Atomic Batteries Explained, How They Work, and their Applications

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Abstract — *Batteries are found in practically all mobile human inventions from the automobile to the mobile phone. This particular power source is a fundamental part of the modern world. Since the 1800's this technology has evolved quite a bit, today they can provide electricity up a few decades. In this paper we will focus on atomic batteries, their various types and benefits. Atomic batteries were first demonstrated in 1913 by Henry Moseley. In the last one hundred years the technology has diversified through arduous research by the academic, private, and public sectors. The development of various types of atomic batteries has been driven by the demand of a small sized energy source that has the capability to function for long periods of time without replacement or the need to be recharged. Some applications for this power source include space exploration, medical devices, unmanned scientific facilities, and underwater exploration probes, among others.*

Key Terms — *Atomic Batteries, Betavoltaics, Radioisotopes, Thermo-nuclear Converters.*

INTRODUCTION

Atomic batteries are known by several names, these include: nuclear batteries, radioisotope batteries, and tritium batteries, among others. They have several characteristics that set them apart from the more conventional chemical batteries. For example, one of their most valuable assets is their ability to operate without a recharge for several years; this in turn makes them suitable to be employed in harsh environments. New breakthroughs have allowed for applications in mobile devices, independently powered sensors in automobiles, medical devices and sensors in humans, sensors used to track animals, sensors used in a variety of structures such as bridges and buildings among many other applications.

TYPES OF RADIOACTIVE PARTICLES

In order to better understand atomic batteries and how this technology operates, we shall discuss the radioactive particles that allow for this energy source to work: alpha, beta and gamma. The first term we will introduce is the alpha particle, which is made up of two neutrons and two protons that are bonded together and have the exact characteristics of a helium nucleus. The alpha emitting isotopes are the most dangerous of the three types. This is due to a high relative biological effectiveness of alpha radiation that causes biological damage in living cells, which makes them anywhere from twenty to a hundred times more deadly. Alpha emitters release Helium nuclei at around four to six MeV per particle.

Second, we introduce the beta particle which is a high energy, high speed electron or positron that is emitted by certain types of radioactive nuclei. Beta emitters are a type of ionizing radiation commonly known as beta rays. The beta particle is sometimes used in medical applications such as a tracer in scans and it is even used to treat bone and eye cancers.

The third, gamma radiation, sometimes called gamma rays has high energy, high frequency, and short wavelengths. This electromagnetic radiation is also very dangerous due to its ionization properties. While the commonly known X-rays are emitted by electrons outside the nucleus, gamma radiation is emitted by the nucleus itself. Gamma rays are frequently used in bone scans for cancer detection. Radionuclide tracers in conjunction with a gamma camera are utilized to create an image and identify the spread of cancer in the bones. [1]

TYPES OF ATOMIC BATTERIES

Currently there are several types of nuclear batteries that can be considered, such as: thermionic, radioisotope thermoelectric, thermo photovoltaic cell, alkali metal thermal, alphavoltaic, direct conversion, betavoltaic, optoelectric, and reciprocating electromechanical. This list breaks down into two main types of atomic batteries: Thermal and non-thermal. [2]

In the next section, we shall discuss briefly some characteristics of the different types of atomic batteries. We will divide them into their two main groups, the first one consisting of the non-thermal converter types and the second group consisting of the thermal converters. [3]

NON-THERMAL ATOMIC BATTERIES

Non-thermal atomic batteries don't use the thermal energy produced by radiation but instead they use the radiation to induce a charge which is then converted to electricity, the process relies on natural spontaneous radioactive decay of an atomic nucleus.

Betavoltaic Nuclear Battery

In the category of non-thermal converter atomic batteries we have one of the most evolving designs which are the betavoltaics; this technology was first introduced in the 1950's by RCA. They can be used in low power electronics for continuous long operating lifetimes of up to 20 years.

Betavoltaic batteries operate by using a radioactive source that emits beta particles. Generally, tritium a hydrogen isotope is used in its gas state for this purpose. The battery employs the use of a flat silicon wafer that captures the electrons emitted from the radioactive gas. Inside this semiconducting wafer, the beta particles traveling through it leave a trail of ionization that creates a chain reaction of electron hole pairs. The wafer has a potential barrier created by applying a thin coat, made of a diode material. This material mimics the potential barrier of a p-n junction. As the radiation is absorbed, it generates the electron-hole pairs that travel through it, creating an electric circuit. Below two schematic designs are presented, Figure 1 shows the main components and Figure 2 demonstrates the process by which betavoltaic batteries operate. [4] - [5]

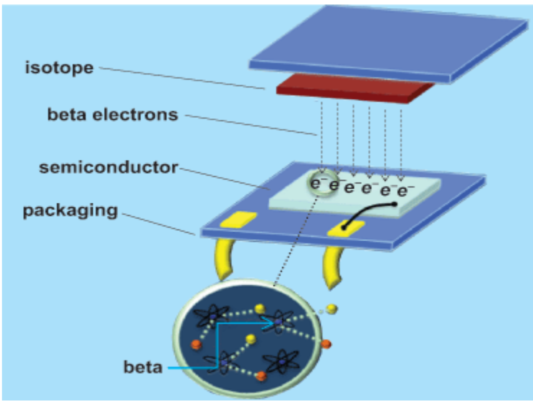

Figure 1
Schematic of Components in a Betavoltaic Battery

These batteries can operate at temperatures ranging from extreme lows at -60 degrees Celsius, all the way up to one hundred degrees Celsius. Betavoltaics can outperform the lithium cell battery's available energy, by up to a thousand times. Some advantages betavoltaics provide are that they are cost effective, safe, reliable, and can be used as constant voltage or current source. They are currently being used in several experimental models of cardiac pacemakers in over 100 cardiac patients thanks to smaller more efficient models.

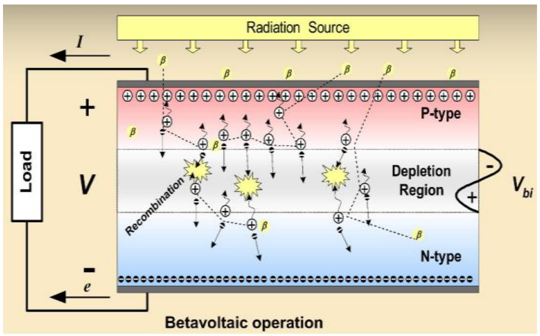

Figure 2
Schematic of Inner Processes of a Betavoltaic Battery

Optoelectric Atomic Battery

The optoelectric atomic battery was introduced in Moscow, Russia. It works by transforming nuclear energy into light, and then it uses that same light to produce electrical power. It utilizes a beta emitter suspended in a liquid or gas that contains luminescent gas molecules of the excimer type.

Excimer, also called excited dimer, consists of two atoms or molecules that do not bond while in ground state. It has a short life no more than a few nanoseconds. This dimeric molecule is made up of two varieties, where one or both are in an electronic excited state. Optoelectrics use a single or a combination of the excimers of krypton, argon, and xenon inside a pressure container that has an interior mirrored surface. This battery also has a finely grinded radioisotope and an alternating ultrasonic mixer, which illuminates a photocell. The photocell has a bandgap calibrated for the chosen excimer. It has almost no loss when emitting beta particles, and it can use nuclides that are recycled from radioactive waste, left by reactors in nuclear power plants.

Reciprocating Electromechanical Nuclear Battery

Reciprocating electromechanical nuclear batteries operate by creating buildup of electrical static charge. The charge is produced in the middle of a flexible plate and a rigid plate. The charge buildup attracts the flexible plate toward the other plate. Once they make contact, a closed circuit is created, and thus the electrical charge is released. As the static buildup is neutralized, the flexible plate goes back to its position of origin. The flexible plate can be made from piezoelectric material. Figure 3 shows a schematic of the components in a reciprocating electromechanical nuclear battery. [6]

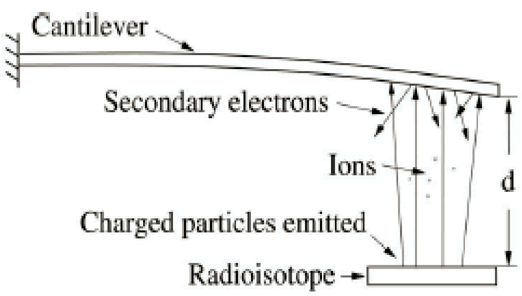

Figure 3
Reciprocating Electromechanical Nuclear Battery

Alphavoltaic Nuclear Battery

Alphavoltaic nuclear batteries are very similar to betavoltaics; they use radioactive material which emits energetic alpha particles along with a semiconductor p-n junction to produce electrical power. The way they do this is by using those alpha particles that have been emitted. As they enter the semiconductor, the particles slow down, thus releasing that energy, which in turn create electron hole pairs. Next the p-n diode collects the electron hole pairs and converts them into electrical power. A schematic of the alphavoltaic battery is shown in Figure 4 This process is very similar to the way solar cells work. [7]

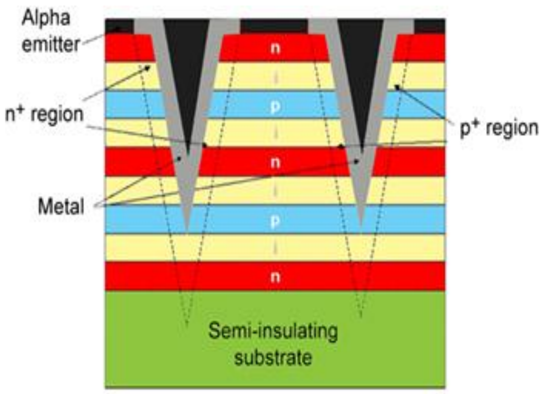

Figure 4
Inner Structure of an Alphavoltaic Battery

Direct Conversion Nuclear Battery

Direct conversion nuclear batteries collect charge emitted by radioisotopes using a capacitor to obtain high voltage ranging anywhere from ten volts to one hundred kilo volts when operated in a vacuum. Figure 5 shows a schematic of the direct charge nuclear battery model attached to a load. [8]

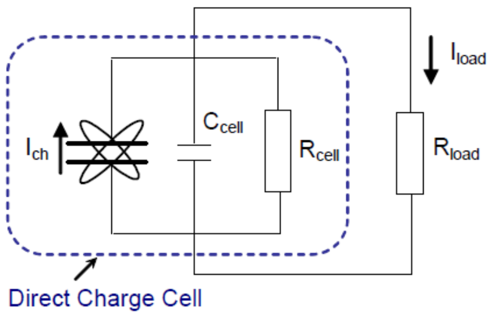

Figure 5
Direct Charge Nuclear Battery Schematic

THERMAL ATOMIC BATTERIES

Thermal conversion atomic batteries use energy derived from radiation and change it into heat, which then is converted into electricity, in some cases a thermocouple is used. Power generated by a thermal atomic battery is ultimately derived from atomic energy. This process shares many similarities with the energy produced by human triggered nuclear fission and fusion, found in the more commonly known nuclear power plants.

Alkali Metal to Electric Converter

Next we shall discuss the thermal converter category of nuclear batteries. The alkali metal thermal to electric converter or AMTEC for short was developed and patented in 1966 at the Ford Company. This is a device categorized as thermally regenerative electrochemical, it converts heat into electrical energy, and has great potential efficiency. The AMTEC possesses no mechanical parts, and the only element that moves within it, is a fluid.

It utilizes sodium flowing through an enclosed thermodynamic circuit. The sodium moves through a high temperature heat tank, and a colder tank at the heat rejection temperature. It utilizes the electrolyte sodium beta-alumina found in the sodium-sulfur battery. This sodium concentration cell uses this polycrystalline electrolyte as a divider between a high pressured area that has sodium vapor. There the temperatures range between 900 degrees kelvin to 1300 degrees kelvin. The low pressure region that encompasses a condenser for liquid sodium ranges between 400 kelvin and 700 kelvin.

A distinctive attribute of this technology occurs in the ion transmission phase. Specifically from the high pressure area to the low pressure area, both sides are extremely ionic, conducting, and refractory. The isothermal expansion of sodium vapor between both regions is almost thermodynamically identical. Figure 6 shows these regions along with the inner workings of the AMTEC energy source. [9]

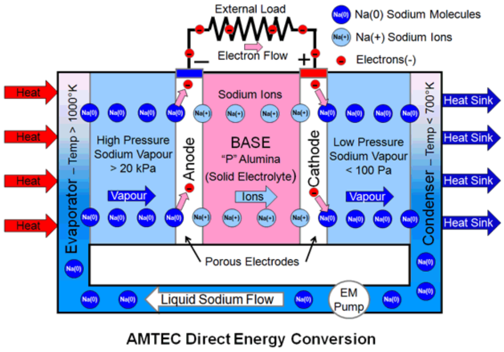

Figure 6
AMTEC Thermodynamic Diagram and Components

Thermo Photovoltaic Cells

Thermo photovoltaic cells convert energy directly through a process where it uses heat differentials and photons to generate electricity using a thermal emitter and a photovoltaic diode cell. The photovoltaic diode creates electricity by absorbing radiated photons and transforming them into free charges.

Solar panels are in essence thermo voltaic cells where the sun acts as the emitter. Spontaneous emission of photons, also called thermal emission, take place here due to the thermal motion of the charges inside the material. The fact that they are made of so few mechanical components allows them to be low maintenance and very silent, which makes them very desirable for remote locations and mobile power generating applications.

Thermionic Converter

The thermionic converter has a pair of electrodes, one is hot the other is cold, and they are separated by a potential energy barrier, where electrons are emitted thermionically, producing electrical power. Here the hot electrode emits the vaporized electrons toward the inter electrode plasma and then the electrons are condensed by the cold electrode that collects them. This process in turn generates an electric current in the range of a few amperes per square centimeter of the surface area.

The surface characteristics of the electrode determine the scale of emitted electrons and therefore the electrical current that will be generated. The chemical element used in this type of atomic battery is Caesium, in its gas state; this alkali metal is chosen because of it is the easiest stable element to ionize.

Radioisotope Thermoelectric Generators

Radioisotope Thermoelectric Generators provide the power for satellites, space probes and many autonomous devices. They use an array of solid-state thermocouples to convert the heat generated by radioactive decay into electricity. They can supply the power needs for devices using less than a few hundred watts for longs periods of time.

In Figure 7 a cutaway model is shown of the radioisotope thermoelectric generator used by NASA many times. Officially called "MMRTG" or Multi-mission Radioisotope Thermoelectric Generator, this model is currently in use, as the power source for the Mars Science Laboratory Rover, named Curiosity, set to arrive in Mars in the summer of 2012. This model has also flown on spacecraft such as Pioneer 10, Pioneer 11, and both Viking landers which were probes sent to Mars in the 1970's. One interesting detail about the MMRTG is that the excess heat produced was employed as a temperature equalizer in order to maintain optimal operation of the spacecraft. [10]

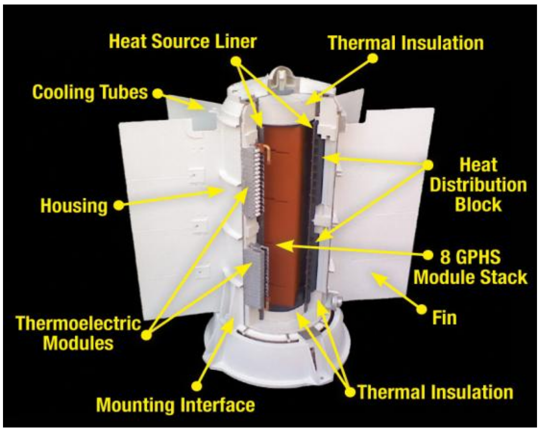

Figure 7
Inner Structure of an Alphavoltaic Battery

CURRENT RESEARCH AND DEVELOPMENT

Betavoltaics for example are being researched developed for a wide spectrum of new applications that were not possible due to their size. The new generation of betavoltaic batteries is being powered by tritium, the one radioactive isotope that can be derived from hydrogen with a half-life of around 12 years.

Tritium also known as hydrogen 3 can be produced by nuclear reactors specially designed for this purpose. The lifespan usage for betavoltaics is dependent on the nuclear half-life of the radioactive substance which can vary anywhere from one year up to a century.

The nuclear half-life of a decaying radioactive substance is the amount of time is needed for it to be reduced by one-half. Although betavoltaics have been around over half a century, they are making a comeback due to recent advances in semiconductor technology. Tritium batteries are now able to provide electrical power from nanowatt to microwatt range without interruption for at least 20 years.

The fact that all current technology is undergoing continuous miniaturization allows for a reduction on the quantity of power needed for all kinds of devices. Pacemakers for example were once made using betavoltaics as a power source, though they used the chemical element promethium. They stopped using betavoltaics when the cheaper alternative of lithium ion batteries emerged. Figure 8 shows one of the earlier models of pacemakers by Medtronix that used nuclear batteries which still functions 35 years later. [11]

Figure 8
Pacemaker Using a Nuclear Battery

New conceptual designs are being proposed using a gallium nitride binary direct bandgap semiconductor. This design shows that it can provide up to 20 years more lifespan when compared to lithium ion batteries currently being used in pacemakers. A few other examples where betavoltaics can be applied are devices such as deep ocean sensors, space probes, micro controllers, buoys, and radio frequency identification tags or more commonly known RF-IDs. Figure 9 shows the actual size of a model manufactured by Widetronix that can be used in such applications as the ones mentioned above. [12]

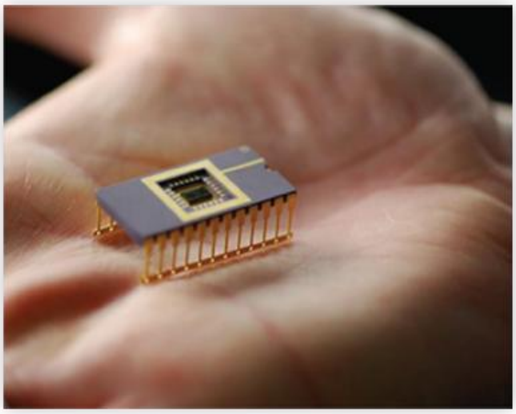

Figure 9
Widetronix Next Generation Betavoltaic Battery

CONCLUSION

Nuclear batteries have evolved quite a bit since they were first introduced. This kind of portable energy source can provide decades of electricity to all sorts of devices.

New developments in the semiconductor industry have been applied in the design of several prototypes, some of which are already being manufactured by companies such as City Labs and Widetronix.

In today's world, the demand for smaller, faster, cheaper more energy efficient technology is constantly increasing. Thanks to this, nuclear batteries will be used in wide range of devices such as: RF-ID tags, gun scopes, pacemakers, hearing aids, neurological stimulators, satellites, space probes, watch dials, missile head security systems, intelligence sensors, cell phones, and laptop computers.

The academic sector is a crucial part for the research and development of this technology. The majority of the breakthroughs in this industry have come from prototypes first proposed in institutions such as Purdue University, Stanford University, University of Missouri, University of Rochester, University of Illinois, and the University of Maryland among many others.

The advantages offered by nuclear batteries are unique, and will keep generating interest in them.

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