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Operational Characteristics of Type
Beta-1 and Beta-2 Isotopic Thermoelectric
Generators

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13. ABSTRACT
Both generators were tested in use, supporting meteorological stations. The characteristics of the Beta-1 varied from the predicted values with time, but never by as much as 10%. The Beta-2 was found to be particularly safe and reliable in operation over extended periods, and can be used for terms of 5 years or more.

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Translation: The Beta-1 and Beta-2 experimental isotopic electric power sources, designed to supply power to the ARMS-N Radio Meteorological Station, were designed to test a number of theoretical assumptions and design characteristics which they incorporate.

In the design of these isotopic power sources fundamental attention was given to the following questions:

1) To obtain an adequate efficiency from the installation by the use of highly effective thermal insulation and semiconductor materials with the maximum Q-factor over the design temperature range, as well as by providing the minimal thermal resistance to heat flow from the isotope element to the thermal element and thence to the ambient medium;

2) To ensure the designed level of ionizing radiation while holding weight and outside dimensions to a minimum by choosing the optimum geometry, using highly effective shielding materials (tungsten, lead) and providing separate biological shielding by the use of two containers (an operating container and a transport container);

3) Providing maximum safety by the use of relatively insoluble fuel compounds and special materials (in making the isotope unit), sealing it completely, etc., making it practically impossible for the radioactive substance to escape;

4) Guaranteeing reliability in operation by using a block thermal battery and special materials and by the simplicity of design, absence of moving parts, etc.

The Beta-1 and Beta-2 isotopic thermal electric generators consist of the following major components: isotope and thermal blocks, thermal element block, body, biological shielding, heat dissipation system and systems for the conversion

and storage of electric energy.

The development process involved component and assembly testing, including: external inspection and check of parts assembly, determination of thermal efficiency, determination of the voltage and current characteristics of thermal element blocks at given temperatures of the hot and cold junctions, checking the sealing of internal cavities in the body, determining the temperature fall from the ambient medium to the cold junctions of thermal element blocks, checking the operation of the electric power storage system with semiconductor voltage converters, testing the isotopic power sources with power storage systems as part of the ARMS-N Meteorological Radio Station, determining the effectiveness of the biological shielding and calorimetry of the isotope block.

After the generators were loaded with the isotope fuel, the control parameters were recorded and permission was obtained from the interdepartmental committee; they were installed for experimental use in meteorological stations in the City of Khimki.

Experimental Operation of the Beta-1 Generator. On 4 January, 1964, the generator was attached to the ARMS-N Automatic Radio Meteorological Station at the experimental meteorological area. It was set up in a pit 1 meter deep and 1.5 meters in diameter. During its operation, the following parameters were measured: thermal EMF, voltage at the input of the voltage converter, current in the thermal battery-voltage converter circuit, charge current of the batteries, voltage at the input to the electric power storage system and temperature of the ambient air.

Figure 1 shows the fall in thermal EMF over time [$E = f(\tau)$], while Figure 2 illustrates the change in electric power of the generator.

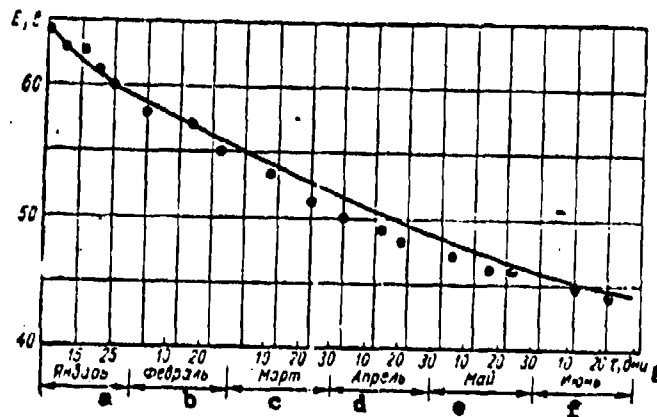


Figure 1. Thermal EMF of the Beta-1 Electric Generator as a Function of Time.

— — Calculated curve; o - Experimental data

a - January; b - February; c - March; d - April; e - May; f - June;
g - τ , days

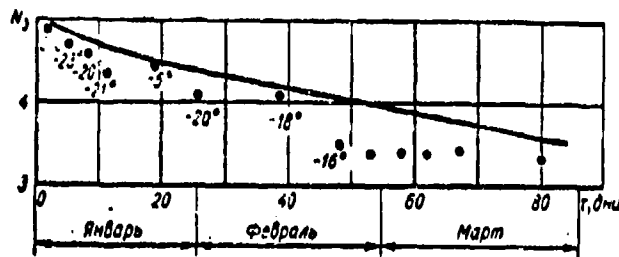


Figure 2. Output Power of the Isotopic Power Source as a Function of Time. Same format as Figure 1.

a - January; b - February; c - March; d - τ , days

As is evident from Figures 1 and 2, the experimental values at the beginning of the service period agree with the calculated values within the limits of error. As time passes, there is a deviation of the experimental data from the predicted, apparently caused by increased heat losses as a result of breakdown in the generator body seal. The maximum error in the measurement of power was no more than 5%, and in the measurement of thermal EMF no more than 3%.

Figure 3 shows the change with time of the internal and load resistance of the thermal electric converter. The maximum error in these measurements did not exceed 7.5 and 5% respectively.

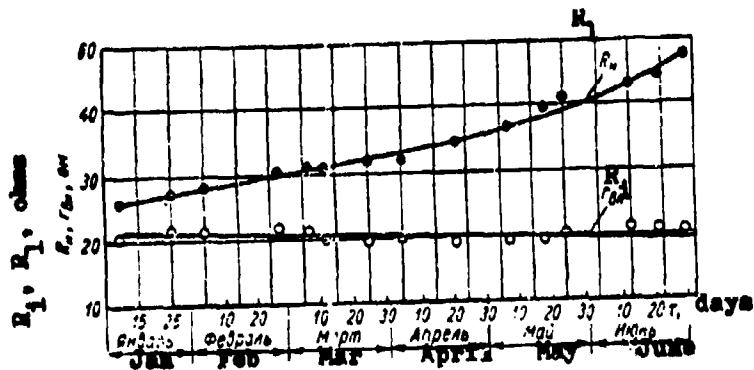


Figure 3. Relationship Between Internal (R_i) and load (R_l) Resistance of the Thermal Electric Converter and the Time of Operation of the Generator:
 ———— - Calculated Curve; \bullet , \circ - Experimental Results

Some reduction in the internal resistance was caused by reduction of the temperature fall across the thermal element. The increase in the load resistance (the input resistance of the voltage transformer) was caused by a reduction in the power deliverable to the input of the voltage transformer over time.

Figure 4 shows curves for the change in maximum efficiency (η_{max}) of the voltage converter, charge voltage (U_b) on the storage battery and input voltage (U_{in}) of the converter over time as the generator is used. The maximum error of measurement as a function of ambient air temperature was considered in determining the efficiency of the voltage converter (the error did not exceed 3%).

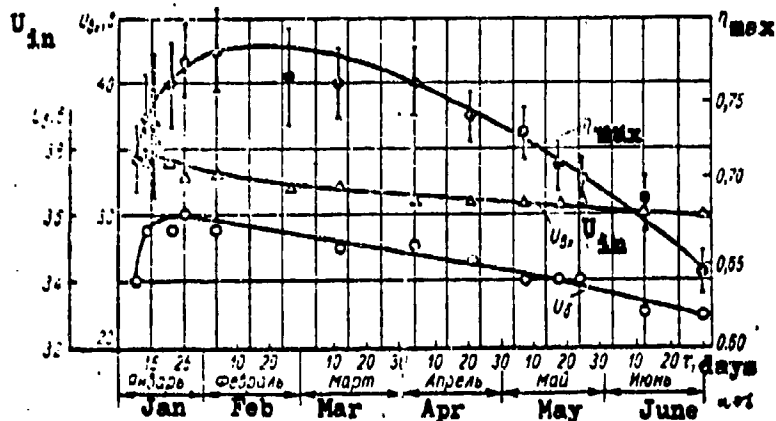


Figure 4. Changes in the Charge Voltage on the Battery U_b and the Input Voltage U_{in} of the Converter.

The voltage converter operated reliably throughout the entire service life of the generator and had satisfactorily high efficiency.

Pulsations in the voltage of the semiconductor converter were absent due to the counter EMF of the batteries.

As the output power of the generator decreased, the operating cycle of the ARMS-N station changed to maintain a balance between the power consumed by the station and the energy accumulated in the battery. These changes occurred after 1, 3, 6, 8 and 12 hours.

Experiment Using the Beta-2 Generator. The Beta-2 isotopic thermal electric generator was put into operation on 3 December, 1964, with a block of thermal elements removed from the Beta-1 generator. This block had already operated for 4300 hours, producing approximately 25,000 watt-hours of electric power.

The power output of the Beta-2 generator is shown in Figure 5.

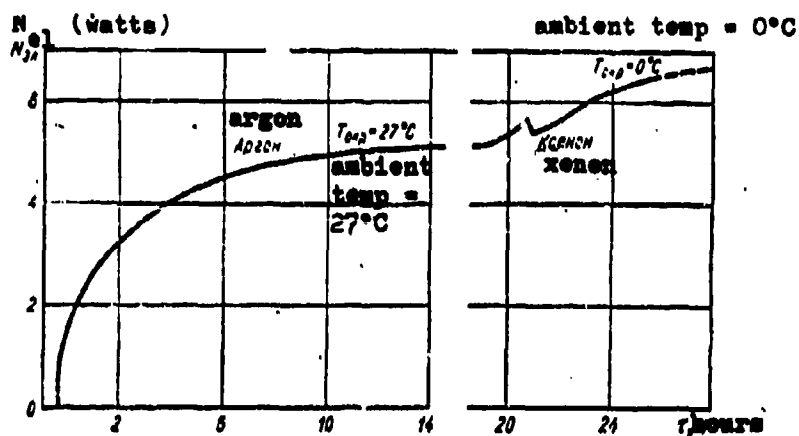


Figure 5. Output of the Beta-2 Generator in Stable Operation. The load corresponds to the most efficient operating level. $R_{nom} = 2.7$ ohms. Thermal power $Q_0 = 148 \pm 8$ watts.

The electrical circuit of the generator was protected against the failure of the current carrying wires from the thermal electric converter, which was particularly important at the beginning of generator service, since the temperature of the hot junction of the converter was close to the melting point of the commutation alloy. An open circuit would lead to an increase in the temperature of the hot junction as a result of the Peltier effect, which could destroy the thermal element block.

The operation of the Beta-1 generator with a continuous recording of output power from the isotopic power source permitted the determination of changes in efficiency with time.

The efficiency of the thermal electric converter when the thermal block was placed in the generator was 5.8%. With the reduction in heat flow through the thermal elements its value decreased. In the determination of thermal efficiency, "useful" energy was that which flowed through the thermal elements. The efficiencies of the thermal element group and the isotopic source are given in Table 1.

Table 1
Efficiency of the Thermal Element Group and the Isotopic Power Source as a Function of Operation Time and Heat Flow

Время экс- плуатации τ , дни	Тепловой поток Q , Вт	К. п. д. блока термоэлемента η_T , %	К. п. д. изотопы τ , %	Температура воздуха, °C
21	128	5,25	3,75	0
32	125	4,83	3,36	-5
46	121	4,62	3,15	-20
53	116	4,35	2,9	-16
67	112	4,27	3,08	-1
90	106	4,3	2,83	-1

b - operation time τ , days; c - heat flow Q watts; d - efficiency of the thermal element block η_T %; e - efficiency of the isotopic heat generator τ %; f air temperature, degrees centigrade.

After achieving stable operation in the argon atmosphere, the generator had the following electrical characteristics, measured at an ambient temperature of 27°C:

Voltage U, volt 3.8
 Current I, amperes 1.365
 EMF, E, volts 6.92
 Electrical Power N_{e1} , watts 5.19
 Internal resistance R_{in} , ohms 2.3

When the interior of the generator, which had been set up in the open air, was filled with xenon at an ambient temperature of 0°C, its power increased to 6.8 volts.

Table 2 shows the basic parameters for the isotopic heat source at various temperatures of the ambient medium.

Table 2

Basic Parameters of the Beta-2

b Наполнитель	$\theta_{окр}$, °C	d U, в	e I, а	f E, в	g N_{e1} , вт	h R_{in} , ом	i R_{ex} , ом	j ΔT , °C
Аргон	+27	3,8	1,36	6,92	5,18	2,3	2,7	193
	0	3,82	1,42	7,0	5,42	2,24	2,7	205
	0	4,28	1,58	7,82	6,78	2,24	2,7	228
Ксенон	-6	4,36	1,61	7,84	7,08	2,2	2,7	230
	-3	4,4	1,62	7,92	7,14	2,17	2,7	230
	-15	4,47	1,63	7,96	7,28	2,14	2,7	235

b - interior spaces filled with; c - ambient temperature, °C; d - U, v;
 e - I, a; f - E, v; g - N_{e1} watts; h - R_{in} , ohms; i - R_{ex} , ohms;
 j - Δt , °C; k - argon; l - xenon.

After the tests were conducted, the interior of the isotopic heat source was filled with argon, and from 1965 until the present the Beta-2 generator has been in operation on the grounds of an experimental meteorological station near Moscow under natural climatic conditions.

The placement of the generator in an underground bunker (Figure 6) filled with soil made it possible to reduce the effect of ambient air temperature on the operating cycle of the thermal converter, thus providing some stabilization of the output electrical parameters of the isotopic power source.

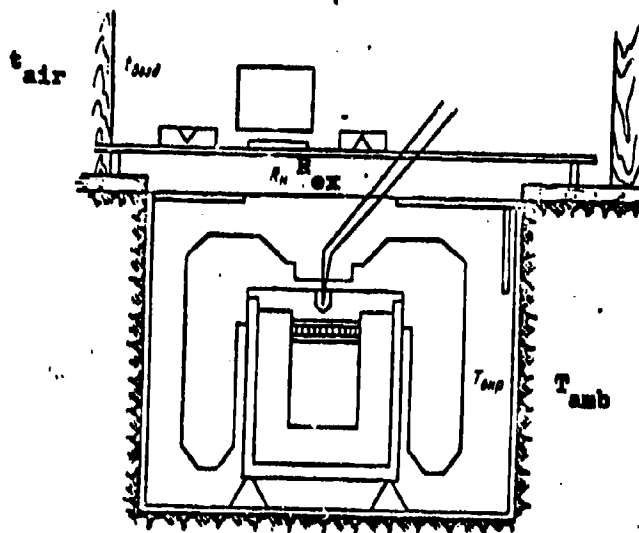


Figure 6. Diagram of the Installation of the Beta-2 Generator Under Operational Conditions.

The data from measurements of electrical parameters carried out over the course of a year are given in Figure 7. As is evident from the chart, the slope of the temperature curve for cold junctions of the thermal generator, T_x is somewhat less than the slope of the temperature curve for the ambient x medium over the same intervals, which indicates some stabilization of the temperature of the air surrounding the isotopic power source.

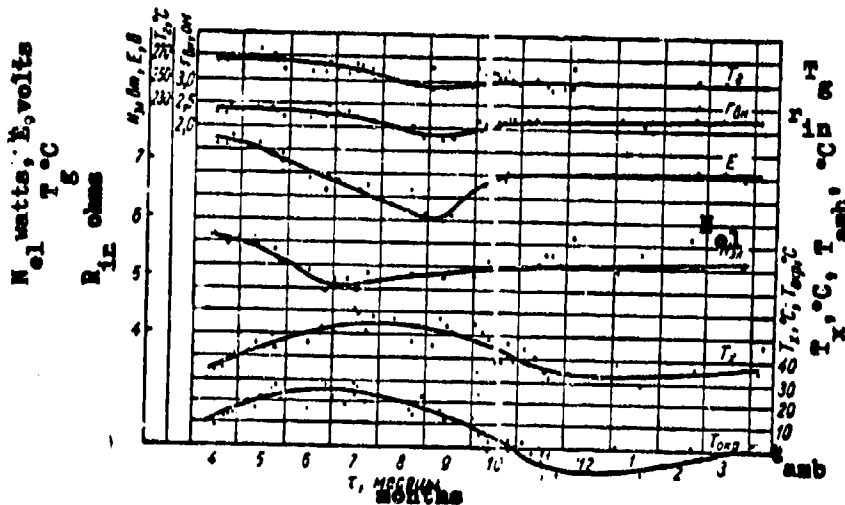


Figure 7. Experimental values of the Electrical Parameters of the Generator Over Time.

Thus we can conclude that the isotopic power source operated normally throughout the entire period of operation.

Changes in the load of plus or minus 0.2 ohms from the nominal value of 2.7 ohms had practically no effect on the output power. The generator operated in the maximum range indicated by the characteristic $N_{el} = f(R_{ex})$.

A drop in electric power by 10% at the end of one and one-half years of use is explained by a reduction in the heat flow to the thermal converters caused by lower heat output due to the decay of the radioactive compound, and also due to the increase in heat losses through the insulation.

Power supplied to the automatic radio meteorological station operating in discrete mode in combination with the Beta-2 isotopic power source was provided by a system consisting of a semiconductor voltage converter and an electric power storage apparatus using a KNG-10D battery.

The voltage converter operated reliably throughout the operating life of the generator and had satisfactorily high efficiency.

The output voltage of the converter changed slightly as a function of the degree of charge of the batteries and the ambient temperature. When the automatic station or equivalent resistive load was in operation the voltage on the battery and at the output of the converter changed correspondingly.

Figure 8 shows curves of the operating voltages of the isotopic generator battery and the efficiency of the converter over a time t equivalent to one cycle of station operation.

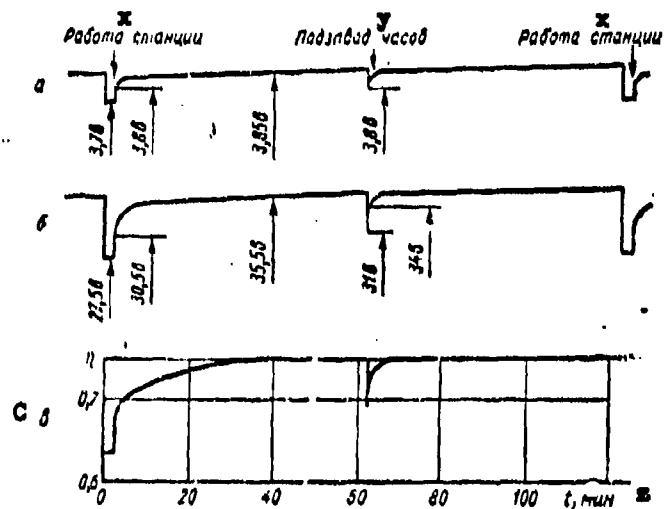


Figure 8. Changes in the input voltage of the converter (a) output voltage of the battery (b) and converter efficiency (c) during a station operating cycle.
 x - station operation; y - clock tick; z - t, minutes

Experimental operation of the Beta-2 isotopic thermal electric generator showed that the installation is reliable in use, and the generator design and biological shielding provide the necessary radiation safety if the generally accepted rules for working with closed sources of ionizing radiation and the rules for use are observed.

Thanks to its high reliability the generator can be used to supply electrical apparatus of various types for service periods of not less than 5 years.

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2. Kazakov, Ye. A., *ibid*, page 313.