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# The History of the Invention of Radioisotope Thermoelectric Generators (RTGs) for Space Exploration

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In December of 1903, the Wright Brothers made the first successful powered flight of an airplane. There are significant levels of examination of Orville and Wilbur's incremental improvements to the original design of their flying machine to build the Wright Flyer II. However, there is not much appreciation of the backstory that inspired the brothers to explore the fundamentals of aerodynamics and pursue the research and development required to make a powered, heavier-than-air aircraft. Wilbur Wright indicated in a letter he wrote in 1912 that the pioneering work of Otto Lilienthal in the late 1800s was a precursor to their efforts. But it was a rubber band-powered toy helicopter their father, Milton Wright, gave them in 1878 that Orville credited as the object that sparked their interest in flight.

As an opening discussion of the history of the radioisotope thermoelectric generator (RTG), it is essential to understand the backstory of the invention that has allowed humankind to explore beyond the solar system's boundaries. In 1954, Kenneth Jordan and John Birden invented the RTG at the Atomic Energy Commission (AEC) Mound Laboratory. Oral history posits that the two inventors drafted their initial design concept during lunch on a napkin in the Mound Laboratory cafeteria. Their initial research efforts used a small steam-electric generator to demonstrate that heat utilized from the radioactive decay of polonium-210 could generate electricity. However, more-efficient methods for producing electricity were required, and Jordan and Birden coupled a polonium-210 heat source to a thermoelectric material array to generate electricity (Figure 1.1). This early prototype used forty chromel-constantan thermocouples to generate power from a suspended sphere containing 146 curies of encapsulated polonium-210. The outside container of the prototype was made of aluminum and used an early

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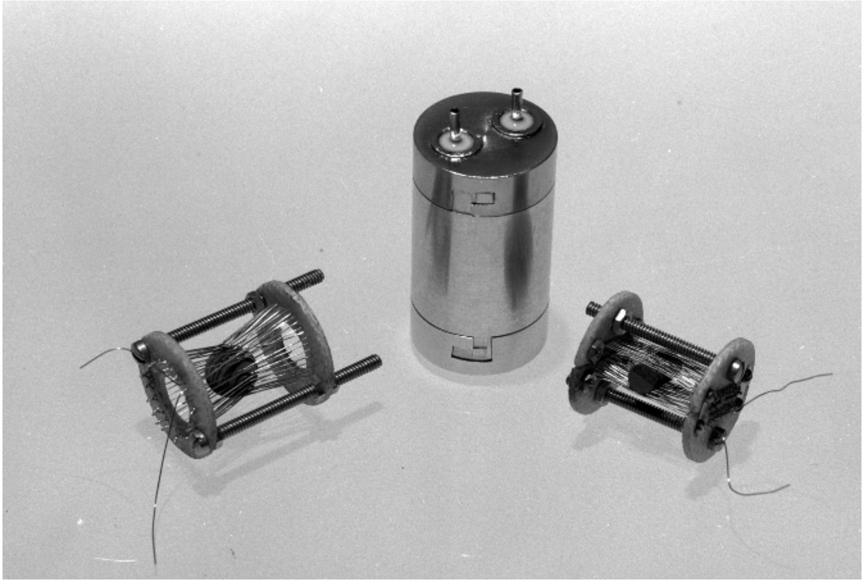

**Figure 1.1** An early experimental thermoelectric generator designed by Jordan and Birden that couples a polonium-210 heat source with a thermoelectric material array. Credit: Mound Science and Energy Museum Association.

form of silica aerogel (Santocel) as insulation. This unit produced 9.4 milliwatts of power for a total efficiency of 0.20%. [1] In 1959, Jordan and Birden received a patent for their invention, which is still the underpinning innovation for all RTGs used by the National Aeronautics and Space Administration (NASA) for planetary and deep-space exploration. [2]

Similarly, the events leading up to the first powered flight at Kittyhawk, the backdrop of Jordan and Birden's early efforts, are not widely known. The US Congress established the AEC in the shadows of World War II to establish centralized governmental controls to manage the research and production of atomic weapons in the post-war era. [3] During the first decade of the AEC, laboratories under the AEC umbrella conducted a broad spectrum of research activities on producing natural and synthetic radioisotopes in reactors and cyclotrons. These early efforts focused on how radioisotopes can influence thermonuclear fusion produced by weapons. In conjunction with research and development activities for weapons programs, research was also ongoing to determine the utility of radioisotopes for particle physics, medicine, geography, and several industrial applications.

Within the same timeframe, the War Department, the predecessor to the Department of Defense, recognized a need for establishing a non-profit, global policy think tank, and the Douglas Aircraft Company created the RAND Project, later the RAND Corporation, to fulfill this need. In 1946, the RAND Project explored the preliminary design of a satellite vehicle [4], and in 1947, RAND expanded its examination to evaluate the use of radioisotopes to address the electrical power requirements for satellite vehicles. [5] This initial analysis considered the use of polonium-210 and strontium-89 as thermal sources for power generation. In 1949, RAND published a study that outlined the use of nuclear power sources for satellites in Earth orbit, and in 1951, the Department of Defense (DOD) requested that the AEC initiate research on nuclear power for spacecraft. [6] As a result, the AEC initiated a series of studies that concluded that both fission and radioisotope power systems were technically feasible for satellites. [7]

In late 1953, President Dwight D. Eisenhower delivered his “Atoms-for-Peace” address at the United Nations to promote the peaceful uses of atomic energy. During that same timeframe, Jordan and Birden built two experimental thermal batteries using polonium-210 and chromel-constantan thermocouples to validate their thermal battery theory and develop fabrication techniques. These experimental units had approximately ten times the work capacity of ordinary dry cell batteries of the same weight. [1]

Jordan and Birden fabricated seven experimental units in total, and the third unit (Figure 1.2) was the prototype of the remaining generators built. These later

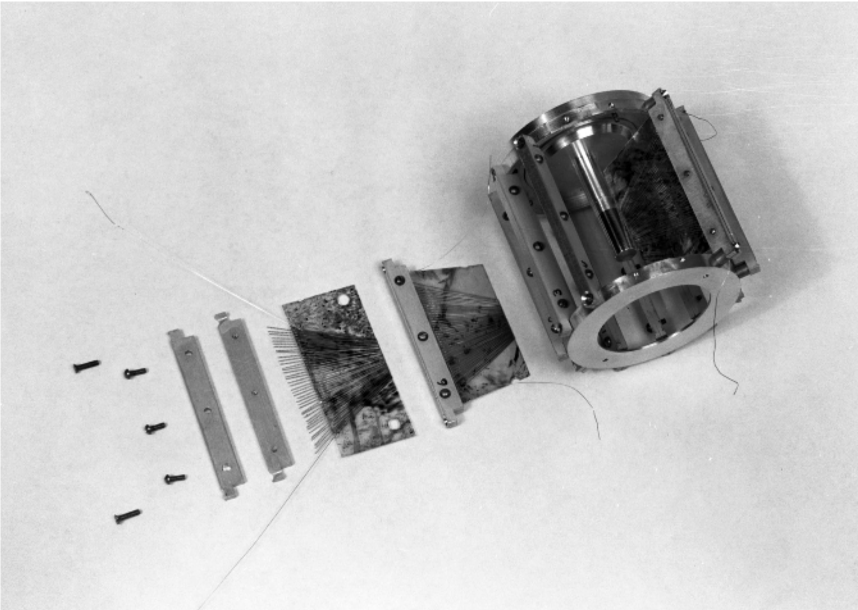

**Figure 1.2** One of the latter prototype thermoelectric generators designed by Jordan and Birden. Credit: Mound Science and Energy Museum Association.

units employed twelve thermopiles, each consisting of thirty-seven chromel-constantan thermocouples supported by mica cards that were vertically mounted and radially spaced on aluminum rings. Figure 1.2 also shows an assembled and disassembled thermopile.

Jordan and Birden made extensive measurements on these units to determine efficiencies and the effects of various types of insulation, including vacuum, noise levels, ambient temperatures, matched and unmatched loads on the units' performance. [8] In general, these latter prototypes produced approximately 50 milliwatts of power for a total efficiency of 0.32%. The last units in this series of prototypes were designed and built based on specifications that delineated load voltage, power, durability, and design life requirements. It was the first step to ensuring that future generators would be sufficiently rugged to withstand the vibrational and quasi-static forces associated with space launches.

In 1955 the AEC formally initiated the Systems for Nuclear Auxiliary Power (SNAP) program, which focused on experimental radioisotope and fission systems. The objective of this program was to develop compact, lightweight, reliable atomic electric devices for use in space and terrestrial applications. Under the SNAP program, odd numbers designated RTGs systems, and even numbers represented fission reactor systems. In 1957, the Martin Company developed the SNAP-1 RTG, which was assembled at the AEC Mound Laboratory. As the development of SNAP-1 progressed, the Martin Company subcontracted with Westinghouse Electric and the Minnesota Mining and Manufacturing Company (3M) to develop the SNAP-3 RTG. In 1958, 3M delivered the SNAP-3 to the Martin Company, which fueled the unit with encapsulated polonium-210 from Mound Laboratory. The SNAP-3 produced 2.5 $W_e$, and President Eisenhower displayed the power system in the US White House's Oval Office on 16 January 1959 (Figure 1.3). [9]

In 1961, the US Air Force launched the Transit 4A and 4B naval navigation satellites from Cape Canaveral Air Force Station. The Navy Transit program required a power source that would reliably operate for five years. To meet this requirement, the AEC modified a SNAP-3 to utilize plutonium-238 rather than polonium-210. This modification extended the design life of the SNAP-3A because plutonium-238 has a longer half-life than polonium-210 (88 years versus 138 days for polonium-210). [10] The Transit 4A and 4B satellites utilized a hybrid power system comprised of a SNAP-3B RTG and solar panels, which provided a total power of 35 $W_e$. [10] These early navigation satellites were a precursor to the global positioning system (GPS), which provides positioning and navigational capabilities to military, civil, and commercial users worldwide. In addition, the successful mission of these satellites demonstrated the feasibility of using RTGs for space missions.

**Figure 1.3** The public debut of the SNAP-3 RTG technology demonstration device in the US White House's Oval Office on 16 January 1959. Pictured left to right: President Eisenhower, Major General Donald Keirn, AEC Chairman John McCone, Colonel Jack Armstrong, and Lt. Colonel Guveren Anderson. Credit: DOE Flickr.

All modern aircraft incorporate some of the essential design elements of the 1903 Wright Flyer, and correspondingly all RTG designs have their antecedents in a thermal battery concept on a cafeteria napkin. The legacy of Jordan and Birden's creative efforts transcend deep space and planetary exploration and has an ongoing impact on technology, culture, art, and literature.

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