ly with space-based satellite, sensor, and laser and particle-beam requirements of the Strategic Defense Initiative (SDI).

SDI Chief Scientist Dr. Gerold Yonas testified at an Oct. 11 congressional hearing on nuclear power for space: "Just the baseload or housekeeping SDI requirements (i.e., power to maintain satellites and sensors in peacetime) are an order of magnitude greater in power level than our present experience in space power. The weapons levels power requirements (i.e., to fire laser, particle-beam, and other anti-missile weapons repeatedly), being 10,000 times greater in power level and voltage than present systems, are truly unprecedented.

"Breakthroughs, innovative concepts and truly imaginative applications of conventional wisdom will be required."

The Reagan administration has acted to revive space nuclear power development in the United States, which entered a prolonged deep-freeze in the early 1970s after Lyndon Johnson had cut down the NASA program in mid-development. Present plans for reviving space nuclear power, being centralized under the SP-100 program of the DOD, DOE, and NASA, are as follows.

For power requirements in the space exploration programs, and on various satellites, in the range of 1-1,000 watts of electric power, Radioisotope Thermoelectric Generators (RTGs) will be used, employing the heat of isotope decay, through special thermoelectric materials, to directly generate low-power electric current. RTGs are projected to operate at 6-7% efficiencies.

GE's PRISM—a mass production breeder reactor

General Electric was awarded the Department of Energy contract in October 1984 for the design of an innovative modular liquid metal breeder reactor to be the focus of the government's breeder program after the cancellation of the Clinch River plant. GE competed with three other U.S. nuclear suppliers for this 39-month contract, which is $6 million for the first year. PRISM, Power Reactor Inherently Safe Module, is about 135-megawatt-electric (MWe) electric and designed for factory assembly and transportation to the site on a railroad car. Any number of modules can be grouped at a site, depending on the needs of the buyer.

The most interesting aspect of this reactor is that it incorporates all the advantages of smaller, factory-assembled reactors with their passive safety systems, plus it breeds enough fuel to feed itself. (It does not breed fuel for additional reactors.) PRISM is liquid-metal-cooled with a low-pressure, high-boiling-point coolant (sodium). Its nuclear envelope or nuclear island is self-contained and the parts are designed to be shop-fabricated, assembled, and shipped to the plant for rapid installation. Their updated design calls for embedding each reactor unit in a silo underground with the steam generator by its side in another silo. The rest of the plant is conventional in design. PRISM is a pool-type reactor with simplified safety systems.

Commercial PRISM plants would have three segments or power blocks, each with three PRISM modules. The segments would be functionally independent; that is, each would have its own intermediate heat transfer system and steam supply, but the various reactors would have a common tie at the steam drum. Low-pressure liquid sodium is circulated through the core by four cartridge-type electromagnetic pumps. Heat is transferred from the hot primary sodium to sodium in a fully isolated intermediate system by means of four heat exchangers. These intermediate heat exchangers are connected to a common header that leads to a separate steam generator.

The containment vessel is 19 feet in diameter and 64 feet high, and the whole assembly (without fuel) weighs 950 tons and is shipable by rail, barge, or road. There are 48 fuel assemblies in the core, which is about 52 inches in diameter and 40 inches high. The breeder blanket has 66 uranium oxide assemblies. The design will also accommodate the new fuel assembly proposed and tested by Argonne, which avoids many of the problems of an oxide fuel. GE is waiting for two more years of tests on this metal fuel before making a final decision. The company notes that the latest experiments with oxides are improving the oxide fuel as well. PRISM would have to be refueled once a year; it breeds this fuel at a slightly faster rate, which takes into account any losses during the reprocessing and fuel fabrication.

There is a seven-foot concrete shield around the unit. The reactor has a double containment system, with the second vessel to keep the sodium from leaking if there is an accident and thus make sure that the core would always be covered. The first containment is the reactor vessel itself, which operates under a pressure of one atmosphere. A new design feature of PRISM is its passive decay heat removal system, called RVACS, for radiant vessel auxil-

For space power requirements of 1-10 KWe, scientists are developing the "dynamic isotope power system" (DIPS), which also uses isotope-decay heat, but employs a miniaturized vapor-cycle or gas generator, and an alternator, to achieve 15-20% efficiencies. These Brayton (gas) and Rankine (vapor) cycles have been extensively tested over years, and are both reliable and weight-efficient for use in space.

Requirements of 100-300 KWe are the central target range for new space nuclear-power concepts in the SP-100 Program; the first-stage analytical work of the program has focused on the development of another type of thermoelectric reactor, known as the "out of core" thermoelectric design. But for power requirements of "multi-megawatts" power and more, the new concepts are yet to be defined.

Reactor prototypes such as the CAREM or the Power TRIGA will not directly meet this space power demand; they would have to be made much smaller, while still producing the same or greater levels of power, particularly in surges. But with the SDI, 15-50 MWe of power is the level toward which space nuclear-power demand is headed (along with new reactors of similar power levels to fire anti-missile beam weapons from the ground into space), and the two long-range demands for these reactors will feed each other's development. The demand for nuclear power in space, while understood for decades, has not been seen in these power levels before, except by those scientists who have thought of transporting nuclear power sources to colonies on the Moon or Mars.

iary cooling system. RVACS removes the reactor's heat whenever there is a loss of off-site power, or the feedwater or circulating water systems fail, or there is any incident that causes a loss of the normal energy conversion systems in the non-nuclear part of the plant. No mechanical devices—dampers, valves, pumps, fans, and so on—are involved, and there is no piping to fail. The shut-down heat path consists of radiant heat transfer from the reactor vessel to the containment vessel, where the heat is removed by the natural circulation of air between the containment vessel and the concrete wall. There is also a series of electrical vaults around the base of the reactor to provide emergency power and automatic controls to shut down the reactor if there is operator failure or equipment malfunction.

If the intermediate heat transport system is lost, the sodium temperature increases to a peak of 1,105°F., which is less than the "upset" temperature of the sodium (1,200°). Thus, the reactor core can be adequately cooled. Even in the unlikely event of a blockage of the air flow over the containment vessel, a safe sodium temperature will be maintained by radiant heat transfer from the containment vessel to the concrete shield, GE says. As is the case in the smaller reactor designs, thermal radiation, "a basic law of nature," is thus used to assure safe shutdown "under all foreseeable conditions."

The installation of the system is done using an overhead crane, enabling the reactor to be moved for resiting or for replacement and decommissioning. Thus the site itself can be reused simply by inserting a new reactor module into the old silo. For each three groups of three modules, there will be one reactor service building, one control/administration building, and one mobile refueling rig. The present reference design would construct each site in segments of about 400 MWe, with the final result a 1,200 MWe plant.

In the GE timetable, PRISM plants are expected to be commercially available at the turn of the century. They assume a three-year concept design phase, a nine-year assembly design and safety test project, and then a commercial demonstration plant. They feel it necessary to go through these 12 years, "in view of the uncertainties now associated with nuclear power."

A crash program

But starting from scratch, GE production managers estimate that it would take 12-18 months to build the factory to produce the modules. They are already looking at sites to convert for such factory production. Mostly these are old nuclear component sites, like Chicago Bridge and Iron, Foster Wheeler's Panama City, Florida site, and a Babcock and Wilcox site. In those 12 months, they would also accumulate the materials necessary for the factory to begin production. It would then take an additional 36 months to begin to turn out modules. Once everything was geared up, they estimated they could turn out one module every 3.5 months.

The estimated requirement for construction on-site is 34 months, but this could overlap with the production cycle. Once the factory was set up and the materials were in the pipeline, they estimate a 34-month schedule for each power block of 3 modules. For a 1,200 MW total station, they estimate 49 months to complete. They are working on a design whereby they could put one module on line at a time, thus supplying power right away at some level. With a revived demand for nuclear power, they expect that they would have modules on the shelf and be ready to ship them as fast as the orders came in.