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**OPERATIONAL CHARACTERISTICS OF THE BETA-1
AND BETA-2 ISOTOPIC THERMOELECTRIC
GENERATORS**

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**Army Foreign Science and Technology Center
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TRANSLATION

ENGLISH TITLE: Operational Characteristics of the "Beta-1" and
"Beta-2" Isotopic Thermoelectric Generators

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ABSTRACT:

The "Beta-1" and "Beta-2" experimental isotopic electrical generators, used as power sources for the ARMS-N Automatic Radio Meteorological Station, were created to check out a number of theoretical premises and design features upon which they are based.

The "Beta-1" and "Beta-2" isotopic thermoelectric generators consist of the following basic components: isotopic and thermal units, a thermopile unit, the housing, a biological safeguard, a thermodischarge system, as well as the generation and storage of electrical energy.

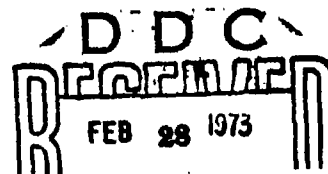
The experimental operation of the "Beta-2" isotopic thermoelectric generator showed that the installation was reliable in its operation and that the design of the generator and the biological safeguard provide the necessary radiation safety—observing the widely accepted rules for operating the covered ion-emission sources and the rules for operation.

Thanks to its high reliability, this generator may power electrical systems for various purposes with a service life of more than 5 years.

KEY WORDS:

Isotope
Thermoelectric generator
Industrial specification
Electric property

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The "Beta-1" and "Beta-2" experimental isotopic electrical generators, used as power sources for the ARMS-N Automatic Radio Meteorological Station, were created to check out a number of theoretical premises and design features upon which they are based.

During the construction of these isotopic thermoelectric generators, the utmost attention was given to the following problems:

1. the use of highly effective thermal insulation and semiconductor materials with a maximum energy factor for a given temperature range, as well as providing minimum thermal resistance in a portion of the thermal flow from the isotopic element to the thermopile and from it to the surroundings to get a highly efficient installation;
2. provision of a set level of ion emission with a minimum overall index selecting an efficient configuration, using highly effective shielding (tungsten, lead) and a separate biological safeguard in the form of two containers (functional and transport);
3. provision of maximum safety by using a slightly soluble "fuel" compound and special materials (from which the isotopic element is made), its hermetization, etc., which would make it practically impossible for radioactive matter to get into the surroundings;
4. guaranteed safety in operation by using a thermopile unit and special materials and a simple design with no moving parts, etc.

The "Beta-1" and "Beta-2" isotopic thermoelectric generators consist of the following basic components: isotopic and thermal units, a thermopile unit, the housing, a biological safeguard, a thermodischarge system, as well as the generation and storage of electrical energy.

During manufacture of the installation, independent and complex power sources were covered, including: an external examination and control of the installation to determine thermal efficiency; determination of volt-ampere characteristics of the thermopiles at given temperatures

for hot and cold seals; a check of the hermetic state of the housing's internal chamber; determination of the temperature drop between the surroundings and the cold seals of the thermopiles; a check of the system for storing electrical energy with a semiconductor voltage transformer; feeding power to the isotopic thermoelectric generators from an electrical storage system in the ARMS-N automatic radio meteorological station; determination of the effectiveness of the biological safeguard; and the measurement of calories for the isotopic element.

After charging the generators from the isotopic elements, removing the control parameters and registering with the interdepartmental commission, they were installed for experimental operation at a weather station in the city of Khimki.

Experimental Operation of the "Beta-1" Generator. On January 4th, 1964, the generator was hooked up to the ARMS-N automatic radio meteorological station located at an experimental meteorological site. It was set in a shaft 1 meter deep and 1 1/2 meters in diameter. During operation, the following parameters were measured: thermoelectromotive force in relation to in the input of the voltage transformer, power in the thermopile-voltage transformer, charge in the storage system, voltage in the input of the electrical storage system and the temperature of the surrounding air.

In Figure 1, a decrease in thermoelectromotive force in relation to time [$E = f(\tau)$], is shown. Figure 2 illustrates the change in the generator's electrical power.

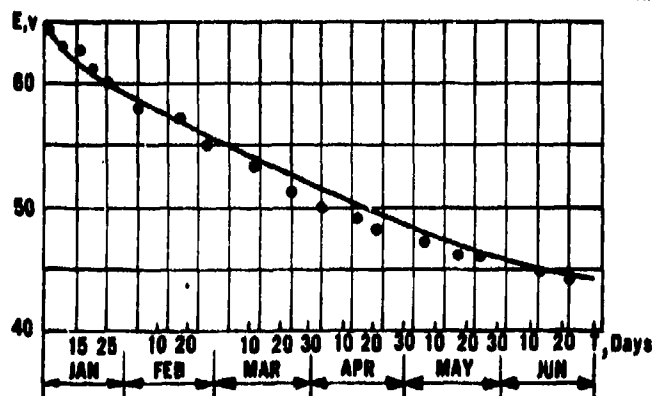


Figure 1. Relationship of the "Beta-1" Electric Generator's Thermoelectromotive Force To Time.
 — - design data; • - experimental results.

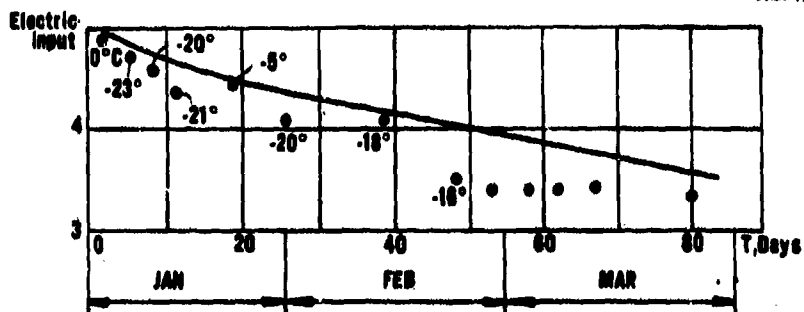


Figure 2. Relationship of the Isotopic Thermoelectric Generator's Power Output to Time. Same symbols as in Figure 1.

It is clear from Figures 1 and 2 that, at the beginning of the service life, the experimental values agree fairly well with the calculations in the amount of error in measurement. Later on, some discrepancy is observed between the experimental data and the calculations which, apparently, is explained by the increased thermal loss due to a disruption of the hermetic state of the generator's housing. The maximum error in the measurement of power was not more than 5% and not more than 3% for the thermoelectromotive force.

In Figure 3, the change in time for the internal and load resistance of the thermoelectric transformer is shown. The maximum error in their measurement did not exceed 7.5% and 5%, accordingly.

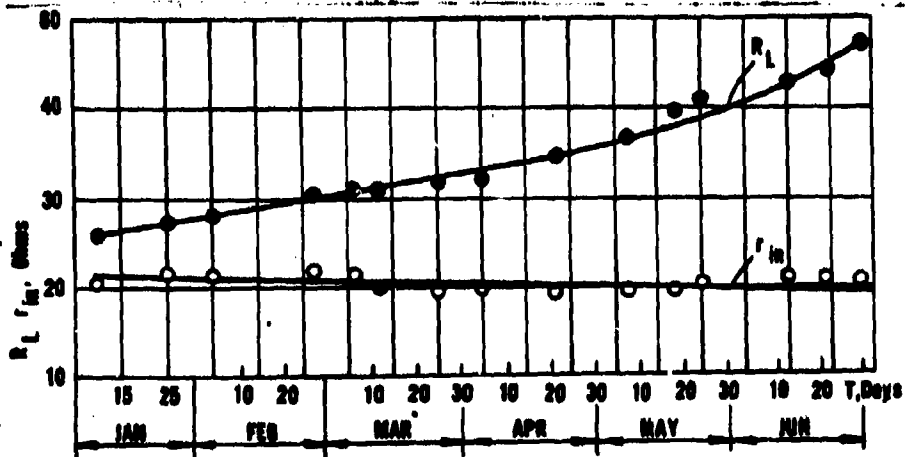


Figure 3. Relationship of the Thermoelectric Transformer's Internal (r_{in}) and Load (R_{load}) Resistance to Time in the Generator's Operation: ———— design data; ●, ○ - experimental results.

Some of the decrease in internal resistance is explained by the temperature drop in the thermopile. The increase in load resistance (incoming resistance for the voltage transformer) is caused by a decrease in the power fed into the voltage transformer.

In Figure 4, the change in the maximum efficiency (η_{max}) of the voltage transformer, the voltage charge (U_{batt}) in the storage battery and the incoming voltage (U_{in}) for the transformer during the generator's operation are plotted. To estimate the voltage transformer's efficiency, the maximum error in measurement was considered -- depending on the temperature of the surrounding air (it didn't exceed 3%).

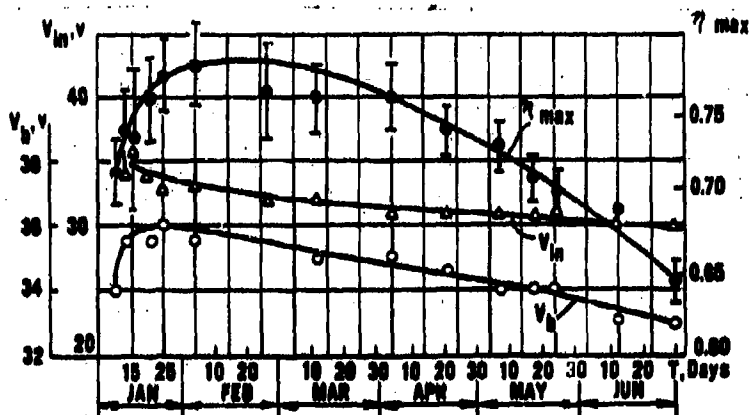


Figure 4. Changes in the Voltage Charge of the Battery U_{batt} and the Incoming Voltage U_{in} of the Transformer.

The voltage transformer performed reliably during the service life of the generator and was quite efficient.

There was a lack of voltage fluctuation in the semiconductor transformer due to the opposite electromotive force of the storage system.

To decrease the generator's power output for the purpose of providing a balance between the energy required by the station and the energy accumulated in the storage battery, the ARMS-N's rate of operation was changed every 1st, 3rd, 6th, 8th and 12th hour.

Experimental Operation of the "Beta-2" Generator. On December 3rd, 1964, the "Beta-2" thermoelectric generator was put into operation with the thermopile unit dismantled from the "Beta-1" generator. This unit had already operated 4,300 hours and had generated some 25,000 watt-hours of electrical energy.

The "Beta-2" generator's power output is shown in Figure 5.

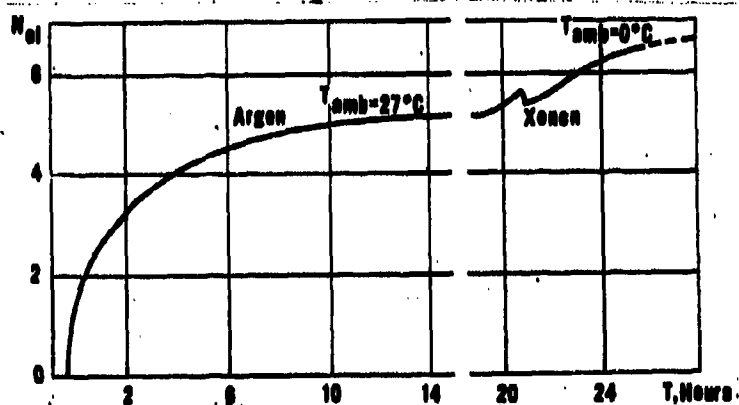


Figure 5. Steady Output of the "Beta-2" Generator. Load corresponds to rate of maximum efficiency
 $R_{norm} = 2.7$ ohms. Thermal power $Q_0 = 148 \pm 8$ watts.

In the electrical circuit of the generator, it was foreseen that a protective interlock would be needed in the event that there was a break in the thermoelectric transformer's live wires. This was especially important at the start of the generator's service life, since the temperature of the transformer's hot junction was close to the temperature for melting the switching alloy. Circuit breaking leads to an increase in the hot junction's temperature, due to the Peltier effect, and may put the thermopile unit out of commission.

Operation of the "Beta-1" installation, with continuous recording of the outgoing electrical parameters for the isotopic thermoelectric generator, permitted determination of the change in efficiency of the installation in relation to time.

The efficiency of the thermoelectric transformer, when the thermal unit in the generator was almost loaded, was 5.8%. By decreasing the thermal flow through the thermopile, the amount of efficiency dropped. Thermal flow through the thermopile was considered in determining the "effective" thermal efficiency. The efficiency for the thermopile and the isotopic thermoelectric generator is set forth in Table 1.

TABLE 1. RELATIONSHIP OF THERMOPILE AND ISOTOPIC THERMOELECTRIC GENERATOR EFFICIENCY TO TIME OF OPERATION AND THERMAL FLOW

Time of Operation, in days	Thermal flow Q, in watts	Thermopile Efficiency in %	Isotopic Thermal Generator Efficiency	Air Temperature, in °C
21	128	5.35	3.75	0
33	125	4.83	3.36	-6
48	121	4.82	3.15	-20
53	116	4.35	2.9	-16
67	112	4.67	3.08	-1
90	108	4.3	2.83	-1

After a steady output of argon, the generator had the following electrical parameters (measured at the temperature of the environs $T_{env} = 27^{\circ}\text{C}$):

Voltage U, in volts	3.8
Current I, in amperes	1.364
Electromotive force E, in volts	6.92
Electrical power N_{elec} , in watts	5.19
Internal resistance r_{int} , in ohms	2.3

In filling the generator's internal chamber (mounted outdoors) with xenon at the temperature of the environs $T_{env} = 0^{\circ}\text{C}$, its power increased to 6.8 watts.

The basic parameters of the isotopic thermal-electric generator, for various temperatures in its surroundings, are set forth Table 2.

TABLE 2. BASIC PARAMETERS OF THE "BETA-2"

Filler	T_{amb} °C	In volts	In amps	in %	N_{elec} Watts	r_{int} Ohms	R_{load} Ohms	T , °Centigrade
Argon	+27	3.8	1.36	6.72	5.18	2.3	2.7	193
	0	3.83	1.42	7.0	5.42	2.24	2.7	205
	0	4.28	1.58	7.12	6.78	2.24	2.7	228
Xenon	-6	4.36	1.61	7.4	7.08	2.2	2.7	220
	-3	4.4	1.62	7.72	7.14	2.17	2.7	230
	-15	4.47	1.63	7.96	7.28	2.14	2.7	238

After checking the internal capacity of the isotopic thermoelectric generator, it was filled with argon and the "Beta-2" operated from April, 1965, until recently at an experimental meteorological station near Moscow under actual climatic conditions.

Installation of the generator in a bunker (Figure 6) deep in the ground reduced the effect of the outside air temperature on the operation of the thermotransformer and provided a set stabilization electrical output parameters of the isotopic thermoelectric generator.

Measurement of these electrical parameters over a year's period of time is shown in Figure 7. It is clear from the graphs that the angle of the temperature curve for the cold junction of the thermogenerator T_{cold} is somewhat less than the temperature curve for the corresponding environs T_{amb} , which indicates some kind of air temperature stabilization for the isotopic thermoelectric generator's surroundings.

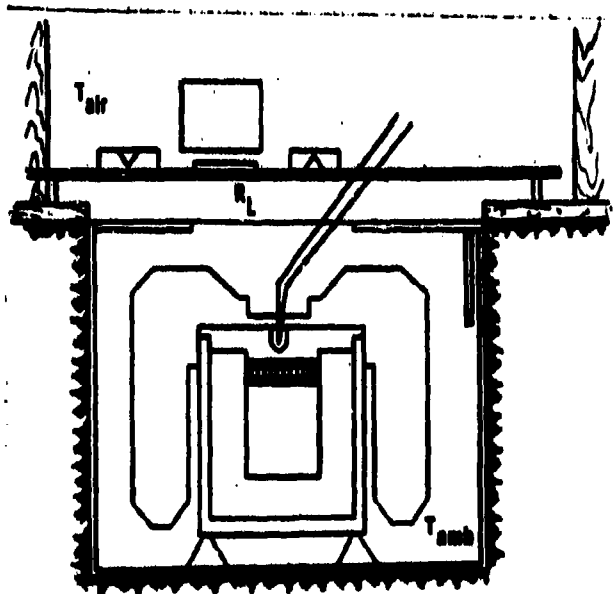


Figure 6. Diagram of the "Beta-2" Generator Installation in an Operational State.

Thus, it is possible to conclude that, throughout its service life, the isotopic thermoelectric generator operated normally.

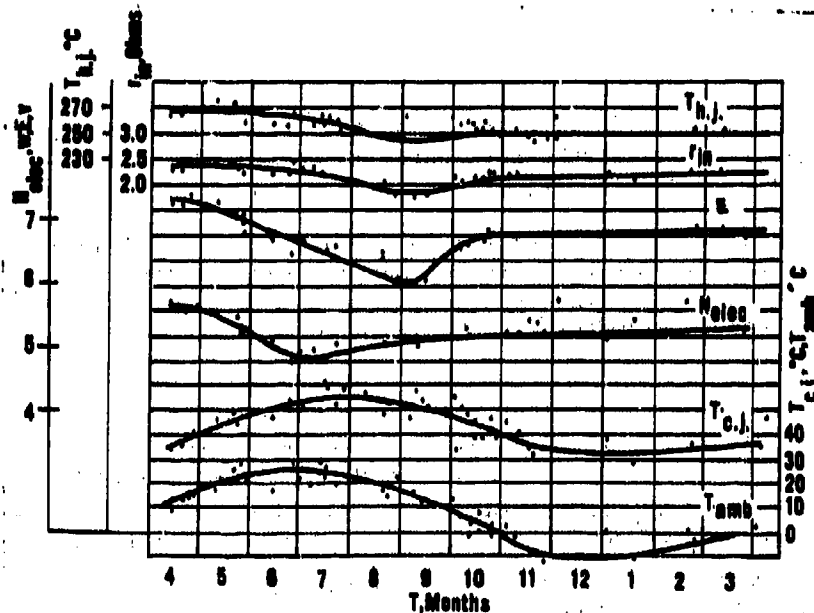


Figure 7. Experimental Estimates of the Generator's Electrical Parameters in Relation to Time.

A change in the load in the amount of ± 0.2 ohms from the normal value of 2.7 ohms was hardly effected in the power output. The generator operated at near maximum, indicated by the characteristic $N_{elec} = f(R_{load})$.

A decrease in electrical power by 10% at the end of 1 1/2 years of operation, in comparison to the initial value, is explained by the decrease of thermal flow in the thermopile due to less thermal release because of decay of the radioactive compound, as well as due to an increase in thermal leakage through the insulation.

Power for the automatic radio meteorological station using the "Beta-2" isotopic thermoelectric generator complex was provided at a discrete rate by a system consisting of a semi-conductor voltage transformer and a KNG-10D storage battery.

The voltage transformer operated reliably throughout the generator's service life with great efficiency.

The transformer's voltage output changed very little in relation to the extent of the battery's charge and the temperature of the surroundings. At the moment of operation for the automatic station or dummy load of voltage in the storage battery and in the transformer's output were changed accordingly.

In Figure 8, plots of the operational voltage in the isotopic generator's storage battery and the transformer's efficiency for one period of time t for the station's operation are set forth.

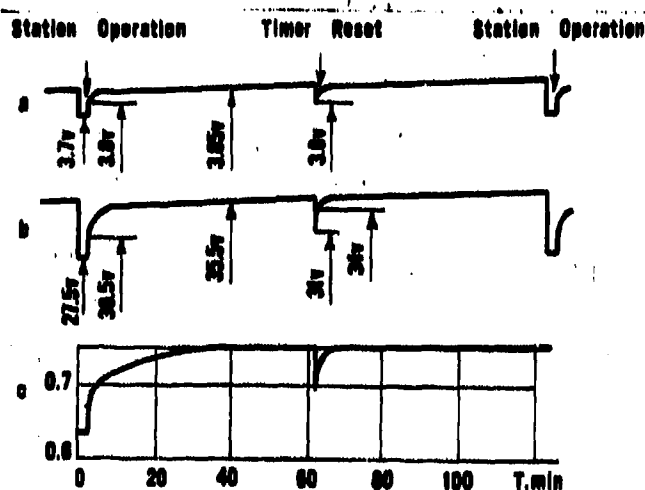


Figure 8. Character of Change for the Period of the Station's Operation in Incoming Voltage for the Transformer (a) Outgoing Voltage of the Battery (b), and the Efficiency of the Transformer (c).

The experimental operation of the "Beta-2" isotopic thermoelectric generator showed that the installation was reliable in its operation and that the design of the generator and the biological safeguard provide the necessary radiation safety -- observing the widely accepted rules for operating the covered ion-emission sources and the rules for operation.

Thanks to its high reliability, this generator may power electrical systems for various purposes with a service life of more than 5 years.

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