PRELIMINARY STUDY ON NUCLEAR BATTERIES FROM NUCLEAR WASTES

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1. Introduction

Batteries promise an era of portability as it powers devices and vehicles via electrochemical technology applying Lithium ion (Li-ion). However, its design depends mostly on the chemical properties of its electrode and electrolyte to aid the ions flow. This design faces two fatal flaws; the limited amount of material can be used to manufacture the battery and the electrolyte of most batteries being sensitive to temperature. These flaws can be overcome by tuning to nuclear electric technology such as Radioisotope Thermoelectric Generator (RTG), Stirling Radioisotope Generator (SRG) and Betavoltaics. These technologies operate under different physical processes. In this paper, betavoltaics technology is studied and emphasized on its potential and advantages over electrochemical technology.

An electrochemical cell relies on the electronegativity difference between two or more ions while a betavoltaic cell functions under the radioisotopes decay that releases beta particles (energy) to induce electrical current. This is the main advantage of betavoltaic cells as its power output is not affected by the cell pressure and temperature which makes it more versatile. This cell has an *active electrolyte* compared to electrochemical cells that has an *active electrode*. It is also known as a *non-contact electrolyte cell* because the radioisotopes do not necessarily required to contact with the electrodes to function.

The longevity of electrochemical and betavoltaic cell rely on the half-life of chemical reactions and half-life of radioactive decays respectively which has a relation to the *electromotive force* (emf) produced. The betavoltaic cell longevity could match or be orders of magnitude longer than electrochemical cell. Promethium-147 (Pm-147) having a half-life of 2.62 years which is similar to lithium cell. Longer half-lives are better however other factors must be considered such as electron energy and by-products of radioactive decay. A long half-life can be shown from the voltage measurement of the cell being relatively stable over long periods of time.

Betavoltaic cell is safer than electrochemical cell because it does not influence by chemical and thermal conditions. Therefore, runaway discharge/reaction will not occur inside the cell. This overcome the main problems facing by high energy density cells where they have the tendency to catch fire and being exploded when physically punctured or damage happened. Furthermore, beta radiation is easy to block and has low ionizing energy which makes it the “goldilocks” particle radiation source to make a nuclear battery. Betavoltaic cell offers the option of a portable and convenient energy dense source that has none of the shortcomings from chemical cells.

Nuclear waste are radioactive substances that is usually the by-product of various nuclear processes. The major source of nuclear wastes come from Industries namely nuclear medicine, nuclear research, vehicle production lines, bottling and canning and rare-earth mining. There are three types of nuclear waste, classified according to their radioactivity: Low-Level Waste (LLW), Intermediate-Level Waste (ILW) and High-Level Waste (HLW). LLW is not dangerous due to very low activity and it can be disposed easily in landfills meanwhile ILW which has higher activity than LLW but lower than HLW usually a fraction of its original activity. ILW requires some shielding when handling and long-term storage in a waste repository. Pm-147 is an example of ILW which usually used for measuring car components thickness.

Producing radioisotopes consume more time and energy. On the other hand, nuclear waste (spent nuclear fuels and decommissioned nuclear warheads) are recyclable. The remaining radioisotopes in the nuclear waste are economical enough to be recovered and reused to generate electricity. This approach is particularly well-suited to low-power electrical applications where long life of the energy source is needed, such as implantable medical devices or military and space applications. This could curb the need to build and maintain expensive repository for the radioactive waste lifetime, reduce the risk of leaking into the earth, cheaper and more powerful iterations

of betavoltaic cells become feasible.

The experiment aimed to investigate: -

a. Power and potential difference needed to light up a Light Emitting Diode (LED).
b. Power and potential difference of Pm-147 nuclear waste as beta source for a betavoltaic cell.
c. The differences in potential difference and power induced by different electrode material.
d. The changes to betavoltaic cell performance when an alpha source is introduced.

2. Methodology

The electrolyte is Pm-147 which is a solid metal under standard conditions that makes it easy to manage and use for experimentation. A digital multimeter is used to measure potential difference and electrical current. It is set to 0 - 2000 ± 1 mV and 0 - 2000 ± 1 mA respectively. An exception is made for the reference data set where the settings are 0 - 5 ± 0.001 V and 0 - 5 ± 0.001 A.

2.1 Reference System

A reference circuit is set up as a baseline data for goals needed to be achieved by a cell to light up an LED.

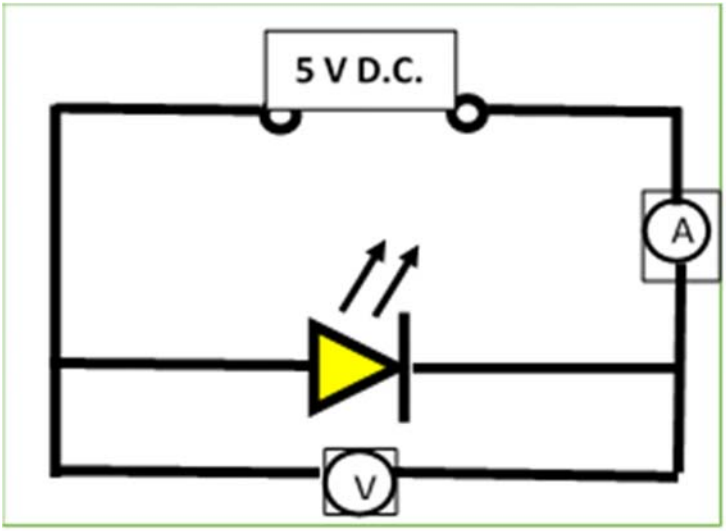

Figure 1: A 5V DC power supply is connected to a circuit with an LED. An ammeter and a voltmeter are connected to the circuit.

2.2 Betavoltaic System

In this experiment, electrode material is manipulated to investigate its effect on the potential difference and power induced in the cell.

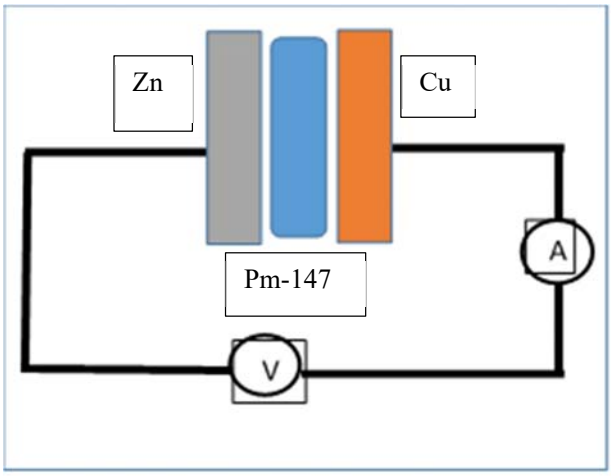

Figure 2: A betavoltaic cell is made up of Pm-147 as an electrolyte and a pair of Zn and Cu as electrodes.

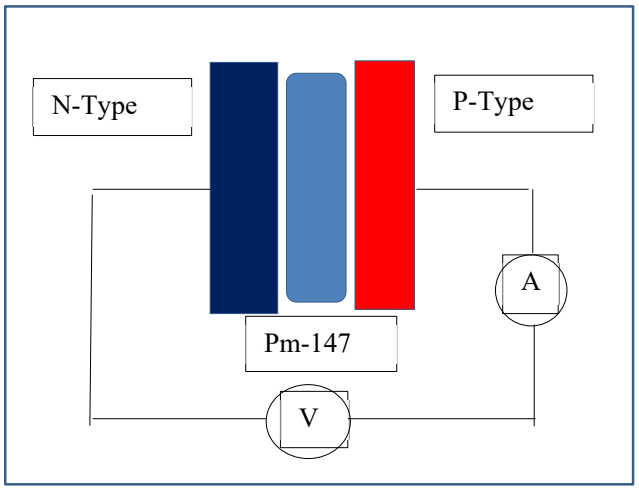

Figure 3: A betavoltaic cell is made up of Pm-147 as an electrolyte and a pair of N-Type and P-Type silicon wafers as electrodes.

2.3 Catalysed Betavoltaic System.

A complimentary particle source is added to a betavoltaic cell could theoretically improve the performance of the cell.

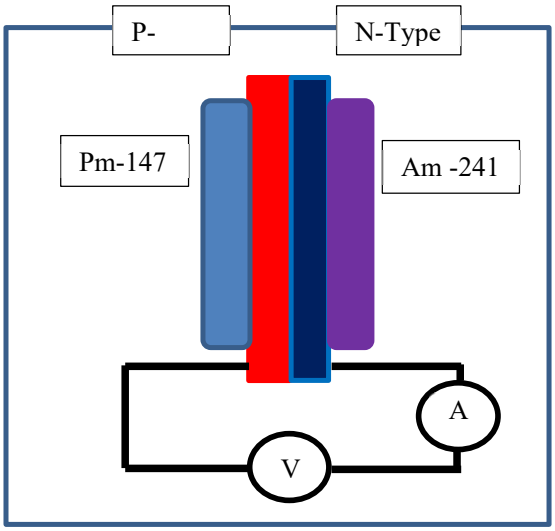

Figure 4: A betavoltaic cell is made up of Pm-147 as an electrolyte and an N-Type and P-Type silicon wafers and it's complimentary as electrodes.

3. Findings And Discussion.

First, the first experiment investigates different electrode material. The data shows electrode material has a significant effect on the output of the cell. The silicon electrode betavoltaic cell shows 25% uplift in the cell output compared to the Cu-Zn electrode betavoltaic cell. The graph shows the best fit line for silicon electrode being higher than Cu-Zn electrode. The possible reason for this, silicon electrode has lower work function than Cu and Zn electrode so it has a higher induction potential which result in a higher potential difference.

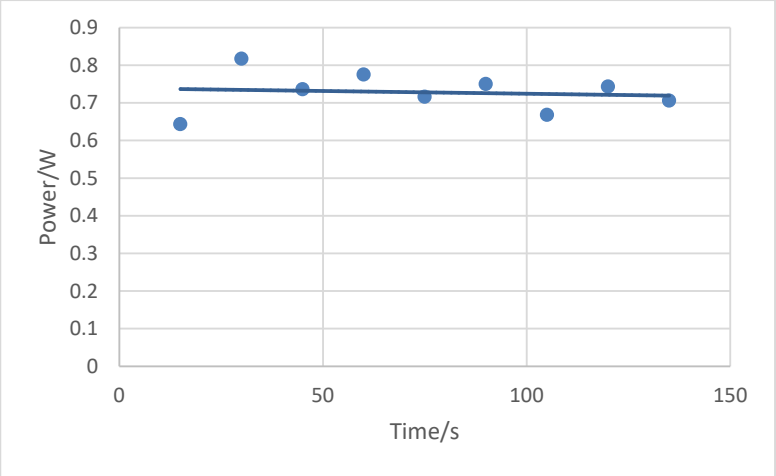

Figure 5: Power needed to light up LED against time.

Next, the second experiment aims to study the effect of an alpha source, Americium-241 (Am-241) as a catalyst to a betavoltaic cell. The data shows a more consistent potential difference induced over time which makes is a good trait for a cell. When compared to the silicon electrode and Cu-Zn electrode cells, the gradient of the

graph for potential difference is significantly lower which shows a lower rate of potential difference decay compared to uncatalyzed betavoltaic cell. The line plotted is also higher average in potential difference. This clearly shows an alpha source is accepted as an effective catalyst to the cell; thus, opposite charges of the particle sources can increase the potential difference of the cell.

However, the thickness and density of electrode may play a fundamental role as the silicon electrode was thicker and dense compared to both Cu and Zn electrodes. The silicon electrode was a pair of uncut silicon wafer while Cu and Zn electrode were in the form of thin sheets. The unequal number of atoms to stop beta particle may affect the rate of attenuation which contributes to the potential difference of the cell. To rectify this, equal thickness in number of atoms should be used to determine the potential difference of the cell when varying the electrode material.

Furthermore, the shape of the cell will affect how much particles that pass through the electrode to induce current. In the experiment, two configurations of electrodes were used, a) *electrode sandwich the electrolyte* and b) *source sandwich the electrode*. This is done due to silicon wafers had to form a P-N junction to function as electrodes which makes it act like a diode. It is noticed that the cell still operated like an electrode at low voltages which is lower than is operational voltage to become a conductor. The likely reason is that the electrons emitted and induce current is from a point like source so it is quickly impeded by resistance and hysteresis but sufficient to overcome the band gap in the junction.

Overall, the result support the initial predictions and aim of the study, regarding betavoltaic cells and the ability of nuclear waste to do useful work.

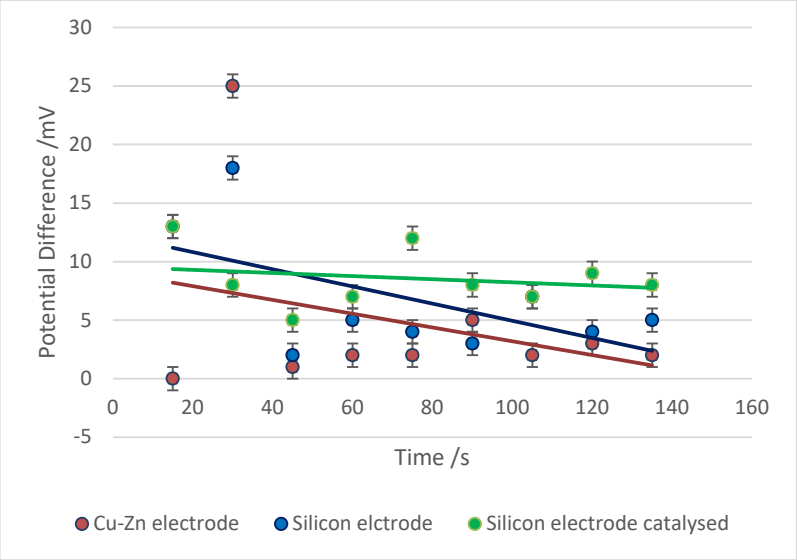

Figure 6: Comparison between Catalysed cell vs Type of electrodes.

4. Conclusion

As a conclusion, nuclear waste is a viable radioactive source of energy in betavoltaic cell. A betavoltaic cell can be made to have different electrode materials that will alter the effectiveness at converting the radiation into energy. Betavoltaic cell does not require expensive and delicate electrode materials like doped silicon wafers to produce an output. Betavoltaic cell output can be catalysed with opposite charge particle source. Nuclear waste like Pm-147 and its catalyst Am-241 is shown to produce significant output compared to uncatalysed betavoltaic cell. This study indicate that the presence of catalyst can reduce the effect of potential difference decay due to decaying activity of radioactive sources.

5. Acknowledgement

Special thanks to Mr. Shahrulnizam Mohamed Kamil, the Head of Science Department of MJSC Serting for facilitating me through this project and the officers at Malaysian Nuclear Agency (Ms. Nurhasfazilah, Mr. Muhammad Khairul Ariff Mustafa, Mr. Naim Syauqi Hamzah, Mr. Muhammad Khairulezwan Abdul Manan and Mr. Mohamad Radzuan Othman) which had helped on performing research and experiments on radioactivity.

6. References

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2. LiveChart of Nuclides – Advanced version|IAEA https://wwwnds.iaea.org/relnsd/vcharthtml/VChartHTML.html
3. Positron Dynamics - www.positrondynamics.com/
4. PH 0101 Unit-5 Lecture-81 Introduction Type of Converter in Nuclear cell Types of Nuclear cell Betavoltaic cell Thermocouple based nuclear cell – https://slideplayer.com/slide/7091349/
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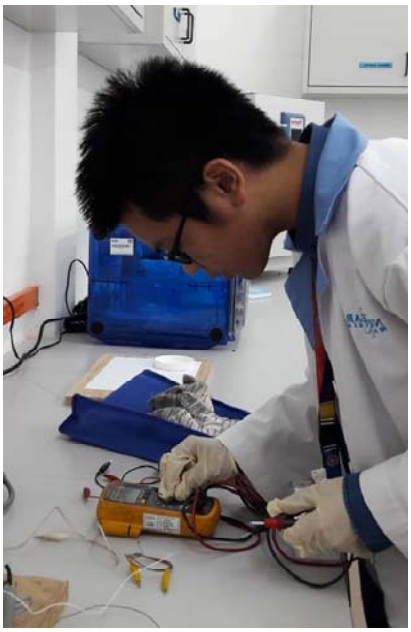
6. https://www.large.stanford.edu/courses/2013/ph241/harrison2/

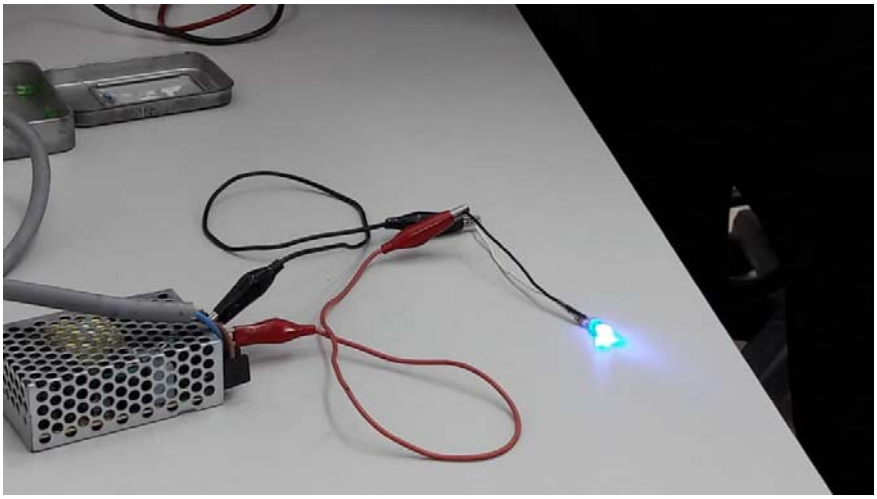
Gallery

From left to right: Am-241 samples (stored in wooden container together with black metallic disks) and a package of Pm-147.

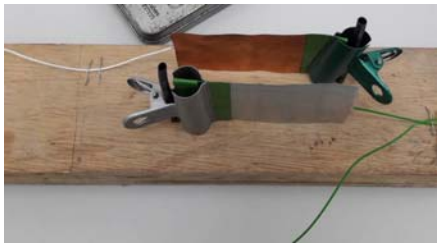
The sample was taking out from a shielded canister (left) and then was weight using a balance (right).

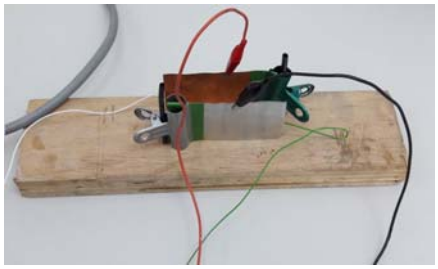


Calibration for digital multimeter used in collecting data.



Reference circuit apparatus setup.

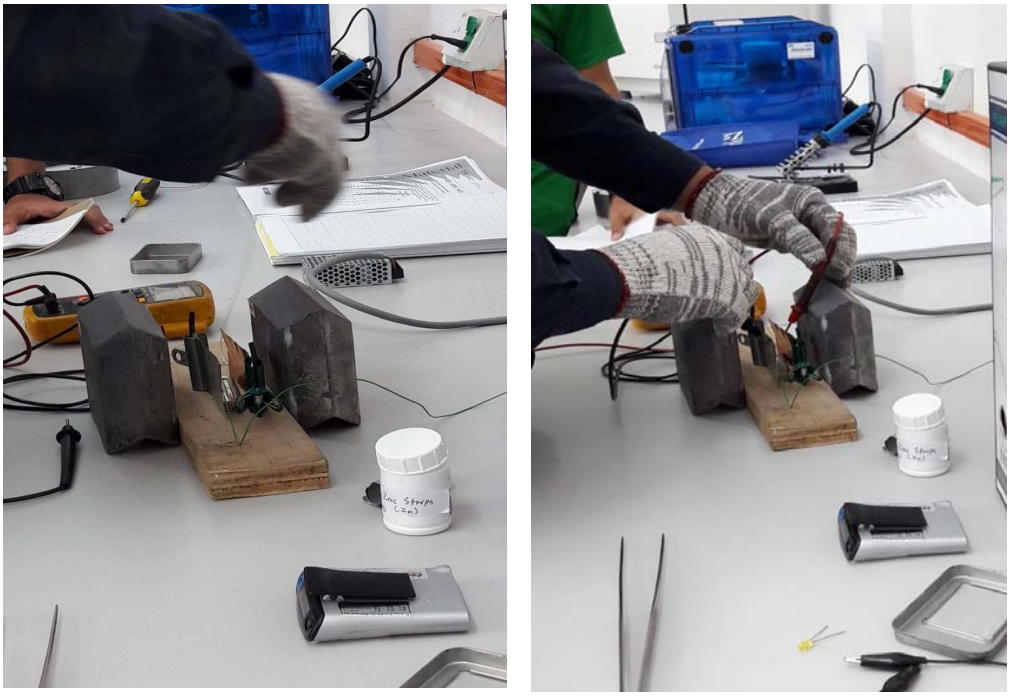




Setup of Cu-Zn electrode for betavoltaic cell.

Testing the effect of alpha-beta sources in direct contact.

Setting up the silicon electrode betavoltaic cell.



Lead blocks used as reflectors and blockers during the experiment.