Radioisotopic battery for long-life, buried autonomous power

R. Walton¹, C. Anthony¹*, D. Chapman², N. Metje² and M. Ward³

¹School of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT
²School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT
³School of Engineering, Design and Manufacturing Systems; Faculty of Technology, Engineering & the Environment; Birmingham City University, Birmingham, B4 7XG

* c.j.anthony@bham.ac.uk

Abstract. Indirect conversion radioisotopic batteries (ICRBs) are investigated for use as long-life power source for autonomous buried applications. As part of this work the optimum configuration of this class of battery has been experimentally investigated. An ICRB was buried at a depth of 90cm for two months during which time its voltage was monitored, with these results presented. The ICRB successfully demonstrated the buried operation of this class of battery and suggested that the power of the device halves at twice the half-life of the radioisotope used.

1. Introduction

Radioisotopic batteries have been investigated before, however indirect conversion radioisotopic batteries (ICRBs) have received little notice. Much focus has been given to thermal cycle types of radioisotopic battery, such as those used by NASA [1], which require a large mass of radioisotope to effectively operate and are therefore unsuited to terrestrial use. The other types of radioisotopic batteries commonly reported either consist of charging a capacitor with the charged particles of radioactive decay [2] (which results in unusably high voltages, often 10kV or more) or involve generating electricity in a PV cell directly from the kinetic energy of the radioactive decay particles [3]. This latter type of radioisotopic battery produces radiation damage and therefore premature degradation of the PV cells, limiting the useful lifetime of the battery [4]. ICRBs do not suffer from these drawbacks.

ICRBs consist of a radioisotope in close proximity to a phosphor which generates photons when impacted by the decay particles of the radioisotope [5]. The photons travel to a PV cell where they are then converted into electrical energy in the conventional manner [6]. This energy may then be stored in a capacitor to be used when required. A schematic demonstrating this process is shown in figure 1.
Gaseous tritium light sources (GTLSs) consist of a glass ampule coated on the inner surface with a thin layer of phosphor and filled with pressurized tritium gas. GTLSs therefore comprise two of the processes necessary to produce an ICRB and were used during this research due to their sturdiness and availability for use under UK law [7].

2. Radioisotopic battery configuration selection
A preliminary investigation of the most effective configuration of ICRBs was undertaken using commercially available PV cells and GTLSs. The layout of the PV cells and GTLSs relative to each other was investigated in terms of the power generated by the manufactured ICRBs. The power of these ICRBs was measured indirectly by charging a capacitor and measuring the voltage in the capacitor at regular and timed intervals. The power ($P$) needed to alter the voltage (and hence energy stored) in the capacitor over the time interval between readings was then calculated through application of equation (1) (where $C$ is the capacitance, $V_2$ is the measured voltage, $V_1$ is the previously measured voltage and $dt$ is the time interval between readings). A bespoke measurement system was used to measure the voltage of these ultra-low power devices while charging a $1\mu F$ 50V aluminium electrolytic capacitor.

$$P = \frac{1}{2}C(V_2^2 - V_1^2)$$  \hspace{1cm} (1)

The investigated configurations of ICRBs are displayed in figure 2, where (a) used two GTLSs on a PV cell without reflective casing, (b) used two GTLSs on a PV cell with reflective casing, (c) used two GTLSs sandwiched between two PV cells surrounded by reflective casing, (d) used one GTLS surrounded by three PV cells and reflective casing, and (e) used two GTLSs surrounded by four PV cells and reflective casing. The results of testing are shown in figure 3, which plots the power generated against the voltage at which that power was produced. The PV cells used during this testing were of amorphous silicon type, chosen due to their superior performance at converting low intensity light into electricity.
The highest power was generated by having two GTLSs sandwiched between two PV cells (configuration (b)) and this was therefore the design which was taken forward for long-life buried testing.

3. Buried, long-life testing

The ICRB was installed in a waterproof enclosure conforming to IP65 standard and was potted with a transparent polyurethane resin (as shown in figure 4) to prevent moisture intruding during the buried operation of the device. The ICRB was then buried at a depth of 90cm in soil of 19% moisture content (at time of burial) and was secured to a water pipe with plastic ties and a jubilee clip, as shown in figure 5. The hole was then backfilled and the performance of the buried ICRB was monitored over a period of two months via a bespoke sensor node, transmitter and data storage system.
The complete set of measured voltage readings from the buried ICRB is presented in figure 6 along with the temperature local to the battery which was read by a temperature sensor attached to the outside of the battery enclosure.

![Figure 6. Measured voltage of ICRB and local temperature reading over a period of two months.](image1)

After approximately 20 days the temperature sensor degraded, most likely due to water encroaching onto the measurement mechanism, and thereafter produced unreliable data as evidence by the sharp spikes in temperature readings. The gap in readings is a result of a power loss in the logging equipment. Meanwhile the ICRB voltage shows a decline over the period of measurement of 24.4mV from a starting reading of 1.8115V. At this rate of change it would take 7.2 years for the voltage to be reduced to half of its starting value. The radioisotope used in this ICRB was tritium, which has a half-life of 12.3 years. Therefore, the voltage of the ICRB declines at a rate 1.7 times faster than the half-life of the radioisotope. This is primarily due to slow radiation damage of the phosphor layer through the creation of impurities and the ejection of phosphor atoms from the phosphor lattice [8].

A further phenomenon revealed during this testing was the close relationship between the voltage output of the ICRB and the local temperature. This relationship is shown more clearly in figure 7, where it can be seen that each drop in temperature correlates to a rise in generated voltage. In addition there is a general rise in temperature reported up to 20 days, which has also decreased the voltage output of the ICRB beyond the decline expected by battery aging. The effect of temperature on the generation of voltage by PV cells was experimentally investigated by Shaari et al. [9], which revealed similar results. For this reason it is believed that this phenomena is primarily due to the temperature dependent operation of the PV cells in the battery.

![Figure 7. A comparison between the measured voltage of the buried ICRB and its local temperature.](image2)
4. Conclusions
Indirect conversion radioisotopic batteries were experimentally investigated as to their optimum configuration which was found to be a sandwich of GTLSs between two PV cells. An ICRB was successfully buried and tested over a two month period proving the durability of this class of battery to this type of environment. Buried long-life testing of the ICRB found that the device would halve in voltage output every 7.2 years. This decline in voltage was due to the decrease in activity of the radioisotope (its half-life) and slow radiation damage of the phosphor layer. The voltage generated by the ICRB is affected by the temperature at which it was operating, which is due to the temperature dependent performance of the PV cells.

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References
[1] Bennett G L, Lombardo J J, Hemler R J, Silverman G, Whitmore C W, Amos W R, Johnson E W, Schock A, Zocher R W, Keenan T K, Hagan J C and Englehart R W 2006 Proc. 4th Int. Energy Conversion Engineering Conference 720
[2] Kavetskiy A, Yakubova G, Lin Q, Chan D, Yousaf S M, Bower K, Robertson J D, Garnov A and Meier D 2009 J. Applied Radiation and Isotopes 67 6 1057
[3] Honsberg C, Doolittle W A, Allen M and Wang C 2005 Proc. 31st IEEE Photovoltaic specialists conf. 102
[4] Deus S 2000 Proc. 28th IEEE Photovoltaic specialists conf. 1246
[5] Lambe J, Klick C C 1955 Phys. Rev. 98 909
[6] Luque A and Hegedus S 2011 Handbook of Photovoltaic Science and Engineering (Wiley & Sons)
[7] United Kingdom government 2011 Environmental Protection, England and Wales: The Environmental Permitting (England and Wales) Regulations, No. 2043
[8] Brese N E, Rohrer C L and Rohrer G S 1999 Solid-State Ion. Diffus. React. 123 19
[9] Shaari S, Sopian K, Amin N and Kassim M N 2009 Am. J. of App. Sci. 6 586