NUCLEAR CELLS

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Abstract: Nuclear cells are the devices converting the energy of ionizing radiation into electricity. This project describes the types and characteristics of nuclear cells. It introduces the reader to nuclear cells, their types and applications. Then the betavoltaic nuclear cell and its components are described. As the next step the available materials will be analysed and the measuring will be performed to check the functionality of the principle.

Keywords: Betavoltaics, Ionizing Radiation, Nuclear cell, Direct Energy Conversion, Radioactivity

1 INTRODUCTION

One of the most important discoveries in the last centuries was the existence of ionizing radiation. There are many effects of that force, positive and negative ones. There is a big potential hidden inside the radioactive materials that humanity is trying to use to its benefit. This project introduces the reader to the topic of nuclear cells, which are the devices converting the energy created by radioactive decay into electricity.

This project describes the possible ways to convert ionizing radiation into electricity, its effectiveness and individual types. The betavoltaic nuclear cell and its components are discussed. After describing the betavoltaic battery work principle, the radiation source and the converter are analysed. The detailed analysis and theoretical background are available in my semestral thesis [1]. The measuring in the laboratory was performed using alpha and beta radiation sources and several semiconductor materials to check if it's possible to acquire sufficient results.

2 NUCLEAR CELL OVERVIEW

Nuclear cells can be divided, based on the principle of the energy conversion. The idea behind Direct Charging Battery is that the radioactive material emitting alpha or beta radiation is placed inside or near one plate of the capacitor, charging it negatively when using beta emitter or positively when using alpha source. Between the plates of the capacitor, where the output voltage of the battery appears, is placed dielectric material or vacuum. Direct Charging Batteries produce very high voltages (up to hundreds of kilovolts) with extremely small currents (nA). Direct Conversion Batteries use alpha and beta radiation interaction with semiconductor's p-n junction. The alpha or beta particle creates electron-hole pairs while traveling through the semiconductor. A proper radioactive source as well as semiconductor material must be chosen to assure the radiation interaction with the p-n junction. Indirect Conversion Batteries first convert the radiation into different type of energy which is later converted into electricity. The form of energy between conversions can vary depending on the technology used. Thermal conversion power cell converts radioactive energy from fuel into heat. The heat is then converted in Thermal Conversion Generator into electricity. Radioisotope Thermoelectric Generator uses thermocouplers for that conversion.

3 NUCLEAR CELL PROPOSAL

The components of betavoltaic batteriesare described below, aspects and their possible material and usability. The typical betavoltaic power source is composed of radiation source, converter that converts radiation energy into electricity and electrical circuit, which enables the electricity measuring and application. Betavoltaic battery also usually includes shielding from radiation, mechanical protection and may include filters between the radiation source and converter to stop unwanted particles. In general, betavoltaic cells work mechanism is very similar to widely known photovoltaic one with the difference, that instead of photons, the electron-hole pairs are produced by beta particles.

3.1 RADIATION SOURCE

The radiation source used must fulfil several requirements, most important ones are the following: high decay energy over lifetime, low beta particle energy and pure beta particles emission. The suitable sources are listed in Table 1.

Parameter	Isotope				
	Tritium ^{3}H	Nickel-63 ^{63}Ni	Promethium-147 ^{147}Pm	Strontium-90 ^{90}Sr	Krypton-85 ^{85}Kr
Half-life $T_{1/2}$ (year)	12.32	100.1	2.62	28.9	10.56
Decays into	Helium-3	Copper-63	Samarium-147	Yttrium-90	Rubidium-85
Max energy (keV)	18	67	225	540	687
Avg. energy (keV)	5.7	17.4	62	198	251

Table 1: Suitable isotope for betavoltaic batteries, specifications and parameters

3.2 CONVERTER

The converter is a semiconductor that absorbs the energy of the electrons from the source by creating electron-hole pairs. The electrons passing through the p-doped region leave part of their energy in the material, creating electron-hole pairs. Freed electrons travel to the space charge region, creating positive charge on the electrode of the semiconductor. For the pair created in n-doped region, this mechanism works inversely. The electrons created in depleted region recombine, causing current to flow. Depending on the material of the semiconductor, the specific wavelengths of electromagnetic radiation can be converted. For betavoltaic applications, the semiconductors with III-V compounds like gallium arsenide or gallium phosphide are usually chosen.

4 AVAILABLE OPTION AND MEASURING RESULTS

To prove the theory, measuring in the laboratory was realised. The available radiation sources were Krypton-85 which is the source of the beta radiation and Americium-241 which emits alpha particles. The measuring was performed using shielding blocks, protective gear and measuring devices. The radiation source was placed in the shielding container built using the shielding blocks and semiconductor materials were being exposed one by one to the radiation. Meanwhile, the measuring using dosimeter was carried out to check for measurement safety. Each semiconductor was attached to the voltmeter to measure output voltage of the device before and after the radiation exposure. The experiment layout is shown in Figure 1. The measuring was realised in the afternoon, which resulted in direct sunlight lighting the laboratory. There were no curtains available and the radioactive materials could not be carried out of the laboratory.

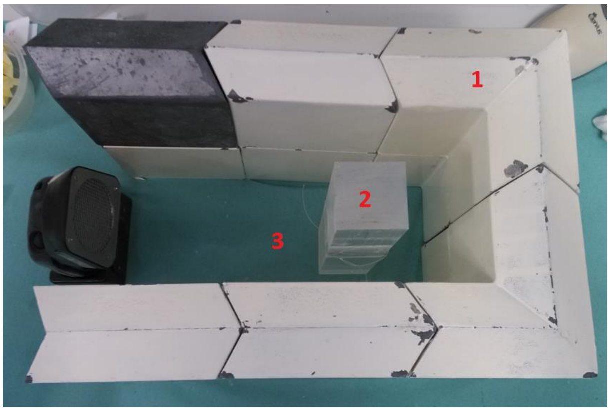

Figure 1: Experiment layout including shielding container (1), radiation source holder (2) and space for semiconductor insertion (3).

The results of the experiment were different than expected, mostly because there was too much light in the room that caused semiconductors to act as photovoltaic devices. While measuring solar cells (shown in Figure 2), the only measured difference was the reduction of the heat humming, causing the measured voltage to drop (approach zero) while the measured cell was near the radiation source. This was caused by the creation of new recombination centres in the semiconductor by the radiation interacting with the cell. While measuring the coil, PIN diode or power semiconductor (shown in Figure 2) no noticeable change of voltage was detected.

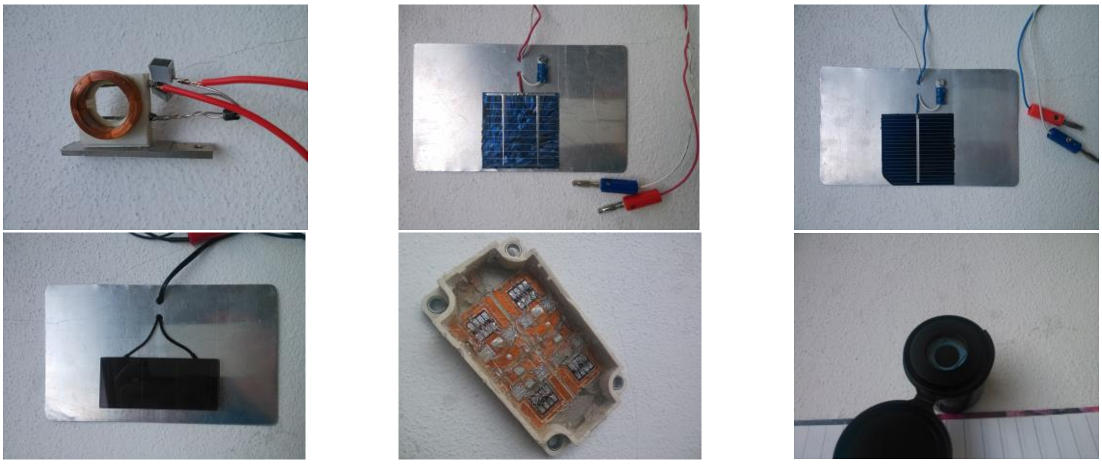

Figure 2: Coil with 1500 threads (top left), polycrystalline solar cell (top centre), monocrystalline solar panel (top right), amorphous solar cell (bottom left), power semiconductor (bottom centre), PIN diode (bottom right)

5 SUMMARY

The purpose of this project was to theoretically and experimentally prove the functionality of the nuclear cells. In theory, the principle works and can be used to produce small amounts of electrical energy. The measuring in the laboratory did not prove the theory, mostly because of the imperfect measuring conditions and available semiconductors that were too thin to convert the radiation energy. Another measuring will be performed during the semester, using more suitable components and environment.

REFERENCES

[1] KLUS, Roman. Nuclear cells Brno, BUT FEEC, 2016. 21 s. Semestral thesis supervisor: Radil Lukáš, Ing., Ph.D. [ref. 14. 3. 2017].