FOUR-POWER PRIORITY

Mass Production of Modular Nuclear Reactors To Industrialize Developing Countries

Until Fusion Power Comes Online

by Ramtanu Maitra

Nov. 10—There are many apparent reasons why the United States has virtually abandoned its nuclear power generation growth. One of the reasons is that the U.S. attitude to industrial development has undergone a sea-change over the last three to four decades. In the 1950s, electricity consumption grew at an annual rate of almost 12 percent. Throughout the 1960s through 1970s, that growth rate hovered between 5 to 8 percent before it collapsed to zero and below zero, resulting in the cancellation of new power generation plants with the approach of this millennium. All this happened because the powers-that-be in the United States chose to move the nation's focus away from maintaining the country as an industrial powerhouse through modernization and innovation, to instead become increasingly a financial hub—pursuing the British model.

Adopting such an active de-industrialization policy—and allowing basic heavy industries to ebb and wither—coupled with a steady infiltration of anti-nuclear activists at various policy-making levels into the U.S. government during the same period, took a heavy toll on the growth of the nuclear power sector. The stagnation of the industrial sector in this country that dragged down the nation's overall productivity, as well as the interrelated decline of the power sector—nuclear in particular—was perhaps an important reason why the nuclear industry did not diversify to usher in other, and equally important, ingredients.

Courtesy of Nuclear Energy Institute

President Eisenhower symbolically starts up the first U.S. commercial nuclear power plant at Shippingport, Pa., in 1954.

One of the key areas of nuclear development that has been largely ignored during the recent decades has been the development of small modular nuclear reactors (SMRs), a technology which would rejuvenate the nuclear sector and establish a future for the nuclear power sector worldwide. One may argue that the United States does not need small reactors since it has the basic transportation and industrial infrastructure and the strong electrical grid needed to support large, "economy of scale" reactors. That is a valid argument. However, there are important reasons why small modular reactors should have been made commercial decades ago.

The Need for Modular Reactors

Looking back, it becomes apparent why nuclear power was born in the more advanced, developed nations. The development of such front-line technology required prime resources, including very skilled manpower in the form of scientists, experimentalists, engineers—and accompanying scientific and technological institutional infrastructure. It also needed a significant level of physical infrastructure, including power and transport, an industrial base, and an economy that generates surplus wealth. The initial development of peaceful nuclear energy took place exclusively in countries that already had a developed electrical power system. The attraction of nuclear power for these countries was the potential to accelerate the process of development, while not having to depend on such finite resources as coal and gas.

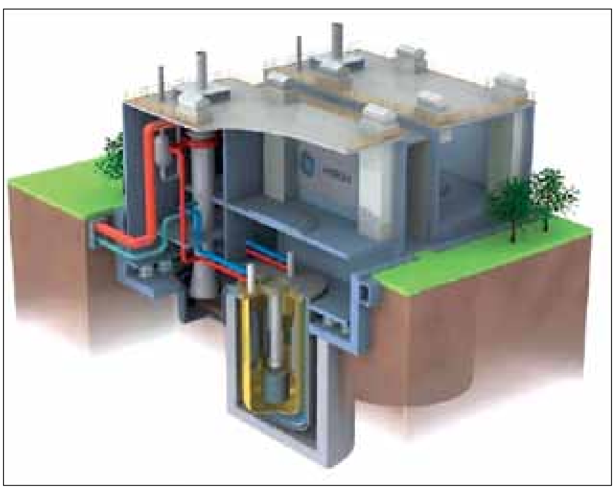
U.S. NRC

Toshiba 4S sodium-cooled small reactor, is intended to be operated underground with a turbine building on the surface, and has an electrical output of 10 MWe (30 MWt).

In other words, nuclear power did not help any country to develop an electrical power infrastructure from scratch. In recent years, China, and to a certain extent India—both now among today's nuclear power generating nations—have succeeded in developing their electrical power capacity significantly, but neither did so using nuclear power. Nuclear power's contribution to these countries came later, mostly for supplementing the power growth, or replacing any number of less-productive or polluting power sources. According to a recent report of the International Energy Agency, nuclear power production will grow by about 46 percent by 2040—and more than 90 percent of the net increase will come from China and India.

Since development of nuclear power was initially the concern entirely of the industrialized West, where bulk power was the need of the hour, this provided little incentive to develop smaller reactors where the production of electricity is more expensive than with the larger reactors.

In the United States, the manufacturing of nuclear reactors, generators, etc., is the responsibility of private entrepreneurs. The installation and daily operation of these reactors also belongs to the private sector. The U.S. government only comes in as the regulator. For the private utility, the prime objective is to make nuclear power economically competitive with coal, gas or hydro. Under the circumstances, the only objective of the private sector is how to optimize profit by building these reactors to fit the economy of scale. Even today, six decades later, this remains the primary concern for those who are building nuclear power plants and supplying power to consumers in the United States.



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PRISM (Power Reactor Innovative Small Module), a nuclear power plant design by GE Hitachi Nuclear Energy (GEH).

Unfortunately, such a market-driven approach obscures the true, far-reaching importance of nuclear power. It is not simply a reliable source of continuous electricity. Rather, understood from Lyndon

LaRouche's conception of *energy flux-density*, it becomes a *revolutionary* ingredient in developing the basic infrastructure and productive power of the nation. Here lies the importance, and the future, of small modular reactors.

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Model of the Toshiba ABWR, which became the first operational Generation III reactor in1996.

Economy of Scale for Reactors

Since nuclear power generation began in the 1950s, the size of reactor units has grown from 60 megawatts (MW) to more than 1600 MW, with corresponding economies of scale as the driving force. At the same time, many hundreds of smaller power reactors have been built for naval use and as neutron sources, yielding enormous expertise in the engineering of small power units. These small reactors did not seek the economy of scale, but catered to a vital need where cost was a secondary factor.

In their paper, "Nuclear Reactors: Generation to Generation," authors Stephen M. Goldberg and Robert Rosner pointed out that "Generation I" refers to the prototype and power reactors that launched civil nuclear power. This generation consisted of early prototype reactors from the 1950s and 1960s, such as Shippingport (1957-1982) in Pennsylvania, Dresden-1 (1960-1978) in Illinois, and Calder Hall-1 (1956-2003) in the United Kingdom.

The Second Generation, or "Gen II," includes pressurized water reactors (PWRs), which began operation in the late 1960s and comprise the bulk of the world's 400+ commercial PWRs and boiling water reactors (BWRs) that are in operation today. These have an expected life-span of about 40 years, although many have exceeded that life-span and will remain in operation for at least 20 more years.

There are other types of reactors, such as Canada's heavy water reactors (CANDU) that are also recognized as Gen II reactors. Gen II designs require relatively large electrical grids and have a safety envelope based on Western safety standards. The economics of existing Gen II plants and of those under construction or in the planning stage are generally favorable, particularly in some parts of Asia.

Gen III nuclear reactors are essentially improved Gen II reactors. These improvements in Gen III reactor technology are aimed to extend the operational life to 60 years, potentially to greatly exceed 60 years, prior to complete overhaul and reactor pressure vessel replacement.[1]

While these developments enhanced the economy of scale, they also pushed aside the development of small reactors, because of the latter's much higher megawatt-to-megawatt cost when compared to these Gen II or Gen III reactors. But the story has a downside. Now that the United States has not built a nuclear power plant for decades, and in the context of the de-industrialization of the nation, the ability to manufacture ultra-heavy forgings—each of which weighs greater than 400,000 pounds—a necessity for the Gen III reactors, no longer exists in the United States. At this point, the United States is today simply incapable of producing a Gen II or Gen III nuclear reactor.

U.S. Can't Make Gen III Reactors

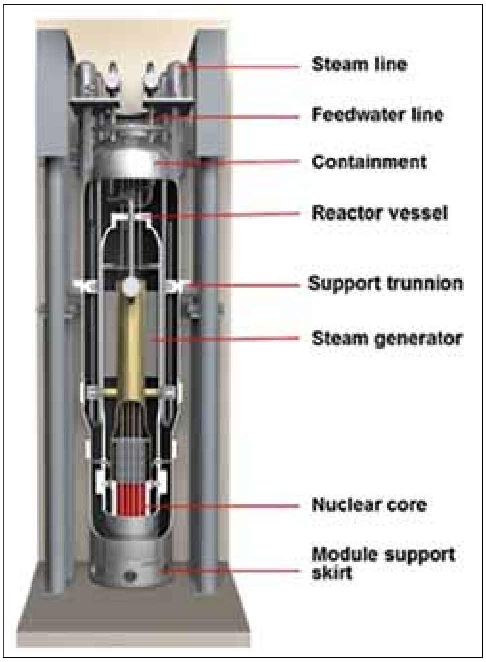
Peter Alpern wrote in 2009,

> Four of the most complex parts of a nuclear power plant—the containment vessel, the reactor vessel components, the turbine rotors and steam generators—are made from over 4,000 tons of steel forgings, and almost none of those components are manufactured in the United States. The reactor vessel functions like the outer shell of an egg, protecting all the vital internal pieces, including the components in which the nuclear reaction takes place. The outer vessel

1. "Nuclear Reactors: Generation to Generation," by Stephen M. Goldberg and Robert Rosner. American Academy of Arts & Sciences, 2011.

alone weighs over 500 tons and is made up of seven very large forgings, including several that make up the nozzle.

The newest nuclear plant design on the market, the Generation III Evolutionary Power Reactor (EPR), from the French nuclear engineering group Areva, uses four steam generators—each of which weighs up to 500 tons. A generator rotor weighs in excess of 200 tons, according to Craig Hanson, vice president and product line manager for nuclear plant builder Babcock & Wilcox. And, for each nuclear plant, there are three to four turbine rotors. . . .[2]



U.S. NRC

The proposed NuScale reactor building is designed to hold 12 SMRs. Each NuScale SMR has a rated thermal output of 160 MWt and electrical output of 50 MWe, yielding a total capacity of 600 MWe for 12 SMRs.

The Gen III reactors require steel ingots weighing between 500 to 600 tons each. No steel producers in the U.S. can handle that size or weight, says Chris Levesque, Areva's president and general manager at its Newport News, VA, facility for fabricating heavy reactor components:

> Forgers are limited because while [a forger] can make his press bigger and he can make his machine tools bigger, he needs a larger ingot. He's limited by the steel mill and the ability of not just a mill that can make that big of an ingot, but [can] also transport it to him by rail. You're talking about a piece of metal that's huge and needs to stay hot and get from the mill to the forge. One of those mills can't exist just to supply the forge.

The largest U.S. ingot manufacturer, the now defunct Bethlehem Steel, could produce an ingot of about 380 tons—good enough for the Gen II reactors, but not so for the Gen III reactors. And that Bethlehem Steel capability no longer exists.

While America dismantled its capabilities vis-à-vis heavy forging, new heavy forgers have emerged—not many, but a few. According to Alpern's article, Japan Steel Works (JSW) is by far the largest, providing 80 percent of the large forged components for all nuclear power plants being built in the world today outside Russia, including the steam generator, reactor pressure vessels and turbine shafts. Several other countries are also involved in Gen III, or similar, reactors, and heavy forging capacity is emerging in those nations, including China (China First Heavy Industries) and Russia (OMX Izhora), along with new capacity emerging in South Korea (Doosan) and France (Le Creusot). It is also being planned in the U.K. (Sheffield Forgemasters) and India.

What SMRs Promise

In May 2018, a Portland, Oregon-based company, NuScale Power, announced that its design of a small modular nuclear reactor (SMR) had completed the Phase 1 review of its design certification application (DCA) by the U.S. Nuclear Regulatory Commission. According to analysts, Phase 1 is the most intensive phase of the six-phase review, taking more hours and effort than the remaining five phases combined.

What NuScale's SMR is offering is twelve 50 MW reactors combined, a scaled-down version of large, light water reactors that can be put together module-by-module to develop a generating capacity of 600 MW. Recently, NuScale says its SMR will produce 20 percent more power than what it was designed for.[3] Because the plant has not been constructed and no power has yet been generated, such claims must remain hypothetical until proven.

What is evident from the cost of the 12-50 MW SMR designed by NuScale, or any other small modular reactor, is that when developed, these reactors, megawatt-for-megawatt, will be more expensive than Gen III large nuclear reactors. However, that cost difference

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2. "U.S. Cedes Capability for Largest Nuclear Forgings," by Peter B. Alpern. *Forging*, June 16, 2009.

3. "Breakthrough for NuScale Power: Increase in Its SMR Output Delivers Customers 20 Percent More Power," NuScale News Release, June 6, 2018.

can be reduced significantly if the SMRs are mass-produced. Even with the higher cost, it is clear that SMRs have a large role to play in the coming decades, particularly in the developing countries.

According to a report, "Small Nuclear Power Reactors," which can be found on the World Nuclear Association's website:

> Small modular reactors (SMRs) are defined as nuclear reactors generally 300 MW equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times.[4]

It is evident that a number of countries, such as China, Russia, Korea, Canada, India, and Argentina, have developed small nuclear reactors, but very little is known about these countries' efforts to produce them as modular units, which would make their production and deployment far more effective.

According to the Canadian Small Modular Reactor Roadmap, there are over 150 proposed designs for SMRs worldwide. The national nuclear science and technology organization, Canadian Nuclear Laboratories (CNL), has set a goal of building a new SMR on its Chalk River site by 2026. In June 2017, the Canadian company, Terrestrial Energy, began a feasibility study for the siting of the first commercial Integrated Molten Salt Reactor at Chalk River. To say the least, this is still at an embryonic stage.

China is also developing a 100 MW SMR, designed by the China National Nuclear Corporation. Called the Linglong One, this ACP100 nuclear reactor has completed its preliminary design stage and is qualified for construction in Hainan province this year. Its first use will be to generate heat for a residential district, replacing coal-fired boilers.[5]

All that the Canadian Small Modular Reactor Roadmap tells us is that the SMRs are under development in many countries, and there is a strong likelihood that some of them might become operative within a decade. Some of these reactors could be High Temperature Gas-Cooled Reactors or even Pebble-Bed reactors. However, little is known of their progress, or the timetable.

What is at hand though, is the definitive work done by NuScale and its success in completing the Phase 1 review of its design certification application by the U.S. Nuclear Regulatory Commission. The NuScale SMR is an advanced light-water reactor. Each module is a self-contained unit that operates independently within a multi-module configuration. Up to 12 modules are monitored and operated from a single control room. The entire reactor sits within a containment vessel 65 feet tall and 9 feet in diameter. NuScale's Russell Ray describes the process in this way:

> The reactor and containment vessel operate inside a water-filled pool that is built below grade. The reactor operates using the principles of natural circulation; hence, no pumps are needed to circulate water through the reactor; instead, the system uses a convection process. Water is heated as it passes over the core, and as it heats up, the water rises within the interior of the vessel. Once the heated water reaches the top of the riser, it is drawn downward by water that is cooled passing through the steam generators.
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> The cooler water has a higher density. It is pulled by gravity back down to the bottom of the reactor where it is again drawn over the core. Water in the reactor [cooling] system is kept separate from the water in the steam generator system to prevent contamination. As the hot water in the reactor system passes over the hundreds of tubes in the steam generator, heat is transferred through the tube walls and the water in the tubes turns to steam. The steam turns turbines which are attached by a single shaft to the electrical generator. After passing through the turbines, the steam loses its energy. It is cooled back into liquid form in the condenser, then pumped back to the steam generator.[6]

SMR Advantages for Developing Nations

In addition to what Russell Ray describes, which emphasizes the safety part of the NuScale SMR, SMRs in general have many advantages that are of particular importance to countries with weak basic infrastructure. To begin with, the major components of SMRs will be small enough to be made on a production line in a factory, rather than being assembled one item at a time.

4. "Small Nuclear Power Reactors." World Nuclear Association.
5. "NuScale's Small Modular Nuclear Reactor—Reliable, Resilient and Flexible," by James Conca. *Forbes*, June 22, 2018.
6. "Can SMR Technology Revitalize the Business of Nuclear Power?" by Russell Ray. *Power Engineering*, June 13, 2018.

That means it will be fully set up in a controlled environment away from the wind, rain, and sand—typically present at a construction site—that often delay construction and assembly.

Among the other advantages, these SMRs provide easy transportability. Since they are only 65 feet tall, 9 feet in girth, and weigh about 300 tons, they could be transported from the factory to the construction site by boat, truck, or even railway car—a task that many developing countries' infrastructure can bear. Another advantage is that SMRs have much smaller emergency planning zones (EPZs), which is the area expected to be affected by a nuclear accident that results in the release of radioactive material.

SMRs require fewer materials and resources, bringing down the one-time capital cost. That suggests the country using SMRs can add power in smaller increments. It also means that the countries with a weak electrical grid—which is a serious problem in most of the developing countries and presents major obstacles to setting up a large single power generation unit—will be able to set up SMRs, which, in return, will provide a steady source of power to develop basic infrastructure, including the strengthening of the electrical grid.

There are other smaller advantages. For instance, a large nuclear power plant needs to change fuel once every 18 to 24 months. Outages are scheduled for the spring or fall when electricity demand is lowest. The outage required for a scheduled refueling is usually no more than 40 days, but during that period, no power is generated or delivered by that plant. In the case of SMRs, although it could be five to six years before a shut-down of one of the modules would be necessary to carry out the fuel change, such refueling outages can be staggered, allowing a module-by-module fuel change. This would enable a multi-module unit to carry on supplying power at near capacity throughout its life-time.

SMRs, once developed and proliferated, will also be the anchor for desalination of sea water and brackish water. Desalination of water along vast coastal areas is an essential ingredient for economic development in many developing countries and island nations. Recently, Ibrahim Khamis of the International Atomic Energy Agency was cited as emphasizing that this is not a new idea. Its feasibility and reliability have been well-proven, and there is the added advantage that the nuclear power plants can supply either thermal or electrical energy, or both, at varying scales. According to Khamis:

> We can think of nuclear-powered desalination in terms of two main applications. One is to serve make-up water resources for the plant; the other is to produce potable water. Both applications have already been demonstrated.[7]

In addition, perhaps the greatest advantage of proliferating these SMRs is that they can be located in areas where the population is sparse, and the growth potential is vast—a very common phenomenon in Africa, in some parts of Asia, Central America and the Caribbean islands, for instance. These SMRs could jump-start the much-required developmental process—not in one stroke, but at a steady and escalating pace.

A Power-Starved World

Despite the last six decades of commercial power generation, nuclear power, as an electrical power source, has not contributed to the electricity generating capacity of the "developing nations," where power generation remains a crucial ingredient for building up the basic manpower, industry, and the absolutely necessary infrastructure of those nations. At present, the world can produce about 20 to 25 large, pressurized light water reactors and a few medium-size (about 700 MW) pressurized heavy water reactors per year, adding up to about 25-30,000 MW annually. That production capability is far, far below what the world needs. For instance, in the period between 2000 and 2010, China alone built about 26,000 MW of power generating capacity, mostly using coal and hydro-electric.

How little has nuclear power contributed to the developing nations? Take the case of the BRICS member nations. These are considered nations that are on the way to becoming developed nations. It is true that in Russia, India and China, nuclear power is growing, and these countries have developed the potential to become major nuclear power generating countries, but in Brazil and South Africa, nuclear power remains an insignificant player in their power capabilities. Brazil has only two reactors, producing about 3 percent of its power in a power-starved country. The same goes for South Africa, where two nuclear reactors at the Koeberg nuclear power station account for around 5 percent of South Africa's electricity production. South Africa is vastly short of power, yet nuclear power is not playing any significant role.

Beyond those examples, one must take a look at

7. "Nuclear-Powered Desalination," by William Steel. *Industrial WaterWorld*, October 1, 2018.

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Aerial view the CAREM-25 prototype reactor building under construction in Argentina.

South East Asia, for instance. Existing in the vicinity of four nuclear power manufacturers—China, Japan, South Korea and India—none of the ten members of the Association of South East Asian Nations (ASEAN)—Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam—has a single nuclear power plant. Nuclear has not played any role whatsoever. Most of these nations desperately need a much larger electricity generating capacity for their growth.

In the entire continent of Africa, populated by 1.2 billion people, other than those two Koeberg nuclear reactors in South Africa, nuclear power has no presence. And, yet, Africa is crying out for more electrical power to grow and provide a future for today's, and tomorrow's, population.

Under current circumstances, these countries cannot have a serious nuclear program based on large nuclear reactors. They simply do not have the infrastructure, or the electrical grid system, to support large Gen III reactors. For instance, in Nigeria, with a population close to 190 million and the potential to become an economic giant, its transmission system does not even cover large parts of the country. Currently, it has the capacity to transmit a maximum of about 6 GW, and the system is technically very weak, thus very sensitive to major disturbances. For connecting a large nuclear power plant (say, 1,000 MW), the estimated capacity of a smooth-running grid required is at least 10 GW. (In other words, a single power generation source's capacity is not to exceed 10 per cent of the grid capacity for smooth distribution.)

The situation in most of the rest of Africa, in terms of infrastructure and electrical transmission capacity, is far worse than in Nigeria.

A similar situation exists in all of the Caribbean and Central American countries, in the vicinity of the United States—the largest producer of nuclear power. One could go on and on about the shortcomings.

SMRs Will Open Up the World

With the advent of the SMRs—not only the NuScale version, but many other versions that can be developed within a short time by other nuclear power plant manufacturing nations—all of these countries can get an opening. What this will require, however, is for the SMRs to be mass produced in assembly-line fashion, and this will need governments—including most empathically the governments of the nuclear-producing nations—to get involved and ensure the job is done. The intention must be to enable the developing nations to build up their basic infrastructure and industrial capabilities. That should be attractive for even those private sector manufacturers who think in terms of developing markets for larger economic interactions.

How will these SMRs accomplish what the large nuclear power plants can not? Take for instance, Indonesia. The Indonesian archipelago has 18,000-plus islands. However, almost 60 percent of Indonesia's 260 million people live on the island of Java. Indonesian authorities' many efforts in the past to redistribute the population to various islands have fallen flat because of lack of electrical power, which provides the basis for sustainable living. For Indonesia, it is not possible to build a large nuclear power plant and string the wires across the seas to provide power to the islands. Nor is it feasible to have boatloads of coal crisscrossing the seas, carrying millions of tons of coal daily to feed the coal-fired power plants set up on those islands. For Indonesia, SMRs will offer a perfect solution.

The same can be said of so many countries in Africa. Look at Chad, Sudan, Mali or the Democratic Republic of the Congo. Developing the lands distant from major population centers will open up the countries and provide an opportunity for growth all across the continent.

These are important factors, and the correct and rapid development of the SMRs will not only put nuclear power at the helm of power generation for centuries, it will enable many of the developing nations to get out of the otherwise insurmountable poverty trap.