HISTORY OF THE PLUTO/PHOENIX FACILITY AT THE NEVADA TEST SITE

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"'Project Pluto' Studied Nuclear Ramjet Propulsion," U.S. Department of Energy, Nevada Operations Office, April 1993, http://www.nv.doe.gov/news&pubs/publications/historyreports/news&views/pluto.htm (October 4, 2001).

'Project Pluto' studied nuclear ramjet propulsion

Tory II-C, a nuclear ramjet engine, sits on a railroad flatcar -- its test bed. The engine was built to demonstrate the feasibility of an air-breathing jet engine powered by a nuclear reactor.

Pan Am photo.

On January 1, 1957, the U.S. Air Force and the Atomic Energy Commission selected the Lawrence Livermore National Laboratory's (LLNL) predecessor, the Lawrence Radiation Laboratory to study the feasibility of applying heat from nuclear reactors to ramjet engines.

This research became known as "Project Pluto" and was moved from Livermore, California to new facilities constructed for $1.2 million on eight square miles of Jackass Flats at the Nevada Test Site (NTS).

The complex consisted of six miles of roads, critical assembly building, control building, assembly and shop buildings, and utilities. Also required for the construction was 25 miles of oil well casing which was necessary to store the million pounds of pressurized air used to simulate ramjet flight conditions for Pluto.

The work was directed by Dr. T.C. Merkle, leader of the laboratory's R-Division.

The principle behind the ramjet was relatively simple: air was drawn in at the front of the vehicle under ram (under great force) pressure, heated to make it expand, and then exhausted out the back, providing thrust.

The notion of using a nuclear reactor to heat the air was fundamentally new. Unlike commercial reactors, which are surrounded by concrete, the Pluto reactor had to be small and compact enough to fly, but durable enough to survive a 7,000 mile trip to a potential target.

The success of this project would depend upon a series of technological advances in metallurgy and materials science. Pneumatic motors necessary to control the reactor in flight had to operate while red-hot and in the presence of intense radioactivity. The need to maintain supersonic speed at low altitude and in all kinds of weather meant the reactor, code named "Tory", had to survive temperatures of 2,500 degrees Fahrenheit, and conditions that would melt the metals used in most jet and rocket engines.

On May 14, 1961, the world's first nuclear ramjet engine, "Tory-IIA," mounted on a railroad car, roared to life for just a few seconds. Despite other successful tests the Pentagon, sponsor of the "Pluto project," had second thoughts. On July 1, 1964, seven years and six months after it was born, "Project Pluto" was canceled.

The Flying Crowbar

by Gregg Herken
illustrations by Paul DiMare from Air & Space Magazine, April/May 1990, Volume 5 No. 1, page 28.

At the dawn of the atomic age, scientists began work on what might have been the nastiest weapon ever conceived.

Once it switched from booster rockets to nuclear power, Pluto would have been a danger to friend and foe alike.

Sidebar: ***Cutting the Gordian knot*** (see page H-14)

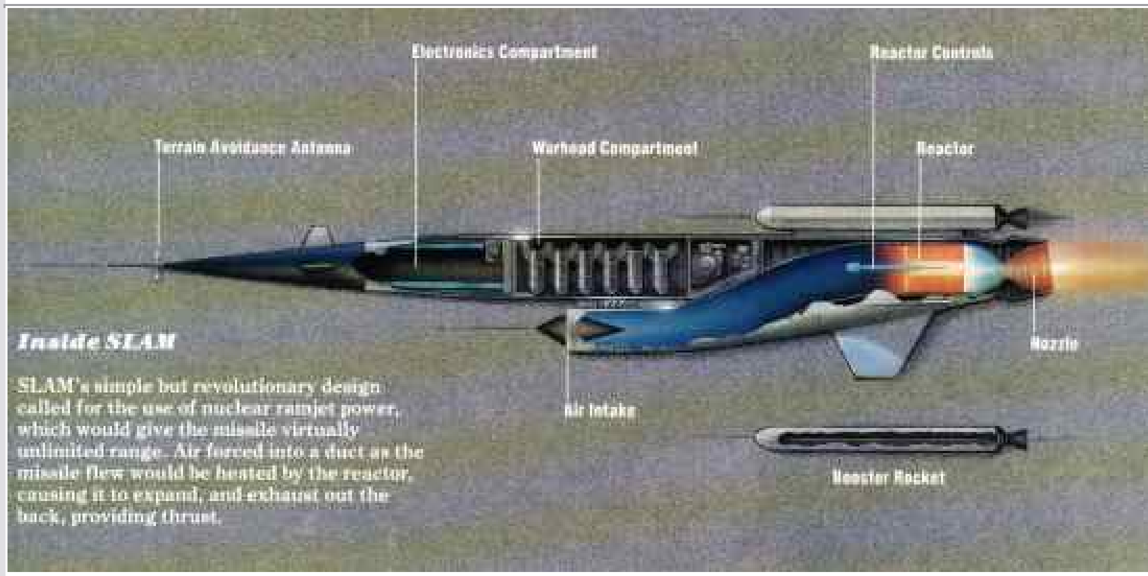
Those who came of age during the era of Three Mile Island and Chernobyl are probably too young to remember the happy days when "our friend the atom" promised electricity too cheap to meter and cars that would run forever without a fill-up. With atom-powered subs like the *Nautilus* cruising under the polar icecap in the mid-1950s, could anyone doubt that atom-powered rocketships, airplanes, and even automobiles would be far behind?

A funny thing happened to that dream on its way to reality: Americans discovered radiation. Project Orion, a futuristic atom bomb-powered rocketship, was grounded in 1963 when the Nuclear Test Ban Treaty forbade atomic explosions in outer space (see "A Spaceship Named Orion," October/November 1988). A nuclear-powered bomber never got off the runway after the Air Force started advertising for pilots past child-rearing age. Later, Congress learned that if such a bomber crashed, the site would become "uninhabitable." *Uninhabitable?*

Less than a decade after the debut of the Eisenhower administration's pro-nuclear power "Atoms for Peace" campaign, nuclear energy no longer meant cheap power and strawberries the size of footballs but man-eating ants and Godzilla.

Fatefully, Sputnik was launched when the dream of the omnipotent atom was still very much alive. Realizing that the Soviets were ahead in missiles, Americans became concerned that they might be ahead in anti-missile missiles as well. To counter that threat, Pentagon planners decided they needed an unmanned atomic bomber or a nuclear-powered cruise missile able to fly below enemy defenses.

What they came up with was SLAM, for Supersonic Low-Altitude Missile. SLAM was to use a revolutionary new type of propulsion: nuclear ramjet power. The project to build the weapon's nuclear reactor was given the code name "Pluto," which also came to refer to the weapon itself.



SLAM's simple but revolutionary design called for the use of nuclear ramjet power, which would give the missile virtually unlimited range. Air forced into a duct as the missile flew would be heated by the reactor, causing it to expand, and exhaust out the back, providing thrust.

Pluto's namesake was Roman mythology's ruler of the underworld -- seemingly an apt inspiration for a locomotive-size missile that would travel at near-treetop level at three times the speed of sound, tossing out hydrogen bombs as it roared overhead. Pluto's designers calculated that its shock wave alone might kill people on the ground. Then there was the problem of fallout. In addition to gamma and neutron radiation from the unshielded reactor, Pluto's nuclear ramjet would spew fission fragments out in its exhaust as it flew by. (One enterprising weaponeer had a plan to turn an obvious peace-time liability into a wartime asset: he suggested flying the radioactive rocket back and forth over the Soviet Union after it had dropped its bombs.)

Like Hula Hoops and Slinkies, Pluto is now an anachronism, an all-but-forgotten remnant of an earlier -- but not necessarily more innocent -- era. At the time, however, deadly as it would have been, Pluto had the almost irresistible appeal of any radically new technological innovation. Like the H-bombs it would carry, Pluto was "technically sweet" to many of the scientists and engineers who worked on it.

On January 1, 1957, the U.S. Air Force and the Atomic Energy Commission picked the Lawrence Livermore National Laboratory, located just over the hills from Berkeley, California, as Pluto's home. Since Congress had recently given a joint project to build an atom-powered rocket to Livermore's arch rival, the Los Alamos National Laboratory in New Mexico, the assignment came as welcome news.

Still, Pluto was not a make-work project or a welfare program for Livermore's highly skilled physicists and engineers. The design and construction of a nuclear ramjet posed a daunting array of technological challenges.

The idea behind any ramjet is relatively simple: air is drawn in at the front of the vehicle under ram pressure, heated to make it expand, and then exhausted out the back, providing thrust. But the notion of using a nuclear reactor to heat the air was something fundamentally new. Unlike commercial reactors, which are surrounded by hundreds of tons of concrete, Pluto's reactor had to be small and compact enough to fly, but durable enough to survive the several thousand-mile trip to targets in the Soviet Union.

The success of Project Pluto depended upon a whole series of technological advances in metallurgy and materials science. Pneumatic motors necessary to control the reactor in flight had to operate while red-hot and in the presence of intense radioactivity. The need to maintain supersonic speed at low altitude and in all kinds of weather meant that Pluto's reactor had to survive conditions that would melt or disintegrate the metals used in most jet and rocket engines. Engineers calculated that the aerodynamic pressures upon the missile might be five times those the hypersonic X-15 had to endure. Pluto was "pretty close to the limits in all respects," says Ethan Platt, an engineer who worked on the project. "We were tickling the dragon's tail all the way," says Blake Myers, head of Livermore's propulsion engineering division.

In the movie *Dr. Strangelove,* the pilot of a low-flying B-52 assures his crew that "they might harpoon us, but they dang sure ain't going to spot us on no radar screen." Pluto would operate on the same strategic principle. In order to reach ramjet speed, it would be launched from the ground by a cluster of conventional rocket boosters. Not until it was at cruising altitude and far away from populated areas would the nuclear reactor be turned on. Since nuclear power gave it almost unlimited range, the missile could cruise in circles over the ocean until ordered "down to the deck" for its supersonic dash to targets in the Soviet Union. Relying upon the same terrain comparison guidance system (TERCOM) used by modern cruise missiles, Pluto would come in below enemy defenses to hit its targets with pinpoint accuracy. Unlike modern cruise missiles, however, one SLAM would be able to strike up to a dozen widely separated targets.

Because of its combination of high speed and low altitude, Pluto promised to get through to targets that manned bombers and even ballistic missiles might not be able to reach. What weaponeers call "robustness" was another important advantage. "Pluto was about as durable as a bucket of rocks," says one who worked on the project. It was because of the missile's low complexity and high durability that physicist Ted Merkle, the project's director, called it "the flying crowbar."

Ted Merkle, Director of Project Pluto

Merkle, a fittingly unorthodox figure at Livermore (see "Cutting the Gordian Knot," p.33), was given responsibility for the design of the 500-megawatt reactor that would be Pluto's heart. The Air Force had already given Chance-Vought the contract for the airframe and Marquardt Aircraft the job of building the rest of the ramjet engine.

Because the efficiency of a nuclear ramjet increases with temperature, "the hotter, the better" became Merkle's motto for the reactor, code-named "Tory." But at Tory's operating temperature of 2,500 degrees Fahrenheit, even high-temperature alloys would become white-hot and lose structural strength. So Merkle asked a Colorado-based porcelain company named Coors to manufacture ceramic fuel elements that could stand the heat and provide even temperature distribution in the reactor.

The company is well known today for a much different product: while making ceramic-lined vats for breweries around the country, Adolph Coors realized that he might be in the wrong business. Although the Coors Porcelain Company continued to make porcelain -- including all of the nearly 500,000 pencil-shaped fuel elements used in the Tory reactor -- the brewery Adolph Coors opened near his ceramics factory soon became the tail that wagged the dog.

But Tory's extreme operating temperature was just the beginning of problems to be overcome. Flying a reactor at Mach 3 through rain, snow, and salt air posed another set of difficulties. Merkle's engineers experimented with a variety of heat- and corrosion-resistant materials for the critical base plates at the aft end of the reactor, where the temperatures would be highest. Just measuring the temperature of the base plates presented a challenge, since heat-sensitive probes would be burned and blasted by Tory's searing heat and radiation. So close were the tolerances that Tory's base plates had an auto-ignition point only 150 degrees above the reactor's peak operating temperature.

The centerpiece of the Pluto effort, the Tory reactor was designed to be durable but compact enough to fly.

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In fact, so many unknowns surrounded Pluto that Merkle decided that it would take a static test of the full-scale ramjet reactor to resolve them all. To carry out the tests, Livermore built a special facility in a desolate stretch of Nevada desert close to where the lab had exploded many of its nuclear weapons. Designated Site 401, the facility --

built on eight square miles of Jackass Flats -- rivaled Project Pluto itself in ambition and cost.

The 25 miles of oil well casing needed to store air for ramjet simulations dominated Pluto's test site at Jackass Flats.

Since Pluto's reactor would become intensely radioactive when run, a fully automated railroad had to be constructed to move the reactor the nearly two miles that separated the static test stand from the massive disassembly building, where the "hot" reactor would be taken apart and examined by remote control. Scientists from Livermore would watch the reactor tests on television in a tin shed located far away from the test stand and equipped -- just in case -- with a fallout shelter containing a two-week supply of food and water.

Just to supply the concrete for the six- to eight-foot-thick walls of the disassembly building, the U.S. government had to buy an aggregate mine. It took 25 miles of oil well casing to store the million pounds of pressurized air used to simulate ramjet flight conditions for Pluto. To supply the high-pressure air, the lab borrowed giant compressors from the Navy's submarine base in Groton, Connecticut. For a five-minute, full power test, as much as a ton of air a second had to be forced over 14 million one-inch steel balls in four huge steel tanks raised to 1,350 degrees Fahrenheit by oil-burning heaters. (Not all dimensions at Site 401 were enormous. When the lab's technicians proved too big to work in Tory's tight confines, a petite secretary from Blake Myers' staff inserted the final set of diagnostic instruments.)

Gradually but relentlessly over the project's first four years, Merkle and his team overcame the obstacles in Pluto's way. After a number of exotic materials had been tried and found wanting as a coating for electric motor armatures, engineers found that exhaust manifold paint -- obtained through an ad in *Hot Rod* magazine -- worked perfectly. When assembling the reactor, the lab's wizards cleverly held support springs in place with mothball spacers, which evaporated after serving their purpose. Another enterprising engineer on Merkle's staff, Richard Werner, invented a way of measuring the heat of the base plates by comparing movie film of the operating reactor to a temperature-calibrated color scale.

On the afternoon of May 14, 1961, as scientists and engineers in the control shed collectively held their breath, the world's first nuclear ramjet, mounted on a flatbed rail car and painted fire engine red, roared to life. Tory-IIA ran for only a few seconds, and at merely a fraction of its rated power. But the test was deemed a complete success. Most importantly, the reactor did not catch fire, as some nervous Atomic Energy Commission officials had worried it would. Almost immediately, Merkle began work on a second Tory -- lighter in weight but even more powerful.

Mounted on a railroad car, Tory-IIC is readied for its highly successful May 1964 test.

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Tory-IIB never got beyond the drawing board, but three years almost to the day after the test of the first reactor, Tory-IIC shattered the desert calm. Tory-IIC was run again the following week for five minutes at full power, producing 513 megawatts and the equivalent of over 35,000 pounds of thrust; less radiation escaped in the reactor stream than had been expected. The test was witnessed -- at a safe distance -- by dozens of admiring AEC officials and Air Force generals.

To celebrate their success, Merkle and his co-workers loaded a piano "borrowed" from the nearby women's dorm onto a flatbed truck. With Merkle at the keyboard the group careened into the town of Mercury, site of the nearest bar, singing bawdy songs. The following morning, subdued but still happy, the celebrants lined up at the lab's medical tent for the vitamin B-12 shots that in those days were thought to cure hangovers.

Returning to the lab, Merkle concentrated on making the reactor lighter, more powerful, and compact enough to be test-flown. There was even excited talk of a Tory-III, capable of propelling the missile to Mach 4.

Meanwhile, at the Pentagon, Pluto's sponsors were having second thoughts about the project. Since the missile would be launched from U.S. territory and had to fly low over America's allies in order to avoid detection on its way to the Soviet Union, some military planners began to wonder if it might not be almost as much a threat to the allies. Even before it began dropping bombs on our enemies Pluto would have deafened, flattened, and irradiated our friends. (The noise level on the ground as Pluto went by overhead was expected to be about 150 decibels; by comparison, the Saturn V rocket, which sent astronauts to the moon, produced 200 decibels at full thrust.) Ruptured eardrums, of course, would have been the least of your problems if you were unlucky enough to be underneath the unshielded reactor when it went by, literally roasting chickens in the barnyard. Pluto had begun to look like something only Goofy could love.

Outside the lab, questions were also being raised as to whether Pluto could do the job it was designed to do -- and indeed, whether that job was still necessary. Although Livermore boasted that Pluto was "destined to be as evasive" as the planet with the same name, military analysts had begun to wonder if anything so big, hot, noisy, and radioactive could go undetected for long. Moreover, since the Air Force had already begun deploying ballistic missiles like Atlas and Titan that would reach their targets hours before the flying reactor, critics charged that SLAM really stood for "slow, low, and messy." The Navy, which had originally expressed an interest in firing the missile from ships or submarines, also began to back away from the project after successful tests of its Polaris missile. Finally, at $50 million apiece, there were doubts that SLAM was worth the price. Pluto was suddenly a technology without an application, a weapon without a mission.

How can you test-fly a highly radioactive missile? One proposal favored flying it over -- and into -- the Pacific.

But what drove the last nail into Pluto's coffin was a question so deceptively simple that the wizards at the lab might be excused for deliberately overlooking it: Where do you flight-test a nuclear reactor? "How are you going to convince people that it is not going to get away and run at low level through Las Vegas -- or even Los Angeles?" asks Jim Hadley, a Livermore physicist and Pluto alumnus who now works on detecting foreign nuclear tests for the lab's hush-hush Z Division. There was, admits Hadley, no way of guaranteeing that Pluto would not become a nuclear-powered juggernaut beyond its inventors' control -- a kind of airborne Frankenstein, a flying Chernobyl.

One proposed solution was to tie Pluto to a long tether in Nevada. ("That would have been some tether," Hadley observes dryly.) A more realistic alternative was to fly Pluto in figure eights near Wake Island, a U.S. territory in the Pacific, then bury the "hot" missile in 20,000 feet of ocean. Even at a time when the AEC was trying to get the public to think of radiation in terms of "sunshine units," the proposed dumping of scores of contaminated missiles in the Pacific was enough to give people pause.

On July 1, 1964, seven years and six months after it was born, Project Pluto was cancelled by the AEC and Air Force. At a country club near Livermore, Merkle hosted a "last supper" for those who had worked on the project, where SLAM tie tacks and bottles of "Pluto" mineral water were handed out as souvenirs. The total cost of the project had been $260 million, in the pre-inflationary dollar of the day. At its peak Pluto had employed some 350 people at the lab and an additional 100 at Nevada's Site 401.

Following Pluto's cancellation, technical director Ted Merkle awarded SLAM tie tacks and appropriately sinister-looking bottles of mineral water to project members.

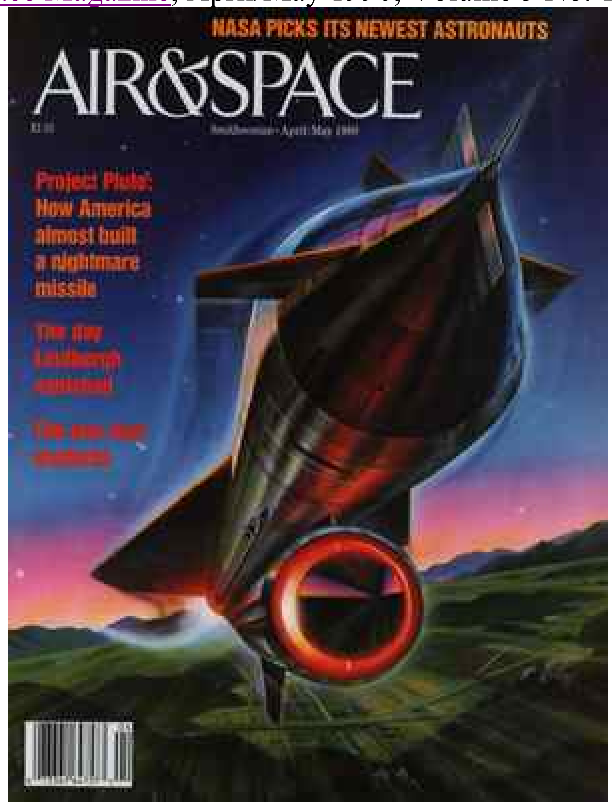
Although Pluto never flew, the exotic materials developed for the nuclear ramjet find application today in ceramic turbines and space-based power reactors. Harry Reynolds, the project physicist for Tory-IIC, now works for Rockwell on the Strategic Defense Initiative.

For some at Livermore, a lingering nostalgia about Pluto remains. "It was the best six years of my life," says William Moran, who oversaw the production of the Tory fuel elements. Chuck Barnett, who directed the Tory tests, succinctly sums up the gung-ho spirit at the lab: "I was young. We had lots of money. It was very exciting."

Every few years, according to Hadley, some fledgling lieutenant colonel in the Air Force discovers Pluto and calls the lab to ask what happened to the nuclear ramjet. Enthusiasm quickly fades, Hadley says, when the questioner hears about the problems with flight-testing and radiation. Hadley has yet to receive a call back.

If someone were indeed serious about wanting to revive Pluto, he would probably find some ready recruits at Livermore. But not many. What was once the weapon from hell now seems an idea best left dead and buried.

Air & Space Magazine, April/May 1990, Volume 5 No. 1, page 28.



Additional information:

- Theodore C. Merkle, "Nuclear reactors for ramjet propulsion," in Lt. Colonel Kenneth F. Gantz (ed.), *Nuclear Flight,* by Duell, Sloan and Pearce, New York, circa 1960, p. 112.
- Barton C. Hacker, “Whoever heard of Nuclear Ramjets?: Project Pluto, 1957-1964,” *Journal of the International Committee for the History of Technology*, *Volume 1*, 1995, pp. 85-98.

“Cutting the Gordian Knot,” Air & Space Magazine, April/May 1990, http://www.merkle.com/pluto/side.html (October 4, 2001)

Cutting the Gordian Knot

This is the sidebar to the article on Project Pluto from Air & Space Magazine

Ted Merkle

As the technical director of Project Pluto at the Livermore lab, Ted Merkle was "a strong wind blowing through the place," says colleague Jim Hadley. To Richard Werner, in charge of developing the base plates for the Tory reactor, Merkle was "a perfect combination of physicist and pitchman -- always running around and shaking things up."

Not all remembrances of him are so kind. One associate calls Merkle "a bull in a china shop." Concedes Hadley, "He wasn't interested in untying the Gordian knot. He cut it."

In fact, Merkle's impatience was legendary. Testifying before Congress on spaceships of the future, Merkle dubbed a nuclear rocket then under development at the rival Los Alamos lab "Old Pokey." He said he wanted to explore the cosmos in a near-light-speed, ion-propelled rocket.

The Pluto project helped steer Merkle's dream of the stars back down to Earth.

Still, he remained impatient. Engineer Blake Myers vividly recalls Merkle driving his old and "totally ripped" Packard convertible at high speed through the lab's parking lot.

Some colleagues attributed Merkle's hard-driving personality to the strain of trying to raise three kids on a teaching assistant's salary. Merkle himself boasted that, while a graduate student at Berkeley in the early 1950s, he was often reduced to feeding his family horsemeat.

While director of Pluto, Merkle forbade "canned briefings" of the military or Congress. "You use chalk and you talk off the top of your head because you know it," he instructed co-workers. "He had no patience whatsoever with people who didn't know how to do things," Werner recalls.

That included his doctors. Merkle, diagnosed as having liver cancer about the time Project Pluto was cancelled, became frustrated with what he felt was the glacial pace of medical technology. Together with Werner -- the engineer who devised an ingenious way of taking Tory's temperature -- he invented an early version of the CAT scan using the lab's computers. "We made a topographical map of Merkle's liver," Werner says.

The patient himself watched the inexorable course of his disease with equanimity. "He knew there was no cure," Werner recalls. "His interest was scientific."

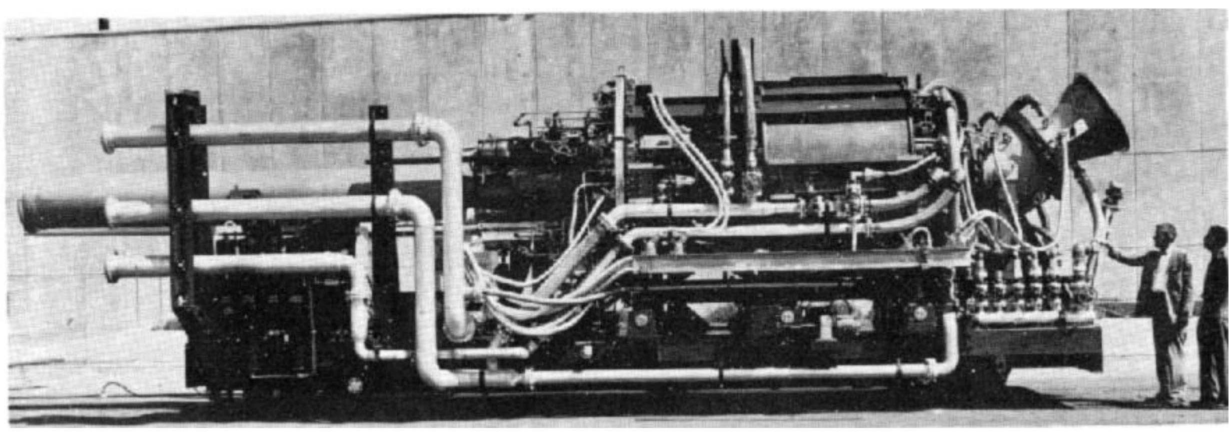
NUCLEAR SPACE POWER IN THE 1960S – NUCLEAR THERMAL PROPULSION

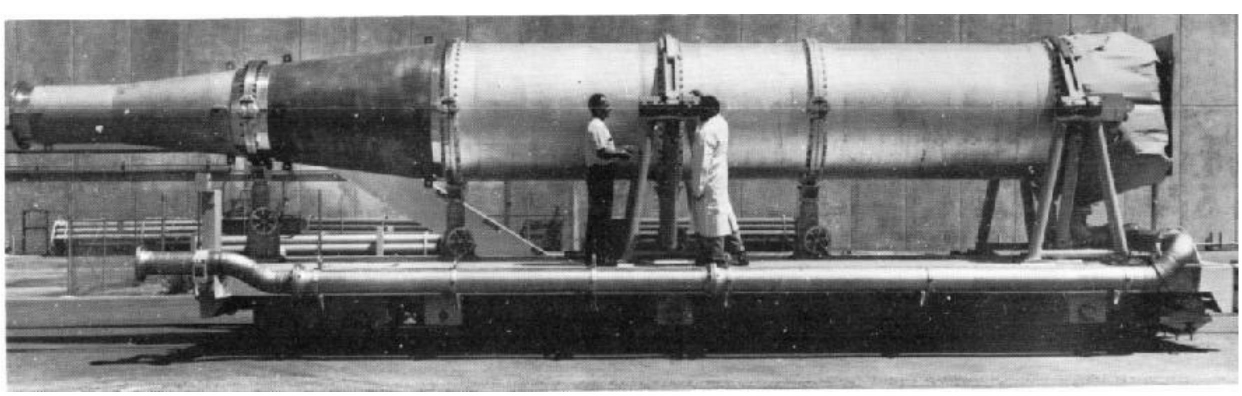
Federation of American Scientists (FAS)

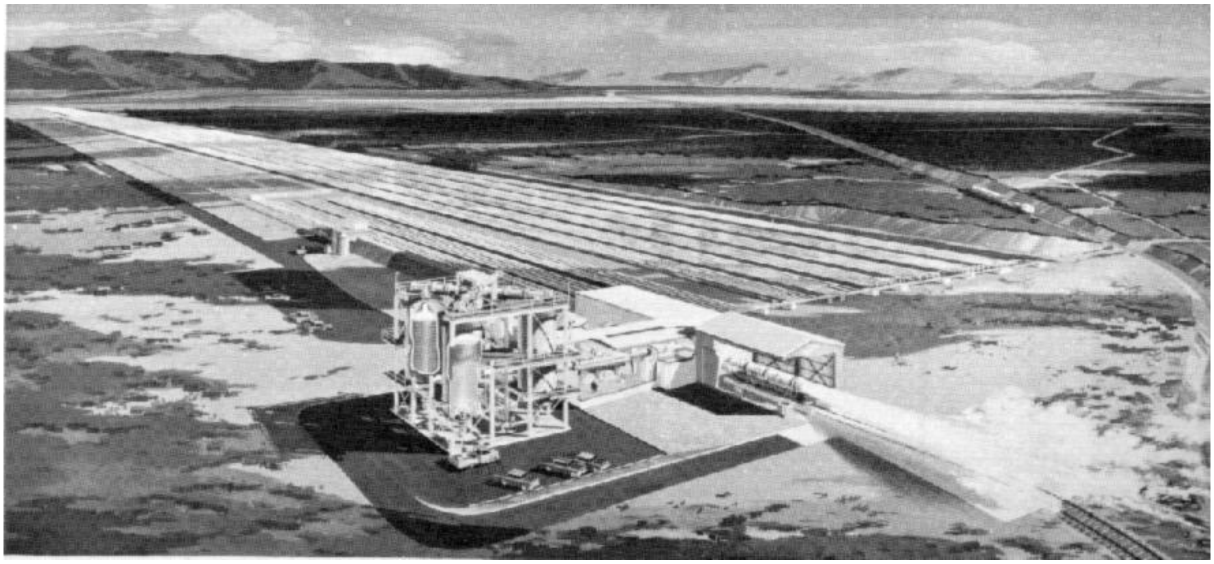
http://www.fas.org/nuke/space/c05other.htm

PLUTO

Lawrence Livermore National Laboratory is the leading proponent of the PLUTO Derivative, PLUTO/NERVA Derivative Reactor, and UB_2 Reactor concepts, which have been evaluated for SDI power applications.(1) These reactor concepts draw on the experience LLNL accumulated in the PLUTO nuclear ramjet program in the 1960s. Along with Idaho National Engineering Lab, Livermore has also investigated Fission Fragment Rockets of the type advocated by Sandia.(2)







B - 710 REACTOR PROGRAM

The General Electirc 710 reactor program was initiated in 1962, to capitalize on the ceramic fuel elements developed under the Aircraft Nuclear Propulsion program.[(3)]

The initial goal of the program was the development of fuel elements for both open and closed cycle fast spectrum reactor systems. Primary characteristics included:

Cycle	Open	Closed
Operating Temperature	2750° K	2420° K
Operating Time	10 hours	
Coolant	hydrogen	inert gas
Restart Cycles	100	100

The selected fuel element was a tungsten matrix impregnated with UC_2, with a tantalum cladding to provide structural support, protect the fuel from hydrogen erosion, and retain fission products. Subsequent development focused on a sintered tungsten fuel particle with a diameter of 1-2 microns.

However, before testing could begin on these configurations, program objectives were reoriented toward development of a closed cycle neon-cooled 10 MW reactor with an outlet temperature of 2420 K.

Program objectives were again reoriented in July 1965, when the goal was established of developing a reactor with a 200 kWe output over a 10,000 hour lifetime. Use of a Brayton conversion cycle mandated a core operating temperature of 2000 to 2250 K. Uranium Nitride was substituted for Uranium Oxide as the fuel.

This program was cancelled in 1967, after having conducted some testing of fuel particle elements.

<u>SOURCES</u> [verbatim from Federation of American Scientists (FAS)]

1. Marshall, A.C., "A Review of Gas-Cooled Reactor Concepts for SDI Applications," SAND87-0558, (Sandia National Laboratory, Albuquerque, NM, August, 1989).

2. Chapline, George, et al, "Fission Fragment Rockets -- A New Frontier," 50 Years With Nuclear Fission, National Academy of Sciences and National Institute of Standards & Technology conference, 25-28 April 1989, (American Nuclear Society, La Grange Park, IL, 1990), pages 601-605.

3. Horman, F.J., et al, "Particle Fuels Technology for Nuclear Thermal Propulsion," AIAA/NASA/OAI Conference on Advanced SEI Technologies, Cleveland, Ohio, 4-6 September 1991, Paper AIAA 91-3457.

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