# Argentina plans to mass produce nuclear power

*Paul Gallagher reports on Carem Project, Argentina's prototype project for mass production of small nuclear reactor modules.*

The capacity of the nations of the Western world to produce nuclear energy, has dropped drastically in the past decade, as those nations have fallen under the brutal grip of the International Monetary Funds, and the devastating impact of the post-1979 "Volcker interest rate regime" in the United States. The current last-chance revolt of Third World nations against the IMF, demands the immediate availability of new nuclear power capacity for both electricity and industrial/chemical heat.

Efforts at recovery mobilization, such as the newly announced Alliance for Latin American Integration, and moves to expand the Andean Development Bank to displace the IMF among those nations, cannot succeed without the ability to add high-quality nuclear power to electrical grids at the maximum reliable pace. The high energy-density of nuclear power, both produces very high concentrations of power for a given-size power plant, and can produce high-quality process heat for both industry and agricultural production at the same time. Nuclear power can rapidly eliminate the high money costs, and even the higher labor costs, of providing fuel for heat and power, which are the scourge of underdeveloped areas.

Argentina's new prototype project for the mass factory production of small nuclear reactor modules, capable of being quickly taken by truck or barge to virtually any region of the continent, is important both because it demonstrates an indigenous Ibero-American capability to supply the area, and for the intrinsic merit of its design. The Argentine prototype, which is scheduled for completion by the end of this year, is known as "Proyecto Carem" (Carem Project); it is designed and engineered by an experienced nuclear firm—INVAP, S.A., of Barriloche, Argentina—linked to the Argentine nuclear energy commission. The CAREM prototype will demonstrate nuclear reactor modules in the power range of only 15-30 megawatts-electric (MWe), which can be serial-produced by factory methods and then either used individually or combined into clusters of up to 200 MWe total power.

A recent survey of the world's nuclear power industries by the Fusion Energy Foundation (FEF), has shown that the Argentine concept—small nuclear reactor modules for mass production—is now shared by most major nuclear technology firms in North America, Europe, and Japan. No fewer than 10 firms, including the nuclear giants such as General Electric, Germany's Kraftwerk Union, etc., are preparing a capability to factory-produce reactors ranging from 11 MWe to 300 MWe. Most of these, however, are in the conceptual design phase. It should be noted that the general preference is toward the upper end of the range, particularly for use in the advanced sector.

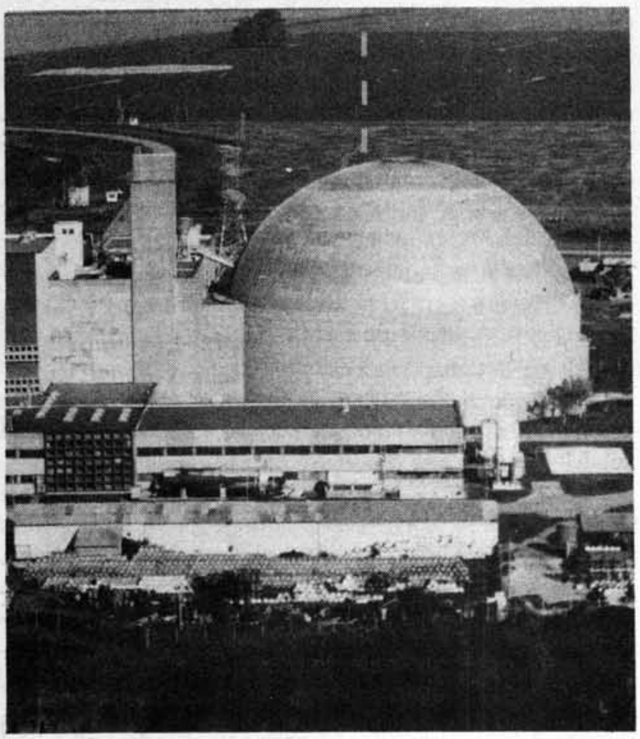
Argentina's INVAP has gone the furthest to prototype production, it is prepared to produce 95% of the reactor's components within that country, and is seeking the markets and the production partnerships with industrialized nation's firms, to produce "CAREM" on a mass basis. This is because INVAP's motivation is explicitly to provide widely available nuclear power sources to underdeveloped nations for industrialization needs.

The FEF's survey found that, with the exception of a potential Italian-Argentine collaboration, the small-reactor projects in the United States and Europe were taking place in ignorance of the Argentine work. This situation is a product of the disarmament lobby's decade-long campaign to isolate and slander the Argentine nuclear program, and should be immediately rectified.

## Real efficiency of scale

As long ago as March, 1984, at a conference of the International Atomic Energy Agency (IAEA) in Lima, Peru, Argentine nuclear representatives argued that the idea of continuous economies of scale, as nuclear power reactors got larger and larger, had not proved itself true over the last 15 years, even in the industrialized countries. As reactors were scaled up from 500, to 1,000, and then to 1,100-1,300 MWe, with higher and higher operating pressures and pressure differentials within the steam generator and cooling systems, the application of the same light-water and pressurized-water designs which worked reliably at smaller sizes, produced sharply increasing "down-time" for repairs of leaks, generator problems, etc. The nightmare of environmental regulations placed increasingly complex and contradictory demands on the same nuclear plant subsystems, sharply reducing both reliability *and* safety, as every competent power engineer now agrees.

The result—50% and even higher "down-times"—robbed the expected economies of scale even when reactors did, miraculously, get operating approval. The only exception has been the French nuclear industry, unquestionably now the world's leader, which has come as close as large reactor sizes allow, to standardized, mass-production of a single reactor design. Small-sized reactors, by contrast, can be produced in factories using pre-stressed concrete or steel containments and standardized subsystems, allowing a breakthrough to much higher rates of production, and with the new designs now being pioneered, greater reliability of operation.



*Argentina's Atucha I nuclear reactor. The International Monetary Fund has frozen large-scale projects like this one, but Argentina has come up with a plan to mass-produce small, modular reactors.*

Third World nations have such extreme electricity shortages for housing and agriculture, not to speak of industrialization, that they cannot tolerate the typical *minimum* of seven years construction and licensing for a nuclear power reactor to come on-line; nor does the large size of the final addition to the grid compensate for this—quite the opposite. The IAEA itself, in its most recent world power surveys, emphasizes that no single unit in a national electricity grid should account for more than 10% of its total capacity, "if the dynamic stability of the system is to be ensured." It is difficult, and degrades reliability, to connect a big power plant to a weak grid, and is far more useful to distribute several smaller plants near the high consumption centers of the grid.

Even more important for an underdeveloped nation with an inadequate power grid full of "holes" in especially backward rural areas, the crucial objective of industrial and agricultural development is the relatively rapid, *continuous* addition of high-quality electric power increments. Particularly for nations without plentiful, easily-tapped hydro-electric power sources, this can only be done with nuclear reactors. The powering of the Panama Canal Zone for 13 years (1949-62) by a U.S. Navy floating barge nuclear reactor of 30 MWe power, is a good historical example of the high-quality, readily available electricity which small nuclear reactors can provide for developing nations, particularly if they are "water mobile." The Project CAREM design study states that "Our proposal . . . consists in using power plants made from small reactors (modules), small enough to enable a serial production . . . for electricity in isolated or remote places, or for being interconnected with small networks. It can also be used for bigger power plants, adding more reactor modules for the production of industrial steam, urban heating, or for desalination" (a small-sized version of the "nuplex" concept for agro-industrial development).

In the entire underdeveloped world, whose nations account for three-quarters of the human population, there are today fewer than 25 nuclear reactors, located in only a dozen nations. In a 1983 survey, the IAEA received a positive response to a questionnaire on small and medium-sized nuclear plants from 17 nations, including Egypt, Argentina, Chile, China, Colombia, Equador, Finland, Indonesia, Malaysia, Mexico, Morocco, Nigeria, Philippines, Sri Lanka, Thailand, Tunisia, Turkey, and Uruguay.

## CAREM's potential

Argentina, particularly in combination with Brazilian industry, should be able to produce and entirely engineer these small reactors, and their enriched fuel, over the next several years, if financing means outside the IMF's grip are established. INVAP estimates the cost per CAREM module (of 15-25 MWe) to be $30 million, a comparable cost, per kilowatt of capacity, to that of today's large reactors, aside from their massive environmentalism-added "delay costs." The company plans a factory facility able to construct three modules at one time, completing the modules in 36 months' construction, but being able to add new "starts" each year, so that the output of the factory would be three units per year from approximately 1988-89 onward. Obviously, a network of serial-production factories could be constructed by cooperative agreements among Ibero-American nations, and with nuclear production firms in North America.

The follow-up "civil-engineering work" of installing reactors of this type will be minimized. They can be barged to their locations anywhere along river or coastal waterways, requiring a relatively shallow draft, unlike the very large floating nuclear reactors Westinghouse planned to mass-produce at its now-closed Jacksonville, Florida, facility. They can be transported short distances by truck to final locations.

The CAREM module unit is a pressure vessel with both reactor core and steam generators enclosed, embedded within a pool-type secondary cooling and containment structure. It is able to share a central control room with other units at the site, along with cooling water supply facilities, and little else

## Potential suppliers of nuclear reactor mass production

The trends the IAEA points out among the 23 various small and medium power reactor (SMPR) designs are: reduced construction schedule, use of systems already proven in commercial operation, simplification of safety systems using inherent small reactor characteristics (natural circulation), a high level of prefab and shop fabrication (maximized in navy year or barge-mounted designs), high seismic design, and ability to function with relatively high cooling water temperatures (in tropical countries), meeting criteria for smaller and weaker power grids.

Most similar to the Argentine CAREM prototype for mass production and developing-sector use, but perhaps also intended for potential uses is space with more advanced and smaller models, is the "Power TRIGA" of GA Technologies Inc. division of General Atomic Corp. The Power TRIGA, modeled on their widely-used research reactor (60 now operate in 23 countries), would cost approximately $40 million, designed for an output of 15 MWe.

The Power TRIGA will be built in five modules and can be preassembled or shipped and then reassembled. GA expects to sell them in clusters for reliability, where the servicing and maintenance would be shared for cost savings. One of the primary uses of the Power TRIGA will be the provision of "district heating," that is, reactor excess heat at appropriate temperatures for use in heating industrial and residential buildings in the area of installation.

The primary system is composed of a reactor module and a heat-exchanger module. These are vertically oriented in below-grade steel-lined pits to provide radiation shielding "as well as to maintain a low building profile." The intermediate loop, consisting of heat exchanger, surge tank, pump, and piping is provided to isolate the reactor system from the district heat network. The modules, pressurizer, service systems, and interconnecting piping are factory assembled, instrumented, and pre-tested to minimize construction time.

The reactor uses an Organic Rankine Cycle for power conversion because this achieves good efficiency at low temperatures; it has a simplified, compact turbine-generator design, and it has a good history of reliability.

A major design objective, GA says, is to retain TRIGA's passive, inherent design safety features, which prevent or mitigate the effects of accidents or transients. This eliminates the need for complex engineered safety systems, and also makes it possible to contemplate automated, unattended reactor operation, "which is very important to the economic viability of small power reactors."

Here is a brief summary of some of the designs for SMPRs.

*Babcock & Wilcox Consolidated Nuclear Steam Generator*: This is a small 91 MWe integral Pressurized Water Reactor (PWR) adapted from the company's nuclear ship propulsion designs. The core and steam generators are located inside the reactor vessel, as is the reactor coolant system. There are modular components, such as 4 coolant pumps and 12 steam generators to improve plant availability. The plant is compact and can be mounted on a single barge. The *entire* plant can be shop fabricated if it is barge mounted; if not, all the major components can be shop fabricated.

*Rolls Royce Prefabricated Nuclear Plant*: This is a 300 MW power station mounted on two barges, one containing the nuclear island and the other containing the conventional part of the plant. The reactor is a standard 4-loop PWR that is prefabricated on the barges and shipped

is needed. Each module has "passive" safety systems, which do not require a significant electricity source, redundant to the reactor itself, to run them; thus the requirements, in case the reactor shuts down, placed upon the local electricity grid into which the CAREM unit would be ad
mal. Heat may be extracted from the secondary cooling circuit, or "vapor cycle," for processes—while CAREM is not a high-temperature reactor capable of producing refining or chemical heat, its temperature of operation is suitable for water desalinization, in particular.

Developing nations' calls for small-reactor construction go back to the 1960s' IAEA conferences, but were bypassed by the nuclear industries of the industrialized countries until the last few years, which have seen calls for new "inherently safe" designs, and the new demand for small nuclear reactors to produce power for space systems. However, CAREM and other small-reactor designs do have one important historical predecessor—the submarine, ship, and barge reactors pioneered by the United States Nuclear Navy beginning 1954.

The Nuclear Navy construction programs, under Adm. Hyman Rickover, have produced significant numbers of small-sized nuclear reactors for submarines and surface ships, reaching production times as short as four years for multiple units at the same shipyard, at Bridgeport, Connecticut and

to the site. Thus, the buyer can build the conventional part of the plant at a shipyard of his choice.

*National Nuclear Corp. (UK) 300 MW Magnox Generating Unit*: This is a gas-cooled (carbon dioxide) natural uranium reactor with on-load refueling and a graphite moderator. Magnox, a magnesium alloy, is used to clad the fuel rods. The aluminum concentration in the fuel rod reduces the rate of swelling, permitting longer irradiation. The reactor core, boilers, and gas circulators are all within a prestressed concrete vessel.

*Ansaldo-Nira (Italy) 300 MW Cirene plant*: This is an indigenous Italian reactor based on a 40 MW prototype scheduled to come on-line this year. It is a pressure tube heavy water reactor cooled by boiling light water. The reactor fuel is natural and slightly enriched (1.15 %) uranium oxide. Like the CANDU reactor, the vessel is a stainless steel calandria, which is housed in a steel lined concrete vault. Ansaldo-Nira is also ready now to bid on a 300 MW PWR based on a Westinghouse design and using the Enrico Fermi nuclear plant in Trino as a reference plant.

*KWU (West Germany) PHWR 300*: This is a pressurized heavy-water reactor designed for on-load refueling, slightly enriched uranium (1.2 %), recycling of plutonium, and tandem operation with light-water reactors, all of which improve the operating economy.

*Framatome (France) NP 300*: This is a PWR enclosed in a small egg-shaped container. The design is based on the 3-loop 900-MW series of the company and a similar 4-loop 1,300-MW series—of which 63 plants have been built or ordered. The total operating experience is 135 reactor years. The design of the core allows refueling only every two years. The compact design of the coolant systems results in short connections between the reactor vessel and the two steam generators, which means that the containment size is reduced and there is very little piping to break in a loss of coolant accident. The design is modular, and uses shop fabrication with an overall construction time of 5.5 years.

*GE Small Boiling Water Reactor*: This 300 MWe Boiling Water Reactor (BWR) includes some innovations to simplify safety and performance. Instead of forced recirculation, which the large BWRs use, this has natural circulation. There is a suppression pool positioned above the reactor vessel. When the reactor pressure is low, valves open in the suppression pool and water flows by gravity into the reactor vessel to keep the core covered. The pool contains borated water. The ability to retain fission products in the suppression pool is considered to be an important factor in mitigating severe accidents.

*Hitachi BWR 500*: Hitachi has 14 reactor years of experience with BWRs with an average availability of 68.4%.

*Mitsubishi PWR 300*: The company has 45 reactor years of experience with PWRs with availability averaging 65%.

*AECL's Candu 300*: This heavy-water reactor is similar to the larger Candu 600 and Candu 950, with a pressure tube reactor, heavy-water moderator, natural uranium fuel, and on-power refueling. The emphasis on the smaller design has been to reduce construction time and cost. Standardization and modularization has always been a key thrust of Candu designs.

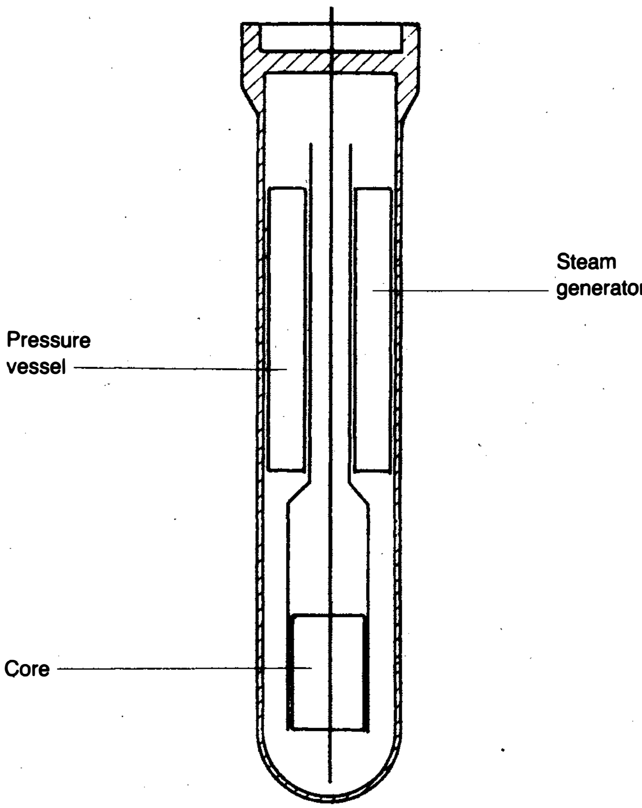
*Atomenergoexport VVR-440*: This is a PWR of which the Soviets have built 30 units, the latest being the Kola power station, which has four units. The concept has options for hot deserts or arctic tundra as well as moderate climates. It has six horizontal steam generators, and six circulation loops with reactor coolant pumps. It can be built with a double or single containment. All safety systems have three or four independent redundant subsystems, whose circuits are located in physically separate areas and supplied with electrical power from separate diesel-backed sources.

elsewhere. Production in a "navy yard" facility proved to be extremely efficient as to manpower, both for construction regulation and inspection. At the peaks of submarine reactor construction programs, yards with multiple reactors under construction have typically employed 70-75 inspectors, compared to 700-1,000 overrunning a beleaguered large-scale nuclear construction site today. The Navy reactors, and a few similar floating reactors built by the U.S. Army for mobile use (as in the Panama Canal Zone case) have been extremely reliable throughout and in some cases beyond their planned lifetimes.

Reactor designers experienced in the marine reactor programs point to the lower pressure of operation of the smaller reactors (typically 25-30% lower pressures than those in units of 1,000 MWe or more), as extremely important to their superior reliability. First, in the navy reactors, the CAREM, and other prototype small reactors now being developed, the small reactor itself is given somewhat more elbow-room within its containment, which is reduced in size but not by quite as much as the reactor. This lowers the operating pressures on reactor and containment walls, and allows simpler layouts of steam, water, and other subsystems around the reactor, which can thus be more easily maintained. Secondly, the small reactor designs remove the traditional sharp pressure barrier between the primary cooling water, which is pressurized to drive it far above its boiling temperature, and the secondary system which drives steam through the generator. In place of this sharp pressure gradient, the small reactor designs use large temperature gradients, which drive the steam through *internal* steam turbines by natural convection, still remaining within the maximum parameter of operating temperature for the reactor. This removes what many experienced reactor engineers call the most important factor in cooling system and related failures which shut down reactors—high-pressure operation of the water and steam systems.

The CAREM reactor (see **Figures 1 and 2**) is technically described as a pressurized-water reactor (PWR), as are most nuclear reactors constructed over the past decade, but its pressure gradients are in fact, quite low. It is an "integral, self-pressurized reactor and primary circuit." Its pressure vessel is a double cylinder, the inner cylinder containing the fuel core, the outer cylinder containing two steam generators—the two cylinders meet in the "vapor chamber" at the top of the vessel, where rising hot vapor makes a 180° turn and heads back down. Cooling water is fed continuously into the pressure vessel, where it heats up around the nuclear fuel core, rises up into the vapor chamber, and then—as steam—flows back down driving the steam generators, which are also inside the pressure vessel. The pressure vessel, should its overall temperature rise, can pass vapor through "design cracks" in the upper vapor chamber, into the containment vessel water pool, which is partly surrounding the pressure vessel.

FIGURE 1
**CAREM reactor vessel**

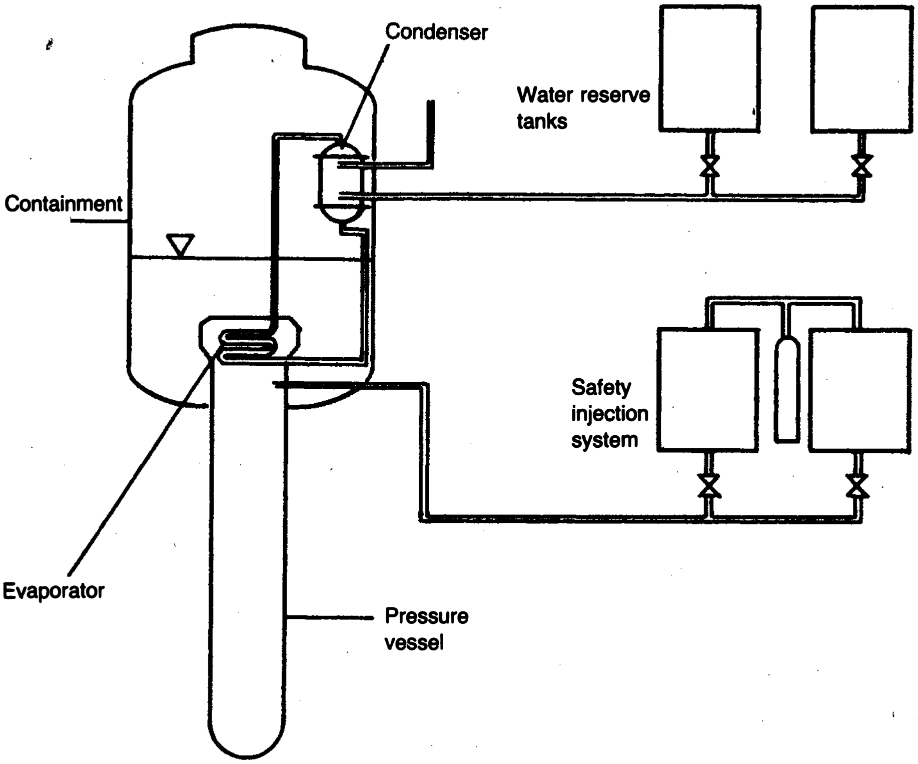



*The 15 MWe CAREM reactor's pressure vessel has effective safety features. If the reactor loses cooling water for any reason, the backup water supply is poured directly on the core, and the resulting higher pressure steam can pass through "design cracks" up into the containment pool. The heat and pressure are passed up into the pool, and the containment building as a whole, until the containment building begins to radiate excess heat into the surrounding atmosphere, stabilizing the temperature and pressure. The reactor does not need to shut down immediately, and in fact can continue to operate for a week using these "passive" safety systems," while necessary maintenance or repair is being planned.*

Both the water circulation from the reactor to the steam generators, and the circulation of external cooling water which begins in the pool, are driven by natural convection, resulting in steam vaporization and condensation.

The reactor generates its own operating pressure, which is the vapor pressure corresponding to the temperature of the outer surface of the fuel core. The neutron moderator indirectly regulates the reactor pressure, so that it stays the same, as the on-line electric power level may be raised or lowered. The upper vapor chamber absorbs the pressure changes dur-

FIGURE 2
**CAREM reactor**




ing power transients, passing them into the surrounding pool as increases in temperature which can be radiated away. There are only very small pressure drops in any of the piping and cooling tubes, and thus the reactor is both safe and highly reliabile in operation.

## Reactor mass production

There are nearly a dozen nuclear production companies in the United States, Europe, and Japan developing small reactor designs for potential factory mass-production, including not only water-cooled reactors but high-temperature gas-cooled reactors, and even mass-produced breeder reactors which will breed their own fuel for their entire operating lifetime. The accompanying box indicates both the broad scope of this mass-production planning, and also the extremely long time frames contemplated by most of these producers, who have internalized the current *financially* collapsed state of electric power production and consumption worldwide. If the IMF is defeated, these and other nuclear producers in the industrialized countries, collaborating with the Argentines and other immediate small-reactor users, could produce 300 or more small reactors per year by 1988-89, *doubling the total available nuclear power in the Third World every year through the early 1990s.*

A sufficient investment in nuclear energy need not interfere with supplying additional energy to the advanced sector as well. The construction of larger plants in the United States, Europe, and Japan could be resumed on an increasingly standardized basis, as has been demonstrated most successfully in France, approximating mass production in a "floating plant" marine construction environment where possible. Clusters of mass factory-produced 300-MWe plants can prove extremely attractive for the advanced sector as well. One additional benefit would be the elimination of the necessity for on-site inspection.

## Nuclear power for space

Over the next generation, the industrialization of the Third World will place one great demand on mass production potentials for nuclear power, both in the developing nations and in what are now best-called the formerly industrialized countries of Europe and the United States. The other great demand will come from the colonization of the solar system and the exploration of interstellar space, beginning most immediately 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.