatsionnoi Zashchite dlya Inzhenerov [Radiation shielding manual for engineers], Vol. 1, translated from the English, and edited by D. L. Broder et al., Atomizdat, Moscow, 1972.

This manual, published under IAEA sponsorship, is in two volumes. This first volume deals with the most widely used current methods for calculations and design of shielding against neutron radiation and γ-radiation: the method of integrating the influence function of a point source, the Monte Carlo method, and others. The latest information on cross sections of various processes is cited in the case of γ-photons. Results of a large number of experimental and computational investigations of radiation fields in a variety of shielding media are given for practical use in design and calculations of shielding.

The second volume will take up forecasting of shielding against radiations from extended sources, calculations of radiation induced energy release and temperature fields in shielding, transmission of radiations through channels, voids, and other inhomogeneities in shielding.

The manual is designed for specialists concerned with the physics of shielding against radiations, or with radiation safety, and can also be used by research scientists working with ionizing radiations.

Kineticheskie Protsessy v Gazakh [Kinetic processes in gases], a collection of articles edited by A. Hochstimm, translated from the English, Atomizdat, Moscow, 1972.

This book is a compendium of articles on kinetic phenomena occurring in gases and in plasma. It consists of ten chapters written by various authors, but all interrelated and arranged in a definite sequence. Attention is focused on the derivation of macroscopic constants from microscopic equations, and on validation of the transport equations. Some of the topics elucidated in the text have been discussed previously only in the original literature. In particular, many readers will undoubtedly be interested in the kinetics referable to the case of frozen degrees of freedom, the relationship between classical gas-kinetic theory and plasma physics, and many-particle processes. Classical topics in the kinetics of plasma are analyzed in detail.

This book will prove useful to physics majors and to research scientists specializing in plasma physics, kinetic theory, and reaction theory.

D. Brown, Galogenidy Lantanoidov i Aktinoidov [Halides of the lanthanides and actinides], translated from the English, edited by I. V. Tananaev, Atomizdat, Moscow, 1972.

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This represents a first attempt to provide a complete and systematic presentation of the chemistry of halides of the rare earths and of the actinides – compounds widely used in the nuclear power industry and in other new areas of science and industry. Methods of synthesis are presented, and the requesite equipment is described. Tabular appendices provide data on the thermochemical properties of the lanthanides, the properties of mixed halides of uranium and protactinium and methods for obtaining and isolating them, and so on.

The laconic style of presentation, with the latest relevant data included, renders this book exceptionally useful to all those who make use of compounds of the lanthanides and actinides in their work. It will also be interesting to instructors, graduate students, and senior undergraduate majors in chemistry.

Vosstanovlenie i Reparativnye Mekhanizmy v Radiobiologii [Recovery and restorative mechanisms in radiobiology], collection of articles translated from the English, edited by A. G. Konoplyannikov, Atomizdat, Moscow, 1972.

The book comprises a collection of reports delivered at a symposium held at the Brookhaven National Laboratory. Results of current research on recovery processes following radiation injury are presented. The genetic aspects of postradiation recovery, adaptation and modification factors, and the effect of cellular and humoral factors on recovery from radiation injury are among the topics discussed.

The book will be of significant interest to radiobiologists, biophysicists, geneticists, and medical radiologists.

K. Streffer, Radiatsionnaya Biokhimiya [Radiation biochemistry], translated from the German, edited by E. F. Romantsev, Atomizdat, Moscow, 1972.

The present state of the art in radiation biochemistry is discussed. Various aspects of metabolism in irradiated mammalian organisms, and the metabolism of the principal classes of biologically important compounds, such as: nucleic acids, amino acids, proteins, carbohydrates, lipids, hormones, vitamins, etc., are clarified. Practical recommendations are put forth on the application of various biochemical tests in diagnostics of radiation injury.

The book is written for a broad readership of biochemists, biophysicists, radiobiologists, and also clinicians concerned with the prophylactics and therapy of radiation sickness.

E. Schrödinger, Chto Takoe Zhizn'? (Fizicheskie Aspekty Zhivoi Kletki) [What is life? (Physical aspects of the live cell)], translated from the English, 2nd edition, Atomizdat, Moscow, 1972.

In this slender but thought-packed volume based on public lectures given by the author, the renowned Austrian physicist Erwin Schrödinger discusses specific topics in applications of physical concepts to biology.

The author launches into a discussion of general problems concerning the physics approach to various phenomena of life, causal factors in macroscopicity, the many-atom nature of the organism, hereditary mechanisms and mutations, from the vantage point of theoretical physics.

Even though over two decades have elapsed since the time the first edition of the translation of this book appeared, the topics treated have not lost their urgency, and the book will be read with great interest by all those interested in the physical aspects of life.

E. Rutherford, Izbrannye Nauchnye Trudy. Stroenie Atoma i Iskusstvennoe Prevrashchenie Elementov [Selected scientific works. The structure of the atom and artificial transmutation of the elements], Nauka, Moscow, 1972.

The book contains some selected scientific works by the outstanding physicist of the 20th century, Ernest Rutherford, primarily his contributions on the structure of the atom and on artificial transmutations of the elements. The collection also includes some popular science contributions by Rutherford.

The articles in this collection appear in Russian for the first time.

The material in the book will be of interest to a wide range of readers, including physicists and historians of science.

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Ocherki Sovremennoi Geokhimii i Analiticheskoi Khimii [Essays on modern geochemistry and analytical chemistry], Nauka, Moscow, 1972.

This is a collection of articles on space chemistry and on meteoritics as well as on the geochemistry of the isotopes and the distribution of the elements in the earth's mantle, the geochemistry of processes and biogeochemistry, also analytical chemistry, etc., with ample use made of the further development of concepts put forth by Academician A. P. Vinogradov. The collection contains contributions by both Soviet and foreign scientists.

The book will be of interest to a broad range of geochemists, geologists, and chemists.

Neitronnyi Aktivatsionnyi Analiz v Geologii i Geofizike. Trudy Instituta Geologii i Geofiziki Sibirskogo Otdeleniya Akademii Nauk SSSR. Vyp. 126 [Neutron activation analysis in geology and geophysics. Proceedings of the Institute of Geology and Geophysics of the Siberian Division of the USSR Acad. Sci., No. 126], Nauka, Moscow, 1972.

The first part of the monograph presents the physical fundamentals of the activation analysis method. Neutron sources used in neutron activation analysis work are described, as well as the requirements and specifications for measuring equipment. The second part of the book deals with the procedure for applying activation analysis to the solution of various geological problems.

The monograph will be of interest to specialists in nuclear geophysics, geologists, and to specialists engaged in the development and application of activation analysis methods in the most varied branches of science and industry.

T. G. Ratner and A. V. Bibergal', Formirovanie Doznykh Polei pri Distantsionnoi Gamma-Terapii [Formation of dose fields in gamma-ray teletherapy], Nauka, Moscow, 1972.

The monograph is devoted to the design, certification, and acceptance in medical practice of therapeutical γ-radiation equipment for mobile irradiation treatment.

The book is written for physicists, dosimetrists, technicians, physicians, and biologists working in the field of radiology, as well as engineers and designers in the field of γ-ray equipment design.

V. S. Martynovskii, Analiz Deistvitel'nykh Termodinamicheskikh Tsiklov [Analysis of real thermodynamic cycles], Énergiya, Moscow, 1972.

The book presents a general method for comparing real cycles (both direct cycles and reverse cycles) which will enable the reader to analyze thermal cycles and refrigerating cycles by utilizing a comparatively restricted number of characteristics. The characteristics in question can be used right at the initial stage of analysis in forming a concept of the expected efficiency of the cycle of the heat power plant or refrigerating plant. Close attention is given to analysis of plants that can be used to generate both heat and cold.

The book is written for design engineers and for designers involved in the development of new types of heat power plants and refrigeration plants.

S. S. Kutateladze and A. I. Leont'ev, Teplomassoobmen i Trenie v Turbulentnom Pogranichnom Sloe [Heat transfer and mass transfer and friction in a turbulent boundary layer], Énergiya, Moscow, 1972.

The authors discuss the fundamental conservative properties of the wall turbulent boundary layer. The concept of an ideal layer with a degenerate viscous region is introduced. Some other limiting properties of wall turbulent boundary layers which are not due to unrestricted diminishing of molecular viscosity are clarified. Theoretical findings and inferences are compared to abundant experimental data. A large number of examples illustrating practical applications of the theory are cited.

The book is written for specialists in the field of physical hydrodynamics and the theory of convective heat transfer and mass transfer.

Magnitogidrodinamicheskii Metod Polucheniya Élektroénergii [The magnetohydrodynamic method of electric power generation], collection of articles edited by V. A. Kirillin and A. E. Sheindlin, No. 3, Énergiya, Moscow, 1972.

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The book comprises a collection of articles presenting results of scientific research work on MHD generators at leading organizations in the Soviet Union. The materials contained in this collection of articles include an engineering costs analysis of electric power generating stations using magnetohydrodynamics, and findings on investigations of liquid-metal MHD power plants.

The book is written for research scientists and engineers working in the field of MHD generators, and may also be useful to students majoring in engineering and physics.

W. Harrison, Teoriya Tverdogo Tela [Solid state theory], translated from the English (New York, 1970), Mir, Moscow, 1972.

W. Harrison is a prominent American physicist whose name is quite familiar to Soviet readers from his book Potentials in the Theory of Metals (Potentsialy v Teorii Metallov, Mir, 1968). His new contribution is a monographic textbook which is original both in contents and in the style of presentation. The presentation is based on the microscopic theory of solids, with attention focused on the underlying physics of the phenomenon. The book encompasses such topics as types of solids and crystal symmetry, electronic states, electronic properties of solids, lattice vibrations and atomic properties, cooperative properties of solids.

Book Reviews

Poiski Uranovykh Mestorozhdenii v Usloviyakh Gornoi Taigi [Prospecting for uranium deposits in the mountainous taiga regions], edited by Yu. V. Sharkov, Atomizdat, Moscow, 1971.

Reviewed by A. I. Tugarinov and S. F. Karpenko.

The book is devoted to major topics concerning prospecting and exploration of uraniferous occurrences under mountainous taiga conditions, i.e., in highly forested regions which differ in the composition of the mantle of friable deposits, and with unexposed strata.

Topics in the geochemistry of mineral halos and scattering flux levels are solved, the possibility of using isotope analysis in the study of flux and halos is demonstrated, a procedure for landscape, terrain, and geochemical zoning to aid prospecting of uraniferous occurrences is presented, and the outlook for in-depth prospecting under mountainous taiga conditions is elucidated, while calculations of prospecting networks are presented.

Not only is there ample material on the development of prospecting methods, but experience on their utilization in concrete sets of circumstances is reviewed and generalized.

The book is in five sections. The first section shows how the general regularities of hypergenetic uranium chemistry, developed by prominent Soviet research investigators, are manifested under specific geochemical conditions. The second section is devoted to the characteristics of parameters of halos and scattering flux levels, as the basic criterion of mineralization. Topics pertaining to zoning of territories according to prospecting conditions (third section) come under discussion next. Primary halos of uranium occurrences playing an exceptionally important role in prospecting for that element, are discussed in sufficient detail in the fourth section. And finally, the fifth section discusses prospecting procedures adapted to use under mountainous taiga conditions. Here methods for selecting prospecting networks and compiling metallometric charts and maps are presented rather fully.

The book deals with prospecting for a single element – uranium, but the procedural points described can be judiciously applied to prospecting for other metals under similar conditions.

The book is written for a broad readership of prospecting and exploration geologists, and will indubitably find a broad response among investigators, while aiding the subsequent development of prospecting activities pertaining to this exceptionally interesting and important metal.

N. M. Voronov, R. N. Safronov, and E. A. Voitekhov. Vysokotemperaturnaya Khimiya Okislov Urana i ikh Soedinenii [High-temperature chemistry of oxides of uranium and their compounds], Atomizdat, Moscow, 1971.

Reviewed by N. P. Galkin.

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This book is a monograph in which research findings on the synthesis and physicochemical properties of complex refractory compounds incorporating uranium trioxide are reviewed. Some of those compounds hold forth promise as materials for the fabrication of fuel elements, since they are superior in some of their properties to the individual uranium compounds (dioxides, carbides, nitrides) currently used for that purpose.

At the present time, a lot of research is being done on the synthesis and on the properties of complex oxides, including uranium complex oxides, and that has prompted a need for analysis and review of the results obtained, which in turn stimulates further and better focused research in that area.

The monograph contains ten chapters. The first two chapters are introductory in nature. Those chapters discuss traditional topics in the chemistry of uranium oxides, the system uranium–oxygen, and the uranyl bond. The presentation is concise, to the point, and organically related to the principal material presented in the remaining chapters.

The chapters from third through eighth deal with the synthesis and properties of complex oxides formed in systems containing uranium oxides, and elements of the I through VIII groups in the periodic table. Very close attention is given to the relationship between the thermal stability and chemical stability of the compounds and the parameters of state and the composition of the vapor phase, and analysis of crystallochemical data, on the basis of which attempts are ventured to account for the thermal and phase transformations experienced by the complex oxides, their stability or proclivity to dissociation, their compatibility with other oxide materials.

The last two chapters go into interactions between the orthouranates of calcium, strontium, and barium and the oxides of other metals, the structure and properties of complex oxide compounds containing uranium, the large number of compounds with a perovskite structure incorporating uranium of different valency.

Different points of view, including that of the book's authors, are compared in doubtful cases, and attempts to ascertain the basic patterns of behavior of the complex oxides are made for each group of compounds. Close attention is given to the crystallochemical characteristics of the compounds. Roughly a third of the text material consists of the authors' own research findings.

Several remarks are in order. First, the title implies a broader presentation of topics than is actually the case. The topic of high-temperature chemistry of uranium oxides implies the production of oxides from a variety of condensed and volatile uranium compounds, plus the thermodynamic and heat-transfer and electrophysical properties of those compounds, the structure and properties of gaseous oxides, etc. Second, insufficient attention is given to analysis and study of the kinetic parameters of reactions involved in the synthesis of complex oxides and reactions involving transformations in different media. Moreover, there are several comments that could be made on the way the material is presented, and also on the reaction mechanism. The latter points are open to discussion.

The remarks ventured do not diminish the great value of the factual material and the level of analysis and review generalization attained in the book.

N. A. Vlasov, Neitrony [Neutrons], Nauka, Moscow, 1971.

Reviewed by K. A. Petrzhak.

The year 1972 is a significant one – marking the fortieth anniversary of the discovery of the neutron. In that comparatively short span of time, the production of neutron sources and the interaction of neutrons with matter became independent branches of nuclear physics in the intermediate and low ranges of the energy spectrum, encompassing both theoretical and practical problems subsumed under the heading: neutron physics.

The new theoretical and experimental material accumulated in recent years has been published as part of proceedings of conferences and symposia, and also in the current scientific periodical literature, and there is of course some need for systematic review of this material and its presentation in monographic literature format. The revised and re-edited book by N. A. Vlasov, Neitrony, acquires a great scientific value on that account.

The way the book is constructed corresponds to the logical development of neutron physics itself. The first chapter outlines the basic properties of the neutron and the history of its discovery, related to

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the study of nuclear reactions brought about in response to the interaction of α-particles emitted by naturally occurring radioactive isotopes and light nuclei, beryllium specifically. Research work done in the Soviet Union is amply represented in the text. Modern methods for ascertaining the mass of the neutron, the radioactive decay of the neutron, as studied in the experiments staged by Spivak and Sosnovskii, Robson's experiments studying the spectra of β-particles in neutron decay, are discussed. Close attention is given to the determination of the spin and magnetic moment of the neutron in the classical experiments by Alvarez and Bloch.

The second chapter constitutes a logical continuation of the first, and reviews all the known types of neutron sources. Here, to begin with, the author acquaints the reader with the evolution of matter in the astrophysical context, with thermonuclear processes taking place in stars, and with neutron transformation processes.

A table of binding energies of neutrons in nuclides all the way to berkelium was compiled on the basis of data published in the scientific literature.

The data on neutron yields when various nuclear reactions are utilized, (p, n), (d, n), (α, n), (γ, n), and the like, are of particularly keen interest to experimental physicists. Here the reader is offered recommendations on the selection of optimum parameters for use in experiments with thin and thick targets, and their effect on the angular and energy distributions of the resulting neutrons is described. The neutron polarization mechanism resulting from the spin dependence of nuclear forces is also discussed here. A description of a nuclear reactor, as the basic high-level source of slow neutrons and fast neutrons in use today, is also given. Methods for the shaping and monochromatization of neutron beams for various problems in neutron physics are discussed.

Uncertainties in the choice of method for detecting neutron fluxes are frequently encountered in experimental practice. The third chapter describes techniques for recording neutron fluxes of different intensity and different energy composition. Current methods of recording by observing recoil nuclei forming in elastic scattering of neutrons, detection of neutrons in splitting of nuclei by neutrons, the use of the process of fission of heavy nuclei in order to record neutrons, the method of induced radioactivity, and the method of threshold indicators, are presented in this chapter. The discussion continues to cover current methods in the spectrometry of neutrons, using a mechanical chopper, the pulsed-beam method and the time-of-flight method, and the crystal monochromator method. The possible accuracy and efficiency are analyzed and compared, in all of the recording techniques discussed, as functions of the experimental conditions and the spectral sensitivity of the neutron detector employed. Methods for measuring polarization of neutrons, utilizing the nuclear and electromagnetic spin interactions, are cited.

The fourth chapter deals with processes involving interaction of neutrons with matter. This chapter starts off with a discussion of experimental searches for the electromagnetic dipole moment of the neutron. The author then acquaints the reader with the problem of Yukawa nuclear forces, the effect of isotopic spin on nuclear potential, the spin—orbit interaction, the Hasiades and Johnston potential, the optical potential, and the Saxon–Woods potential. All of those theoretical concepts are presented in a straightforward and lucid form.

Close attention is given to reviews of processes involving nucleus—nucleus interactions. Elastic scattering, capture and inelastic scattering of neutrons, nuclear reactions due to neutrons, are all described in detail. The description is illustrated by accounts of experiments performed, and elucidates the basic problems in neutron physics. For example, astrophysical concepts pertaining to s-processes and r-processes occurring in stars are brought up in the discussion of synthesis of elements (nucleosynthesis), and fundamental problems in nuclear physics are discussed in the light of the concepts of the stability bound of neutron-excess nuclides.

The fifth chapter is devoted to the process of slowing-down and diffusion of neutrons in different media. On the basis of now established theoretical concepts on the slowing-down process in various media, and the theory of neutron age, some basic characteristics are discussed: the logarithmic mean energy loss of the neutron in a collision sustained with a nucleus, the slowing-down length, the diffusion length, the average lifetime of the neutron in a slowing-down medium, the albedo, and several other parameters. The chapter ends with elementary calculations of the critical mass of the simplest type of reactor.

The last chapter describes the wave properties of the neutron. The marked similarity between the diffraction nature of scattering of slow neutrons and the nature of x-ray diffraction made it possible to find

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general patterns in the description of that phenomenon, and to present the problem in an explicit and straightforward way be taking advantage of the similarity. The topics covered in this chapter include current achievements in neutron diffraction studies and experimental refinements in that division of neutron physics. A special section of the chapter is reserved for reflection and refraction of neutrons.

The book is written in straightforward and lucid language. Despite the complexity of the material, the theoretical topics are not burdened by excessive detail. Both the experimental data and the theoretical data are amply illustrated by graphs and figures. Extensive new information on the nuclear physics constants of processes involving neutrons is presented, in the format of curves and tables.

On the whole, the book must be judged successful and fills an important gap in the literature. It can be recommended both as a textbook and as a desktop reference for specialists working in the field of neutron physics.

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