Aiming for the Stars in Pennsylvania: The Forgotten Legacy of the Westinghouse Astronuclear Laboratory 1959-1973

by

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Prior to his death in 2008, renowned science fiction writer, inventor, and futurist Arthur C. Clarke confidently declared that the space age has not yet begun, and will only really commence when reliable nuclear powered space vehicles are available to drastically reduce the cost of moving humans and heavy payloads from the surface of the earth to the farthest reaches of our solar system. It is a little appreciated fact that the Westinghouse Electric Company of Pittsburgh, Pennsylvania played a central role in bringing that vision much closer to reality through their participation in the NERVA (Nuclear Energy for Rocket Vehicle Applications) program between 1959 and 1973. With recently renewed interest in the human exploration of Mars and destinations in the outer solar system, attention is once again focusing on the remarkable accomplishments that Westinghouse made toward the development of the still largely untapped potential of the nuclear thermal rocket.

As early as 1949, Los Alamos Laboratory began conducting research into developing a solid core nuclear thermal rocket engine to power intercontinental ballistic missiles. The idea of a nuclear powered rocket had already captured the imagination of many serious science fiction writers as demonstrated by Robert A. Heinlein's 1948 novel entitled *Space Cadet* that featured a sleek nuclear-powered rocket ship that inspired the 1950 CBS television series *Tom Corbett, Space Cadet* starring Frankie Thomas. With encouragement from science advisor Willy Ley, in1951 Joseph Lawrence Greene, writing under the pseudonym Carey Rockwell at Grosset and Dunlap, launched a *Tom Corbett, Space Cadet* juvenile novel series that fired the imagination of an entire generation of America's youth with images of a sleek manned single-stage-to-deep space atomic powered rocket called the *Polaris*. Like the nuclear rocket engine eventually developed under the NERVA program, the *Polaris* employed turbo-pumps to supply propellant to a uranium-fueled reactor core. Virtually all of the sleek single-stage rockets of the golden age of science fiction were described at that time as using some form of atomic energy for propulsion. In a classic example of scientific theory inspiring art that in turn inspired practical engineering concepts, by 1957 Los Alamos Laboratory had acquired a test facility at Jackass Flats, Nevada to test the first KIWI series of nuclear rocket engines under Project Rover. (Since these were ground tests rather than actual flight tests, these early engines were named after the flightless Kiwi bird. The tests were conducted with the engines mounted upside down on their test stands and the rocket plume firing upward into the atmosphere.)

In 1959 Westinghouse Electric Company of Pittsburgh, and its Bettis Atomic Power Laboratory in West Mifflin, were already building nuclear reactors for the Navy and had also designed the nation's first commercial nuclear power plant at Shippingport that went online in December 1957. In anticipation for landing further lucrative government contracts, in 1959, John Wistar Simpson, Frank Cotter, and Sidney Krasik convinced Westinghouse CEO Mark W. Cresap, Jr. to approve the creation of the Westinghouse Astronuclear Laboratory (WANL) to investigate the feasibility of building nuclear rocket engines. Authorized in May 1959, the Astronuclear Laboratory officially became a Westinghouse division on July 26, 1959 and consisted of just six employees with John W. Simpson at the helm. Cornell University physicist Sidney Krasik served as the technical director and Frank Cotter served as Simpson's executive assistant and marketing director. Born in 1914, Simpson graduated from the United States Naval Academy and joined Westinghouse in 1937 where he subsequently earned an MS from the University of Pittsburgh in 1941. Working in the switchgear division of the East Pittsburgh plant, Simpson helped develop electric switchboards that could survive the extreme impacts experienced by naval vessels under bombardment in the Pacific theater. In 1946, he took a leave of absence from Westinghouse to work at Oak Ridge to familiarize himself with atomic power and upon his return in 1949 became an assistant manager in the engineering department of Westinghouse's Bettis Atomic Power Laboratory. He subsequently managed the construction of the Shippingport Atomic Power Station in 1954 and in 1955 was promoted to general manager of the Bettis Laboratory and elected a Westinghouse vice president in 1958. By 1959 Simpson and his team were enthusiastic about taking on the new challenge of building nuclear powered rockets to explore the solar system.

The Astronuclear Laboratory was at first headquartered in a shopping mall in the Pittsburgh suburb of Whitehall and by 1960 Westinghouse Astronuclear Laboratory and Aerojet General decided to team up to compete for the NERVA (Nuclear Energy for Rocket Vehicle Applications) program contract from NASA's Space Nuclear Propulsion Office (SNPO). In 1961 Aerojet and Westinghouse jointly won the contract to develop six nuclear reactors, 28 rocket engines, and six RIFT (Rocket In Flight Test) flights. With this substantial contract in hand, the Astronuclear Laboratory increased its staff to 150 and moved into the Old Overholt Distillery site. By 1963, Westinghouse and its collaborators employed 1,100 people on the project that was based near the small town of Large along Rte 51, about 13 miles south of Pittsburgh in Allegheny County. (The small town of Large was somewhat anomalously named for a former distillery on the site that was originally founded during the early 19th century by Joseph Large.) Together, Aerojet and Westinghouse developed the NRX-A series of rocket test engines based on an 1120 MW Westinghouse reactor. Assembled in Large, the reactors were loaded on rail cars for delivery to the nuclear test facility at Jackass Flats, Nevada for field testing.

The initial objective of the NERVA program was to build a rocket engine that could deliver at least 800 seconds of specific impulse, 55,000 pounds of thrust, at least ten minutes of continuous operation at full thrust, and the ability to start up on its own with no external energy source. Seventy pounds per second of liquid hydrogen pumped from the propellant tank into the reactor nozzle would provide regenerative cooling for the rocket nozzle. The cylindrical graphite core of the nuclear reactor was surrounded by twelve beryllium plates mounted on control drums to reflect neutrons. The drums also contained boral plates on the opposite side of each drum to absorb neutrons and the drums were rotated to control the chain reaction in the core. The core itself consisted of clusters of hexagonal graphite fuel elements, the majority of which consisted of six fueled element sectors and one unfueled sector. The fuel consisted of pyrographite-coated beads of uranium dicarbide coated with niobium carbide to prevent corrosion caused by exposure to the hydrogen passing through the core. Each fuel rod cluster was supported by an Inconel tie rod that passed through the empty center sector of each fuel rod cluster and a lateral support and seal was used to prevent any of the hydrogen from bypassing the reactor core. (Inconel is a high-temperature alloy, one version of which was at that time being used as the skin on the famed X-15 rocket plane.)

The Solid Core Nuclear Thermal Rocket used highly enriched uranium embedded in a graphite matrix the design of which evolved over time. When the highly fissionable Uranium 235 atoms absorb a neutron they split to form lighter elements, more neutrons, and a large amount of thermal energy. The solid core nuclear rocket uses the tremendous thermal energy generated by a controlled nuclear chain reaction to heat hydrogen that is forced through the very narrow channels in the reactor core. The hydrogen propellant is delivered under high pressure to the reactor core using turbo-pumps. The nuclear chain reaction in the reactor core causes the hydrogen to be superheated and expelled through the rocket nozzle at very high velocity as an explosively expanding reaction mass resulting in a very high specific impulse of 825 seconds. In a chemical rocket, where a fuel (such as liquid hydrogen) and an oxidizer (such as liquid oxygen) are brought together and burned in a combustion chamber, the maximum specific impulse achievable is only about 450 seconds. (Specific Impulse is a measure of efficiency of a rocket and is defined by Konstantin Tsiolkovsky's rocket equation as the pounds of thrust produced for the pounds of fuel consumed per second and is expressed in seconds.)

With a high specific impulse, the ability to conduct multiple shutdowns and restarts, and a highly favorable energy/weight ratio, the nuclear rocket was the kind of vehicle that the early rocket pioneers Konstantin Tsiolkovskey, Robert Goddard, Herman Oberth, and Wernher von Braun had long dreamed about. (As early as 1903, Tsiolkovsky had hoped that it might be possible to somehow extract atomic energy from Radium in order to power a rocket but it was not until 1938 when Otto Hahn in Germany first succeeded in causing Uranium to fission, and his former colleague Lise Meitner, who was then living in exile in Sweden, figured out the significance of what he had done, that the door to the Atomic Age was flung open.) This is because the power density of traditional chemical rockets is puny compared to the extraordinarily high power density of a nuclear rocket engine, resulting in the need for chemical rockets to consist of numerous throwaway stages and also require an enormous volume of their mass devoted to carrying both a propellant and an oxidizer. In contrast, a nuclear rocket can be built as a single stage vehicle, requires no oxidizer because it merely heats a propellant that serves as the reaction mass, and can also undergo numerous shutdowns and restarts making long duration missions to the ends of the solar system both possible and economical. While the inefficiencies inherent in chemical rockets result in nominal costs of $3,500 - $5,000 per pound to deliver payload to low earth orbit, the much more favorable propellant to payload mass ratio of the nuclear rocket promises costs in the range of just $350-$500 per pound, and perhaps even far less as the technology further matures.

When radiation safety concerns were raised in NASA's Space Nuclear Propulsion Office (SNPO) over launching such nuclear powered rockets directly from the surface of the earth, it was Dr. Wernher von Braun at the Marshall Space Flight Center in Huntsville, Alabama who developed a proposal to boost a nuclear propelled second stage NERVA rocket to the edge of space using his Saturn V first stage before firing the nuclear rocket engine after it was well above the thickest part of the atmosphere. (There is some debate as to whether this precaution is really necessary for a well-designed nuclear rocket but the current prevailing climate of hysteria regarding anything nuclear renders it unlikely that direct ascent from the earth's surface will be found acceptable to the general public anytime soon. It should be noted that all of the early NERVA rocket engine tests were, in fact, open atmospheric tests.)

Most of the nuclear fuel for the NERVA project was supplied by the Westinghouse Astrofuel fabrication plant at Cheswick, Pennsylvania. Fuel element corrosion was tested by electrically heating the fuel elements by their own resistance, first at the Large site, and then at a new facility constructed for the purpose at Waltz Mill, Pennsylvania. In order to ensure fuel corrosion resistance and the stability of dimensional tolerances to several thousandths of an inch, the materials in the core elements were extruded into a bar possessing a hexagonal cross section having nineteen longitudinal holes. The extrusion was then polymerized, baked at a low temperature, and graphitized at a higher temperature of about 2,200 degrees Centigrade. The spherical uranium dicarbide fuel element particles measured about 150 micrometers in diameter including a pyrographite coating thickness of roughly 25 micrometers. The resulting unfinished fuel element was subjected to a high-temperature chemical vapor deposition process to coat the surfaces of the longitudinal channels with a gas mixture of niobium pentachloride, hydrogen, and methane. This mixture reacted with the graphite to form a niobium carbide coating intended to prevent corrosion of the core when it was exposed to the hydrogen propellant. The great challenge of this process was to achieve a good match between the thermal expansion coefficients of the graphite and the niobium carbide in order to prevent cracking when the reactor core was heating up and cooling down.

On September 24, 1964 the NRX-A2 established proof of concept by providing six minutes of power. By April 23, 1965 Aerojet and Westinghouse tested the NRX-A3 nuclear rocket engine at full power for sixteen minutes and also demonstrated a three-minute full-power restart. Pulse cooling was also introduced at this time in which bursts of LH2 were used to cool down the reactor core. This was followed by a test of the NRX/EST (Engine System Test) engine equipped with Aerojet's new nozzle and turbopump mounted next to the engine in place of the earlier Rocketdyne pump that had been housed separately behind a concrete wall. This permitted full operational testing of all of the equipment in a high radiation environment that would be typical of an actual spaceflight. By 1966, Aerojet and Westinghouse commenced an additional aggressive series of tests to demonstrate ten bootstrap startups on the NRX-A4/EST and full power operation of the NRX –A5 engine for two periods that totaled 30 minutes of operation. On December 13, 1967, the NRX-A6 achieved a full 60 minutes of operation at full power. According to data compiled by Aerojet and Westinghouse on June 11, 1969 the XE engine was started 28 times for a total of three hours and 48 minutes and eleven of those minutes were at full power. By 1970, the proposed NERVA I concept vehicle that evolved out of all of this work was projected to be capable of delivering 1500 MW of power and 75,000 pounds of thrust. It also had a projected lifetime runtime of ten hours and could be started and stopped 60 times while delivering 825 seconds of specific impulse for each one hour of continuous operation. Especially encouraging was the fact that it was projected to have a total weight of less than 15,000 pounds.

Capable of starting up on its own in space and reaching full power in less that a minute, the design operating temperature of the reactor was 2,071 degrees centigrade and its reliability was projected to be at least 0.997. (The .003 projected failure rate covered all forms of failure to operate and is not to be confused with a catastrophic failure such as a crash or explosion.) In one test conducted at Jackass Flats on January 12, 1965 a KIWI-TNT nuclear rocket engine reactor was intentionally caused to explode in order to accurately assess the consequences and cleanup implications of a truly catastrophic launch pad accident. Off-site radiation from this test was judged to be statistically insignificant, adding just 15% to a person's average annual exposure at a distance of 15 miles from ground zero, and technicians were able to thoroughly clean up the site at ground zero within a matter of weeks.) Aerojet and Westinghouse were prepared to begin construction of five reactors and five NERVA I rocket test engines for actual flight testing from the Kennedy Space Center in Florida beginning in 1973, the year in which the NERVA program was terminated by the federal government. Total government expenditure by that time on the combined Rover/NERVA program from 1955 to 1973 had reached just over $1.45 billion. (This is equivalent to roughly $4.5 billion today.) As a result of the cancellation of this program, a NASA plan to use a NERVA-type vehicle to place humans on Mars by 1981 was quietly shelved.

Based upon the rapid improvements made in the design of the NRX engines in just over a dozen years, it has been argued that with subsequent improvements in materials science, and a better understanding of the physics, that the solid core nuclear thermal rocket could have been improved to the point where it would have delivered at least 1000 seconds of specific impulse, 3000 MW of power, and been capable of perhaps 180 recycles. Such a rocket would have been capable of continuously cycling back and forth to Mars about fifteen times with each transit taking as little as 45 to 180 days depending upon the transfer orbit configuration chosen instead of the six to nine months required for a chemical powered rocket to make the same trip. This faster transit would actually lower astronauts' exposure to radiation from cosmic rays, the van Allen radiation belts, and solar flares and also make it possible to launch heavier vehicles having larger crews and better shielding against cosmic radiation and solar flares.

With the end of the NERVA program in 1973, the Westinghouse Astronuclear Laboratory in Pittsburgh continued to work on several other projects including a nuclear-powered artificial heart. Amidst a changing political climate concerned with finding so-called "green" energy sources, in 1976 the Astronuclear Laboratory became the Westinghouse Advanced Energy Systems Division (AESD). Here, Westinghouse engineers experimented with a heliostat and worked on the Solar Total Energy Project (STEP) in Shenandoah, Georgia that used five acres of solar collectors to power a knitting factory. The AESD also worked on a prototype for a magnetohydrodynamic system to reuse exhaust gases to increase the electrical output of a coal powered plant by 30%. After Westinghouse closed the AESD, several former employees formed Pittsburgh Materials Technology, Inc. in 1993 at the site of the former Astronuclear Laboratory that today specializes in producing high temperature specialty metal alloys for government and industrial customers.

During the 1970s Westinghouse Electric Corporation sold off its home appliance division and oil refineries and closed its East Pittsburgh manufacturing plant in 1988. In 1995 it purchased CBS and Infinity Broadcasting in 1996. Renaming itself CBS Corporation in 1997, it sold off the nuclear energy business to BNFL (British Nuclear Fuels Ltd) which in turn sold it to Toshiba in 2006. Under the wing of Toshiba, the nuclear energy business continues to operate under the name Westinghouse Electric Company and, due to rapid expansion in overseas demand for nuclear power plants, in 2009 moved its corporate headquarters to a new larger campus at in Cranberry Township, Butler County.

By 1963 when Westinghouse CEO Mark Cresap died, John Wistar Simpson was responsible for eighteen major Westinghouse divisions and in 1969 became president of Westinghouse Power Systems. He earned the Westinghouse Order of Merit and was elected to the National Academy of Engineering in 1966 and awarded the IEEE Edison Medal in 1971. A member of the board of governors of the National Electric Manufacturers Association (NEMA) and chairman of the NEMA Power Equipment Division, he was also a fellow of the American Nuclear Society where he served on the board of directors, on the executive committee, and as chairman of the finance committee. In 1995 the American Nuclear Society published his book, *Nuclear Power from Underseas to Outer Space,* in which he recounts his experiences at Westinghouse, including a detailed description of the Astronuclear program. Simpson passed away at the age of 92 on January 4, 2007 at Hilton Head, South Carolina.

The Westinghouse Astronuclear Laboratory was a product of an era of bold optimism in the promise of science and technology to solve problems and also of a vision long shared by such rocket pioneers as Konstantin Tsiolkovsky, Robert Goddard, Hermann Oberth, Wernher von Braun, Sergei Korolev, Stanislaw Ulam, and Freeman Dyson, and many others for eventually spreading mankind across the solar system. Much of the science fiction of that era, such as the Tom Corbett television and juvenile novel series, was grounded in the hard science as it was understood at that time. Overtaken by the social and political upheavals that accompanied the growing disillusionment with the Vietnam War and social dissension at home, the NERVA program nonetheless achieved remarkable successes that were cut short by shifting political events and a narrowing of national horizons. Despite a long hiatus, those successes are now inspiring a new generation of aerospace engineers to once again think boldly and embrace the difficult challenges enunciated by President John F. Kennedy (himself a strong early supporter of the NERVA Program) at Rice University in 1962: “We choose to go to the moon in this decade, and do the other things, not because they are easy, but because they are hard.” The collaboration of Westinghouse Electric and Aerojet General in doing the hard work of developing a viable solid core nuclear thermal rocket engine is a down payment on the eventual human exploration and settlement of the solar system. The full utilization of such nuclear technology will make possible the fulfillment of the dream first enunciated by Russian mathematics teacher and visionary Konstantin Tsiolkovsky who proclaimed more than a century ago that “The earth is the cradle of mankind, but a man cannot live in the cradle forever.” Nurtured by the dreamers in the cradle of Pennsylvania’s Three Rivers Valley for a brief but shining period of fourteen years, that dream of one day setting off boldly into the new frontier moved a little closer to reality.

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