Федеральное государственное унитарное предприятие
НИИ НПО "ЛУЧ"

НАУКА И ИННОВАЦИИ

РОСАТОМ

ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

Betavoltaic Power Source based on Nickel-63 Isotope

Speaker: Mokrushin Andrey

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Basic Premises for Modern Development of Nuclear Batteries

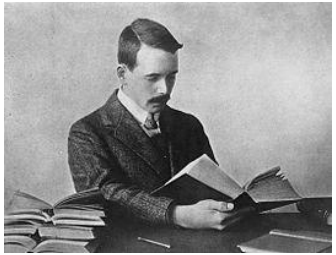
Distribution. Each element has its own power supply.

Service life comparable to that of the device (from several months to decades

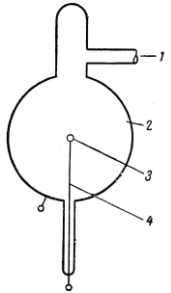
Miniaturization

Self-sustainment. Independence of external power sources

Operability in a wide temperature range.

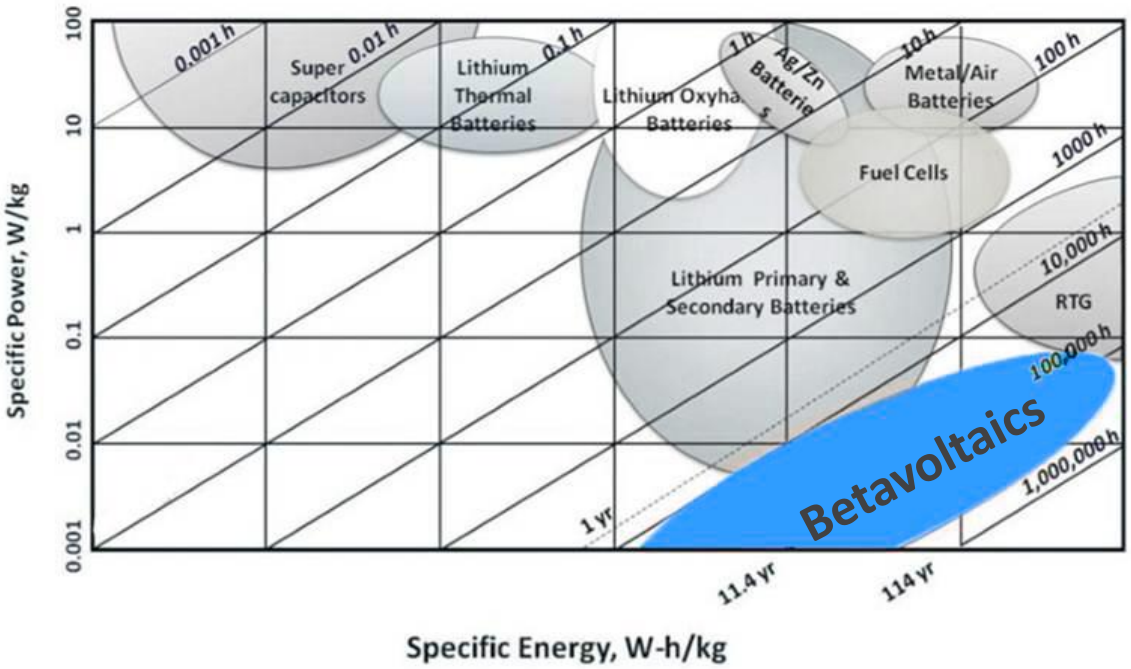


Henry Moseley (1887-1915) is the creator of the first vacuum β– voltaic cell in 1913



Moseley's Beta-Cell

Why the β-voltaics

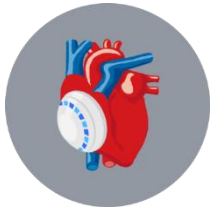


- Power sources with β-excitement (Ni-63; T; Sr-90, Pm-147) take the lead in the energy stored 3×10^5 – 2×10^7 W·hour/kg.

- In terms of specific power, 100 – 10000 W/kg capacitors are unsurpassed.

- Combining the functions of the capacitor and self-charger in a single device provides an opportunity to create a next-generation power source.

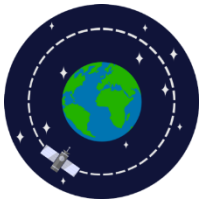
Applicable for:



Medical technologies

Cardiac stimulators;
Neurostimulators;
Biosensors and analytical systems-on-a-chip;
Life support systems.

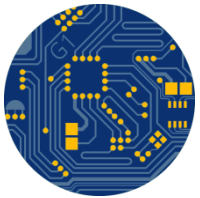
U = 5-15 V;
I = up to 80 mA (implants);
P = 400-1200 mW;



Self-sustainable systems

Submersible and surface;
Subterranean;
Space;
Geological;
Detectors of radiation and substances

U = 0.5-2.5 V;
I = 50-300 nA;
P = up to 0,75 µW;



Micro- and nanoelectronics

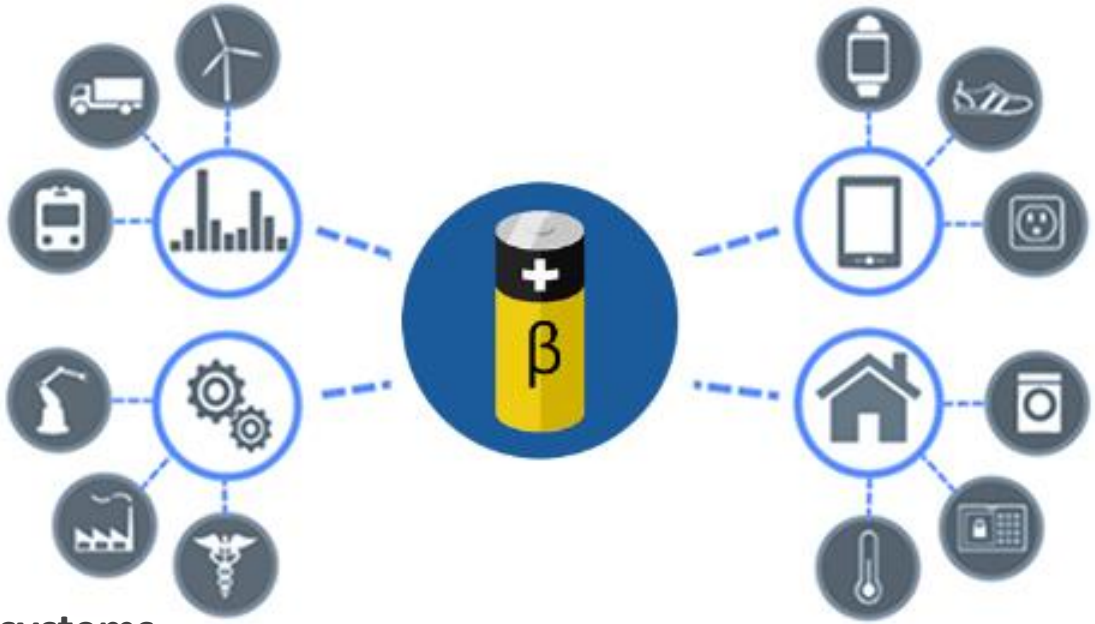
MEMS, NEMS;
Low power consumption microchip systems;
Power-independent memory.

U = 2.5-3.5 V;
I = up to 4 mA;
P = up to 12 mW;

Promising Areas of Application

Industrial Internet of Things

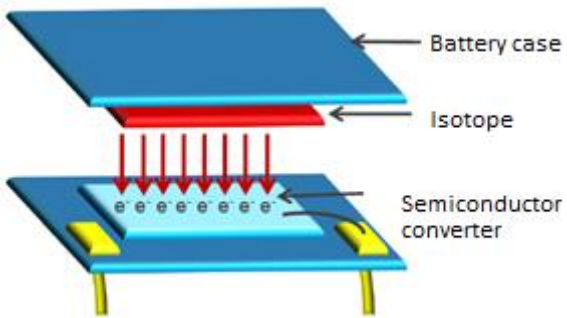
Portable devices



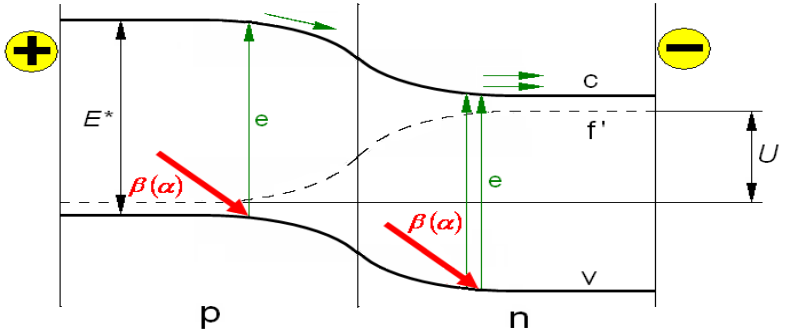
Implanted devices

Self-sustainable systems

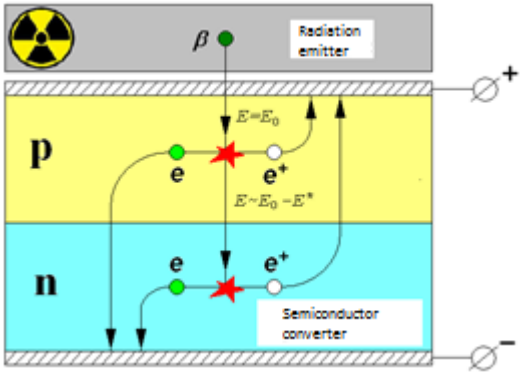
Schematics and Principle of Operation of the Betavoltaic Power Source



Schematics of a betavoltaic power source



Energy diagram for the p–n junction

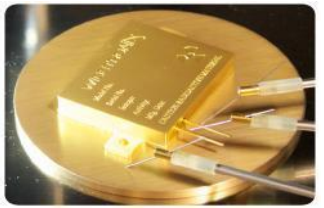


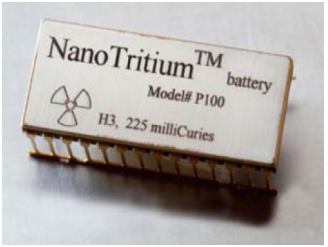
e – electron; **e**⁺ - “hole”;
E – energy of a β-particle;
E* - semiconductor bandgap width

Formation of excess carriers near the p-n junction

Состояние разработок бета-вольтаических элементов

Производитель	Тип источника	Источник ионизирующего излучения	Тип преобразователя	Выходное напряжение, В	Выходной ток, нА	Выходная мощность, мкВт	КПД, %
WIDETRONIX	Firefli-T	Тритий	SiC	2-6	-	0,010 -1	1-5
	Firefli-N	Никель-63	SiC	2-6	-	0,005-0,5	1-5
CITY LABS	28–Pin ERDIP	Тритий	GaAs	0,8-2,4	50-350	-	1-3
	LCC 44	Тритий	GaAs	0,8-2,4	50-350	-	1-3
	LCC 68	Тритий	GaAs	0,8-2,4	50-350	-	1-3
BetaBatt	Trench 2/6	Тритий	Si	4,5	-	0,1-0,5	1-5
	Trench 1/4	Тритий	SiC	4,5	-	0,4-0,6	1-5
	Film-Jelli-Roll	Тритий	AlN	4,5	-	-	1-2
	Trench 1/4	Никель-63	SiC	4,5	-	0,09	1-2





Competitive Solutions. Comparison with the Counterparts

Competitive solutions

• Chemical power sources.

- Their service life doesn't exceed 10-12 years;
- Low stored energy per unit weight (W*hour/kg);
- Narrow operation temperature range (–20; 60 °C);
- Limited number of charge/discharge cycles (~1500), self-discharge.

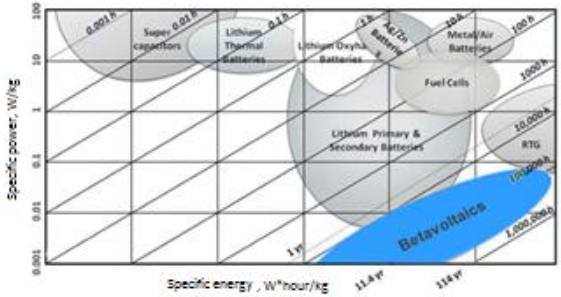
• Batteries based on alpha emitting isotopes.

- Direct conversion of the energy of alpha-particles is virtually impossible;
- Pu-238, Am-241 emit neutronic radiation as per (α,n) reaction;
- They are toxic.

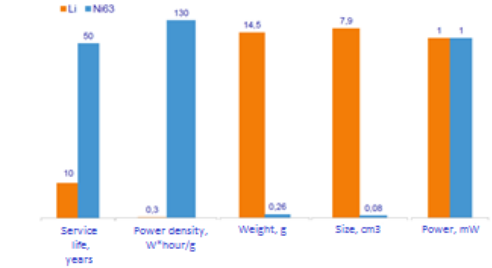
Comparison with the counterparts

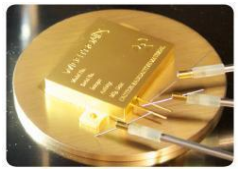
• Batteries based on beta-emitters (tritium)

- Half-life 12.3 years – insufficient service life;
- Low energy of the beta-particles results in low power specifications;
- Being a gas, tritium is not as well adaptable for production as metals



Comparison with Li-ion batteries





Radiation Emitter. Definition of the Optimal Parameters

Utilization of alpha- and beta- radioactive nuclides was considered for the power source. These nuclides were to meet the following requirements:

- The half-life is to exceed the specified service life of the power source;
- The penetrating gamma and X radiation concomitant with the nuclide's decay should be minimal;
- The emitted charged particles should not cause significant radiation-induced disruption in the semiconductor materials employed.

Parameters of the long-lived radio-nuclides

Isotope	Half-life, years	Specific weight, g/cm3	Specific activity, Bq/ $cm^3 \cdot 10^{14}$	Type of decay	Energy of decay E, MeV			Specific power w_0, $W/cm^3 s$
					Alpha	Beta	Gamma	
Cadmium-113m	14	8,6	7637	β	–	0,19	–	2,3
Cesium-137	30	1,90	618,6	β	–	0,19	–	0,19
Nickel-63	96	8,902	1975	β	–	0,17	0,0048	0,54
Lead-210	22	11,34	3230	β	–	0,038	<0,001	0,2
Radium-228	5,8	5,5	5698	β	–	0,017	–	0,36
Samarium-151	90	7,52	549	β	–	0,020	–	0,017
Strontium-90	29	2,54	1315	β	–	0,20	–	0,42
Tritium ^3H	12	$9 \cdot 10^{-5}$	$326 \cdot 10^{-5}$	β	–	0,005	–	$26 \cdot 10^{-4}$ for gas

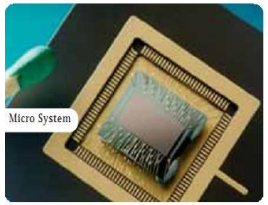
Nickel-63 radioisotope is the most promising beta-emitter. Its half-life is ~ 100 years, mean energy of the beta-particles is 17 keV. The optimal thickness is 2 microns at most.

Establishment of Production of Long-Term Service Current Sources

The experts of JSC “PA ECP” have been the first in the world to develop and implement the fabrication process of gas centrifuge enrichment of nickel by ^{63}Ni isotope.

In 2018 a pilot batch of the products with an enrichment of over 69% was fabricated. The products were delivered to the Customer – FSUE “MCC”. They will be used for development of long-term service current sources – service life of up to 50 years.

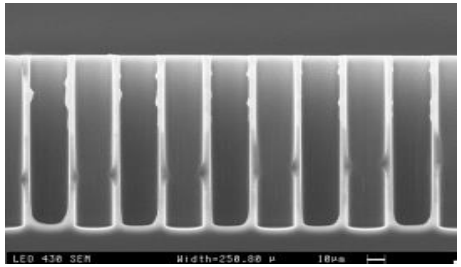
Production of nickel with an enrichment of over 80% by ^{63}Ni has been scheduled for 2020.



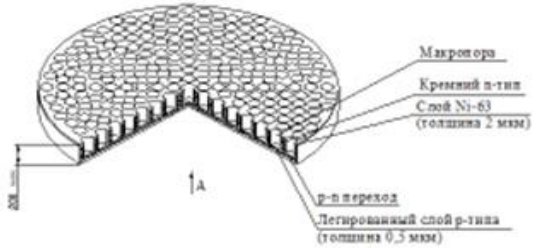
^{63}Ni

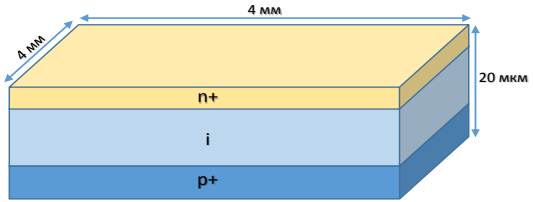
Nickel-based current sources of long-term service (up to 50 years) outperform the modern lithium ion batteries by a factor of tens.

Beta-Radiation Converter



The short-circuit current is defined by the intensity of formation of the electron-hole couples, and the open-circuit voltage is defined by the features of the rectifying contact, in particular, by the bandgap width and the crystallography of the semiconductor.



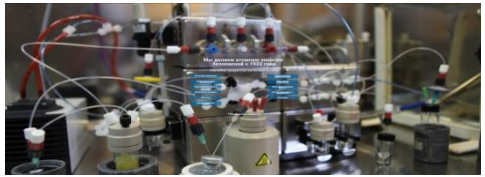


The following beta-radiation semiconductor converters (BRSCC) are proposed for development and production on the basis of:

- Silicon (Si) 3D structures with a developed surface (slit-type)
- Thinned-out diamond (C) converters
- Honeycomb structure of aluminum nitride

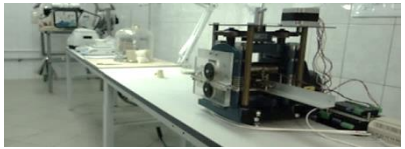
Participants /Expertise

Production and enrichment of Ni-63
JSC "PA ECP"



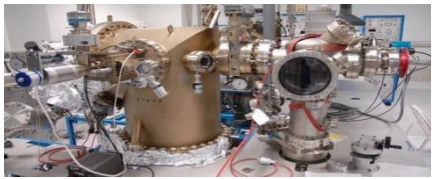
- Reactor for working gas production
- Gas centrifuges
- Apparatuses for radiochemical purification
- Mass-spectrometers

Production and studies of beta emitters
FSUE "SRI SIA "LUCH"



- Chemical and electrochemical equipment
- High-temperature furnaces (vacuum, argon, oxygen)
- Rolling machines
- Electrophysical test benches
- Systems for deposition of coatings (sputter deposition, cathodic arc deposition)

Development and studies of BRSCC, commutation and assembly of the specimens
FSUE "SRI SIA "LUCH", FSBI TISNCM, BIAPOS



- Equipment for growing of monocrystals
- XRD and materials science studies
- Scanning probe microscopy (SPM) and scanning electronic microscopy (SEM)
- Apparatus for ion-plasma alloying
- Apparatus for molecular-beam epitaxy
- Apparatus for selective etching

Parameters of the Betavoltaic Power Source in Development

Before 2020 specimens of betavoltaic power sources of various designs are going to be produced and tested. Their specifications are going to be as follows:

Laboratory test specimens:

Power of the electric generating element not less than 1.0 µW;

Power reduction in the temperature range of 0 to 60 °C not exceeding 10 %;

Nominal voltage output of the electric generating element: Uo = 1.8 – 3.0 V.

Test specimens:

“Type 1”:

Power Po not less than 5 µW.

Volume of the electric generating element (Vo): not exceeding 0.085 cm^3.

“Type 2” :

Power Po not less than 60 µW

Volume of the electric generating element (Vo): not exceeding 1.0 cm^3.

Area of Application of the Project Results

The results can be applied for the needs of:

- Space industry. The Space Research Institute of the Russian Academy of Sciences is interested in the development and provides support for the Project;
- Space, rocket and aviation engineering (in particular – application for autonomous power supply of the on-board equipment);
- Automatic control systems of the special-purpose equipment (JSC “TSNIITOCHMASH” (State Corporation “RosTech”) is interested in the development and provides support for the Project);
- Equipment for medical application (cardiac stimulators and neurostimulators)

РОСКОСМОС

ИКИ
ИНСТИТУТ КОСМИЧЕСКИХ ИССЛЕДОВАНИЙ РАН

ФГУП ЦНИИТОЧМАШ

МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ РОССИЙСКОЙ ФЕДЕРАЦИИ