DOE's Way-Out Reactors

The Department of Energy wants to spend $72 million next year to design and build reactors for military space applications; nothing like them has been built before

FROM a public relations standpoint, 1986 may not be the best year to ask Congress to buy military reactors to be sent into space aboard the shuttle. The space program is crippled. The axe of Gramm-Rudman may fall heavily on engineering projects, and if some congressmen have their way, it will fall most heavily on those with a military cast.

Nevertheless, the Department of Energy (DOE) wants to build several minireactors and is making a pitch for them now. DOE cannot tarry. Already it has made promises about a device it hopes to deliver to the military by 1993, a reactor called the SP-100 that will generate far more power than anything that has been put in orbit.

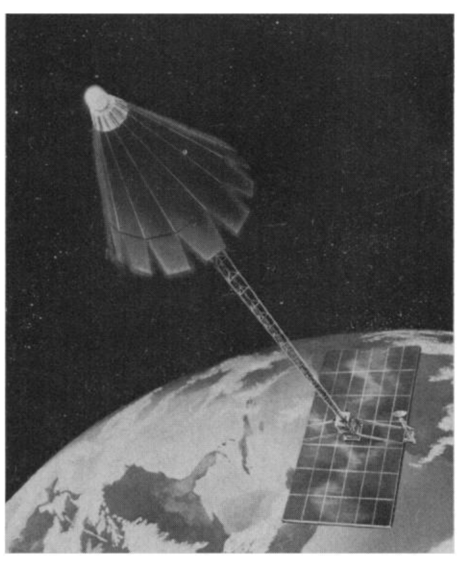
According to Gerold Yonas, chief scientist for the Strategic Defense Initiative Organization, the SP-100 will be the "cornerstone" power station of the entire SDI effort. It will not deliver enough power to run directed energy weapons that pierce the atmosphere. Rather, it will be used as a no-maintenance, general source of energy for the military's infrastructure in the heavens. Weapons-scale power will come later.

DOE must get rolling soon, to support not only its own promises but those of the Strategic Defense Initiative. Building this reactor will be a formidable engineering feat, a crushing task to complete in the 5 years allotted. Many novel components will have to be devised and made to work in harmony for the first time. DOE promises that the next step to follow the SP-100, the multimegawatt reactor, will have enough power to run directed energy weapons. But, by expert forecast, this totally new technology will not be ready for flight testing before the 21st century, after the SP-100 has proved itself.

Despite its new importance, something like the SP-100 was envisioned long before "Star Wars." In earlier days, its purpose was to power civilian structures such as the space station and orbiting commercial labs. Now the President has declared the Strategic Defense Initiative to be first among equals in space technology, and this has pushed other missions aside. For DOE, it means that civil nuclear R&D projects will yield to those with a military-space connection. (See "Utilities press Congress to salvage nuclear R&D," *Science*, 14 March, p. 1241.)

This shake-up reflects what the White House wants. It reflects another kind of strategic defense as well, the type practiced by civil servants who have lived through many fads and intend to survive this one, too. One senior DOE scientist says: "The practicality of it is that there just isn't enough money to go around right now." The "bright hope of many program managers" is that they can "tie their programs to SDI, which is relatively immune to budget cuts." But he had doubts about DOE's public rationale for this move, the argument that space reactors will somehow benefit the commercial nuclear business. Undoubtedly the research will produce new materials and electronics of value, but few argue that the reactors themselves will have any application except in space.

Because the SP-100 is a liquid metal system, facilities built for the breeder and other liquid metal reactors can be converted to support this new R&D thrust. The conversions have begun. If Congress approves, about $23 million will be spent to refurbish a building at the Hanford Reservation in Richland, Washington, where the SP-100 ground test will start in 1990. Smaller improvements will be made elsewhere. Three agencies—DOE, NASA, and the Strategic Defense Initiative Organization—signed a memorandum of agreement last October to fund this work jointly. They have spread the work around. It will involve federal labs in California, Idaho, Illinois, New Mexico, Ohio, Tennessee, Washington, and perhaps New York.



Orbiting nuclear power station

Sitting atop the cone is a small SP-100 reactor, radiating waste energy through an umbrella-like structure of heat pipes. The electric power is sent to the platform below.

The entire ground test will cost $450 million through 1991, about half the funds coming out of DOE's budget and most of the rest from the Strategic Defense Initiative Organization. NASA will contribute a small share. At some point before 1991, the three agencies will probably request another $500 million for a flight test.

The driving force behind this effort is the realization that space weapons will need a power source unlike any that has been launched before. By conservative estimate, military platforms will require generators that produce at least several hundred kilowatts of power each (a kilowatt being a thousand watts)* just for "housekeeping" chores. In a crisis, space weapons will need 100 to 300 megawatts (300 million watts), far more capacity than is envisioned for any radioactive system now in reach.

The largest solar-powered vehicle ever sent aloft was Skylab. It generated about 15 kilowatts, or between one-twentieth and one–one thousandth of what is needed on a military platform. The solar collecting panels used by vehicles like Skylab are hard to maneuver, easy to damage, and highly vulnerable. For this reason, the consensus is that the Strategic Defense Initiative cannot depend on solar power. It will be powered by radioactive devices. The latter are compact, relatively hard, and light. Another option, chemical generators, can provide large bursts of energy. Chemical power is being considered, but with present technology it would be prohibitively heavy and could emit laser-blinding fumes.

The radioactive power sources now used by the United States, called radioisotope thermoelectric generators (RTG's), are fairly weak. They are not reactors at all but packages of slowly decaying plutonium-238 that emit heat as they decay. They have no moving parts. The heat stimulates an electric

*Wattage numbers in this article refer to electric output, which in space reactors may be less than 20 percent of thermal output.

current in thermoelectric materials, providing power, even in the absence of sunlight, for many years. The 9-year-old Voyager probe runs on an RTG, for example, and large RTG's will power the Ulysses and Galileo missions that once were scheduled to go on the shuttle this spring.

While they are reliable and long-lived, RTG's are not efficient, wasting 93 percent of the heat they produce. The biggest RTG's put out only 300 watts or so. If redesigned to generate a great deal more power, they would be very large, demanding huge amounts of plutonium and raising very serious concerns about portage aboard the shuttle. It may be possible to add a heat engine to an RTG, raising output to between 1 and 10 kilowatts. One DOE research project will attempt to do just this in the next few years. But to get a significant increase in power for a strategic platform, a new device will be needed. This is where reactors, fueled by highly enriched uranium-235 and cooled by pumped liquid metal, will play a role.

On 27 February, DOE took its plans for the first step along this path to Capitol Hill to present them to Representative Marilyn Lloyd's (D–TN) energy research and production subcommittee. The budget review is a friendly gathering, bringing together DOE managers and the politicians in whose districts DOE spends much of its R&D money. But DOE's reception this year was chilly. Assistant Secretary for nuclear energy James Vaughan was peppered with questions about cutbacks in civil programs and laboratory layoffs in Tennessee and Illinois.

Meanwhile, opponents of nuclear power and the space defense program are sharpening their knives. They ask whether DOE can really expect to deliver these high-powered reactors within the time and cost limits promised. Representative Edward Markey (D–MA), chairman of the energy conservation and power subcommittee, also has challenged DOE's assurance that it is safe to put nuclear materials aboard the shuttle. At a hearing on 26 February, he roundly criticized DOE Secretary John Herrington for creating a "Frankenstein" by "seeking to militarize the civilian nuclear energy research program."

The total cost of the space reactor program in 1987, DOE says, will be $71.7 million, about $51 million more than last year. The money will pay for conceptual work on one large system and testing of two small ones. The conceptual study (costing $23.7 million this year) will look into the far-off multimegawatt reactor or MMW proposal. "The requirements are so poorly defined," says an expert at one lab, "that it's virtually impossible to know what you mean when you say 'multimegawatt.' " Its development will take 10 to 20 years, he said. At this point, the intended output is unfixed but fantastically large, at least 1000 times greater than the one successful reactor sent into orbit by the United States in 1965. This 1960's device was called the SNAP-10A, and it achieved a level of 500 watts in a brief, 43-day run before an electrical part failed. It is still orbiting.

Aside from conceptualizing the MMW, the agency has two major projects in mind. One involves design work on DIPS, the dynamic isotope power system ($15 million this year). This is an attempt to improve

Shooting Plutonium into Space

Radioactive devices have been shot into space since the early 1960's with no apparent injury to life or limb. But there have been several accidents. Of approximately 43 U.S. and Soviet satellites carrying "hot" loads, at least four have ruptured and contaminated the environment. That suggests an uncomfortable failure rate of almost 1 in 10.

One of the failed devices was American, the SNAP-9A. It burned up on reentry in the atmosphere in 1964, dumping more plutonium into the atmosphere than open-air bomb tests. Since then, U.S. devices have been redesigned. Now, if they fall, they are meant to stay intact. So far, this approach seems to have worked. Two U.S. radioactive packages have fallen to earth; one was fished out of the water off California, and another left intact on the ocean floor in the South Pacific.

But it is still unclear whether enough care has been taken to guard against catastrophic events. Suddenly, the question has become urgent. The Challenger explosion of 28 January has given credence to scenarios that not long ago were called virtually impossible. The Challenger flight planned for this May would have carried the first radioactive package on the shuttle, one of the largest ever. This package is really double, being two radioisotope thermoelectric generators (RTG's) for the Galileo spacecraft, containing a total of nearly 21 kilograms of plutonium-238.

RTG's are less complex than reactors. While the Soviets often use reactors—one of which fell on Canada in 1978—the United States has sent only one into space and at present relies on RTG's. A new space reactor using uranium-235 should be ready by 1993. According to the Department of Energy, it will be less hazardous than plutonium-burning RTG's. However, a Los Angeles nuclear watchdog group, the Committee to Bridge the Gap, says there is a possibility that a reactor could go critical if dropped into the ocean. This hazard will be prevented, according to DOE, by a novel and still unfinished design.

Some RTG hazards were reviewed in a hearing held on 3 March jointly by the House space applications and the energy research subcommittees. The chairpersons, Bill Nelson (D–FL) and Marilyn Lloyd (D–TN), seemed reassured by official testimony. Nelson told *Science* that he was satisfied with estimates given by DOE and NASA that a catastrophe had very little chance of occurring, about "1 in 10,000,000."

However, the hearing revealed that this estimate rests on two key assumptions, both of which are disputed. The first has to do with the chances of a catastrophic explosion that might blow apart an RTG. NASA has maintained that the odds are minuscule.

It came out in the hearing that the Air Force Weapons lab, which had partial responsibility for RTG safety, did not trust NASA's numbers. An independent contractor working in conjunction with the Air Force and the RTG builder came up with a fairly alarming estimate. Based on a reading of 1900 solid rocket firings back to the 1950's, the contractor—Sierra Energy and Risk Assessment—found that the mean risk of a rocket failure was 1 in 70. The failure of one solid rocket, as Challenger showed, can cause a huge explosion.

NASA's own failure estimate, its chief engineer Milton Silveira said at the hearing, was 1 in 100,000. The number seemed plausible until 2 months ago, when the shuttle exploded on its 25th flight. Asked to explain how NASA generated an estimate so much different from Sierra's, Silveira said NASA did not use historical data because they did not take account of NASA's high quality control standards, or of the improvements NASA had made in these rockets. NASA's estimate was based, in essence, on its own judgment.

upon existing RTG technology by adding a cooling system and an engine.

DOE's other development project and its main thrust will be to produce the SP-100, a 300-kilowatt reactor. A feasibility study was completed last year; a contract is to be let this summer; and preparations for a ground test are to begin in the fall. DOE's contribution is to be $30 million this year.

The clearest promise in DOE's agenda is that by 1993 it will have the SP-100 in hand, fully tested and ready to fly. Both the power size and the delivery date are a bit slippery, earlier given as a 100-kilowatt reactor to be ready in 1991. The device will fit into one-half (earlier one-third) of the cargo bay of the shuttle. The reason for confusion is that feasibility studies were based on a 100-kilowatt device. But DOE has confidence that its engineers can transform the 100-kilowatt study into a 300-kilowatt reactor, given extra time and a little more space in the cargo bay.

Size is crucial, for the reactor will have to leave room in the shuttle for the defense gear it is to power and for a rocket that will carry the entire bundle to deep space. The shuttle cannot reach high orbit. Vincent Truscello, program director for the SP-100 at NASA's Jet Propulsion Laboratory, says that the reactor will be designed to go up as part of a complete package, but that it may be necessary, if other parts of the package turn out to be large, to carry the parts up separately and assemble them in space.

There will be many "firsts" in this program. The SP-100 will be the hottest-running reactor ever built, running at 1350 Kelvin. Although research has ventured near these areas, this reactor will be the first space system to use uranium nitride fuel; the first to be cooled by liquid metal lithium; the first to circulate a secondary coolant without pumping, in a no-gravity environment, through wicks in a "heat pipe" radiator; the first to use strong (and potentially brittle) refractory metals to contain the primary coolant; the first to have to start up with its coolant frozen; the first to have two independent control mechanisms (for safety); and the first to use electronic semiconductors under such intense heat and radiation stresses. Furthermore, the components will run in an environment that is at once extremely hot and extremely cold. They will have to work without maintenance for 7 years, a feat to put the Model T to shame.

One top DOE official in Washington agreed that the SP-100 program is "very ambitious," but noted that the feasibility studies found "no technical roadblocks." David Buden, an expert in space power systems at Science Applications International, said, "I argue with different parts of the schedule, but I think it's very do-able." He pointed out that the SNAP-10A space reactor was built in 7 years starting from a much narrower technological base in 1958. In the present case, he said, "They're not counting on technological breakthroughs, but there certainly will be engineering challenges that could bite you."

All promises are off, of course, if funds do not come through in the quantities DOE has anticipated. This key variable—the money—is caught up in the guns-versus-butter struggle being played out on Capitol Hill. ■ ELIOT MARSHALL

The Sandia National Laboratory was called in as a referee. At the hearing, Sandia's David Carlson testified that he found merit in both sides of the argument and suggested a compromise at 1 in 1000. NASA rejected this as still overstating the risk. The debate remains open.

Parallel with the dispute over rocket failures is another less publicized dispute. It has to do with the likelihood that the RTG would survive intact if it were caught in a blast.

Until the fall of 1983, no one had tested an RTG for survivability in a live explosion. "Shock-tube" tests in the laboratory showed the casing would remain intact at blast overpressures up to 1070 pounds per square inch (psi), and the design strength was said to be 2200 psi. The Challenger explosion appears at first look to have generated a low overpressure of around 200 to 400 psi. On the basis of this, NASA and DOE spokesmen said in the hearing that if an RTG had been aboard, it almost certainly would not have ruptured.

But back in 1983 DOE researchers put together a lifelike test called "Project Direct Course." It was piggybacked onto a military detonation on 23 October 1983 at the White Sands, New Mexico, Air Force base.

The overpressures in Direct Course were meant to be 1300 psi, but were probably greater, for they destroyed the measuring instruments. In a computer analysis, the Lawrence Livermore National Laboratory figured the overpressure to have been as high as 1800 psi. The effects were catastrophic, and the implications for public safety not reassuring. A mock-up RTG was totally destroyed and scattered over the entire 75 by 200 meter test plot. The fuel elements were so finely divided that a cleanup crew recovered only 70 percent of the original mass.

Since then, DOE has run several other studies, including more potent shock tube tests. The effect has been to undercut the Direct Course data. In the words of DOE's "Explosion Working Group Report" of July 1985, the explosion test data "cannot be applied to launch abort scenarios" because the parameters were "not sufficiently well known to draw direct conclusions" and because "explosion products" in the test did not resemble those of a shuttle explosion. Thus, DOE has discounted the only hard data from an explosion.

DOE and NASA do not make the final decision on whether or not a particular mission is safe. That is done by the White House science office, following recommendations made by a group known as the Interagency Safety Review Panel (INSRP). In the case of the Galileo and Ulysses RTG's, the panel was due to give its final report to the White House on 18 February. But when the shuttle exploded, all work came to a halt.

NASA's delegate to INSRP, Leven Gray, maintains that the group had reached no conclusions, even though its deadline was only 3 weeks off. Further, he says he thinks the data from Direct Course were not terribly significant. "Early on, it was a very significant issue, but later, DOE had run some additional tests which made the issue a lot less substantive. . . . It was not as big a deal."

One federal laboratory scientist who has followed the discussion thinks Direct Course is a big deal. He says the debate over whether or not RTG's can withstand a Challenger-type blast is very much alive in the technical community. Even if Direct Course did not mimic a shuttle explosion precisely, he says, "Some people thought very carefully about that experiment when they designed it." One threat to the RTG that is hard to analyze is flying shrapnel. It also may be one of the most important. DOE has studied this problem very little, as agency witnesses confirmed in the hearings. Flying fragments may have destroyed the RTG mock-up in Direct Course, and if so, that would make the test quite significant. Such fragments may be present in any big explosion. "You have that data point," says the DOE scientist,"you can't just throw it away." ■ E.M.