Expand Nuclear Power For the World's Survival

Much of the world lives in virtual darkness, lacking the electricity essential for modern life; but world leaders are not prioritizing the solution to the problem. Ramtanu Maitra reports.

Over 1.2 billion people—20% of the world's population—are today without access to electricity, and almost all of them live in developing countries. This includes about 550 million in Africa and over 400 million in India. It is incumbent upon all the world leaders to bring this number to zero at the earliest possible date, and thus provide these people with a future to look forward to within a span of 25 years. Can this be done with fossil fuels, wind, and solar power? The answer is a resounding "No!"

The only way world can meet the power requirements of one and all is by fully exploiting the highest energy-flux density power generation achieved through nuclear fission now, and by starting to move to an even higher level by using hydrogen as fuel in generating power through nuclear fusion. As of March 11, 2014, in 31 countries, 435 nuclear power plant units with an installed electric net capacity of about 372 GW were in operation, and an additional 72 plants with an installed capacity of 68 GW in 15 countries were under construction. Altogether, the existing nuclear power plants provide a shade over 11% of the world's installed generating capacity. Most of the other 89% comes from the burning of fossil fuels.

What becomes evident from those figures is that almost no country—big or small—has made the essential commitment to generate power in the future entirely through nuclear fission. Why have world leaders refrained from fully using this cleanest and most efficient energy source? Instead, we see countries such as China and India, among the larger ones that are committed to greater agro-industrial growth, mining and hauling hundreds of millions of tons of coal on a daily basis to generate power to meet their developmental requirements.

It is widely recognized that coal-fired power generation not only makes the air less breathable, but also that the technology exists to overcome that problem. But the other problem that coal-based power generation systems cause is virtually unsolvable. To begin with, vast amounts of water are needed on a daily basis to clean these millions of tons of coal before burning. The polluted water from coal washeries needs to be cleaned up before it pollutes waterways and sub-surface groundwater. In addition, handling these vast amounts of coal is burdensome: Millions of tons of coal are shipped from ports or coal mines to the coal washeries. The rule of thumb suggests that an average coal plant burns the contents of approximately 200 coal cars a day, with 100 tons per car. This makes 73,000 cars per year, or 7,300,000 tons per year. The average nuclear plant uses about 0.005 of a rail car of fuel per day—20 tons per year.

The logistical nightmare that coal-fired power programs cause does not end there. Burning vast amounts of coal produces vast amounts of fly ash, which contains acidic chemicals ready to poison the land, clog the waterways, and kill all living things that inhabit the waterways. In the United States alone, coal-fired power plants on an average produce 130 million tons of fly


NASA

The Earth at night: 20% of the world's population has no access to electricity.

ash. All countries that are building up their power generation programs based on coal-fired plants encounter the same logistical nightmare. What that means is that a good part of a nation's railroads remains clogged, hauling in coal from the ports and mines to inland destinations where the power plants are, and then hauling the fly ash out. That situation becomes worse as more such plants are built.

While it should be obvious to policymakers that this policy could lead to a long-term disaster, nonetheless these countries have not committed themselves to create the conditions whereby their future electricity generation will come entirely from a clean source, such as nuclear fission, which uses very little fuel and remains the most reliable and efficient source of power.

The World Power Scene, Briefly

Over the years, the two most populous nations in the world, China and India, have developed indigenous capabilities to manufacture a complete nuclear power plant, with the intent to provide hundreds of millions of their citizens with the electricity that is a vital requirement for living. But while China is making efforts to rapidly enhance its electrical power generation capacity, it is doing so by mining and importing more and more coal, while nuclear power remains a supplementary power source. It is evident that China has not geared up to change that situation in the foreseeable future. According to some analysts, China is expected to add coal-fired capacity of 36 GW in 2014, 42 GW in 2015, 45 GW in 2016, and 47 GW per year starting in 2017. In other words, between 2014 and 2020, China is expected to add about 310 GW of coal-generated electrical power.

By contrast, according to World Nuclear Association reports, while China presently produces about 20 GW, or 2% of its total electricity generation capacity, from nuclear fission, additional nuclear reactors that have been planned, including some of the world's most advanced ones, will help the country to produce a total of 58 GW of electrical power by 2020 using fission.

That means that during the next six years, during which China wants to add 310 GW of electrical capacity from coal-fired plants, nuclear reactors will produce only 38 GW—less than 13% of new coal-based power generation capacity planned. That would bring up nuclear power-generated electricity capacity in China's power-generation mix to 6%. More long-term plans for future capacity show that nuclear-based power generation is expected to rise to 200 GW by 2030 and 400 GW by 2050. The conclusion is that while China has realized the importance of nuclear fission, it has not yet made the necessary commitment to base its entire power generation on nuclear, even in the long term.

India's power situation is much worse than China's, although it has well-developed nuclear power generation capabilities, and has been building its own small nuclear reactors for a long time. But the commitment to

Bobak

China's coal-fired power plants create the country's notorious air pollution, seen here in Beijing. Only the rapid expansion of nuclear power will solve the problem.

nuclear power as its only source of future power generation has remained wholly theoretical. At present, India has installed capacity to generate about 235 GW of electricity, and of that, only 7 GW comes from nuclear, or about 3% of the total. Since India has 400 million people without full access to electricity, it is evident that it needs another 250 GW of power in the short term to provide electricity, education, and productive work to fully exploit the inherent productive potential of its own people. Its short-term nuclear program suggests that it will have about 15 GW of electrical power generated from nuclear reactors by 2020, a negligible amount compared to what the gravity of the situation calls for. By 2030, India's program calls for about GW from nuclear power, which would be much less than 10% of the total power generated.

What Commitment to Nuclear Means

To begin with, the installed electricity-generating capacity of today's world is about 5,200 GW. Five countries (China, the United States, Japan, Russia, and India) account for about 2,900 GW. The rest of the world, which constitutes 55% of the world's population of 7 billion-plus, has a generating capacity of 2,300 GW; much of this is in the European Union, which has a population of 500 million. In other words, much of the world lives in virtual darkness.

However, electricity produced per hour across the world is nowhere near the stated generating capacity. "Capacity" is the maximum electric output a generator can produce under specific conditions, whereas "generation" is the amount of electricity a generator actually produces over a specific period of time. Many generators do not operate at their full capacity all the time; they may vary their output according to conditions at the power plant, fuel costs, and/or as instructed by the grid operator.

The one major reason that the actual generation of electricity around the world is way below the generating capacity is that only 11% of world's electricity comes from nuclear. Nuclear power plants, on an average, have an efficiency of 92-100%. Only one other power source, hydropower, reaches an efficiency of 90%. By contrast, coal-fired power plants, which constitute almost 45% of world's generating capacity, operate at 50-55% efficiency, and natural-gas-burning power plants at about 60% efficiency. Solar and wind-based power plants operate at 20-30% efficiency.

In other words, only nuclear power plants, which can be set up almost anywhere on land, and even at sea, provide power reliably and at the stated generating capacity. By contrast, hydropower can be generated only where the water is flowing, and therefore has severe limitations.

Looking 30 years ahead, it becomes evident that the world's electricity-generating capacity must double to 11,000 GW by 2050. Again, a large amount of this additional power will be required in China and India. It is expected that these two countries, between them, will require an additional 2,500 GW of installed capacity. A similar approach is required for Africa, South America, Central Asia, and parts of South, Southwest. and East Asia. A vast majority of this additional 6,000 GW of power, say 5,000 GW, in the next 30 years, needs to be generated from nuclear plants.

To generate 5,000 GW of nuclear power in the next 30 years means the world will have to manufacture 5,000 nuclear reactors of 1,000 MW capacity. Since it takes 4-5 years to construct one nuclear plant, during the next 25 years, the world will have to manufacture

5,000 plants with 200-1,000 MW reactors, and associated equipment, annually, ready for installation. As of now, world's capacity to manufacture large reactors (1,000-1,100 MW) and the associated steam turbines, which together form the nuclear power plant (NPP) set, is limited to about 30 annually. India, where pressurized heavy-water reactors are used for power generation, has the capacity to manufacture a few 600-700 MW installed capacity NPP sets.

That means the world's NPP manufacturers will have to quickly bring up their capacity from 30 to 200, to develop an economy based on the highest energy-flux density.

Another issue that has emerged with manufacturing of the new generation of reactors is metallurgy. Generation III+ plants can use existing metal alloys, but Generation IV plants, operating at higher temperatures, will require new materials. At 700°C, degradation problems are much more severe than at today's operating temperatures. Gen IV reactors are being developed by an international task force. Four of these are fast neutron reactors, and all of these will operate at higher temperatures than today's reactors. Fast neutron reactors have been designated particularly for hydrogen production.

What Rapid Expansion Entails

What, then, must China and India do? A critical issue for accelerating nuclear power plant construction, besides advanced materials, is the availability of heavy engineering plants to make the reactor components, especially for large reactor vessels. Although the world has seen some new investment in forges and steelmaking in recent years, the amount remains woefully inadequate, because no country, with perhaps the exception of France, has committed itself fully to nuclear power. The challenge is not confined to the heavy forgings for reactor pressure vessels, steam turbines, and generators alone, but it extends to other engineered components as well.

During the period in which the first- and second-generation nuclear power plants were built, they mostly came from integrated suppliers, such as Westinghouse, in each country, who required little help from external vendors. Today, most of a new plant comes from a range of international suppliers, while companies such as Westinghouse are focused on design, engineering, and project management.

For very large Generation III+ reactors, production of pressure vessels requires forging presses of about 14-15,000 tons capacity, which accept hot steel ingots of 500-600 tons. These are not common, and individual large presses do not have high throughput—about four pressure vessels per year appears to be common at present, fitted in with other work, though the potential exists to enhance these numbers significantly.

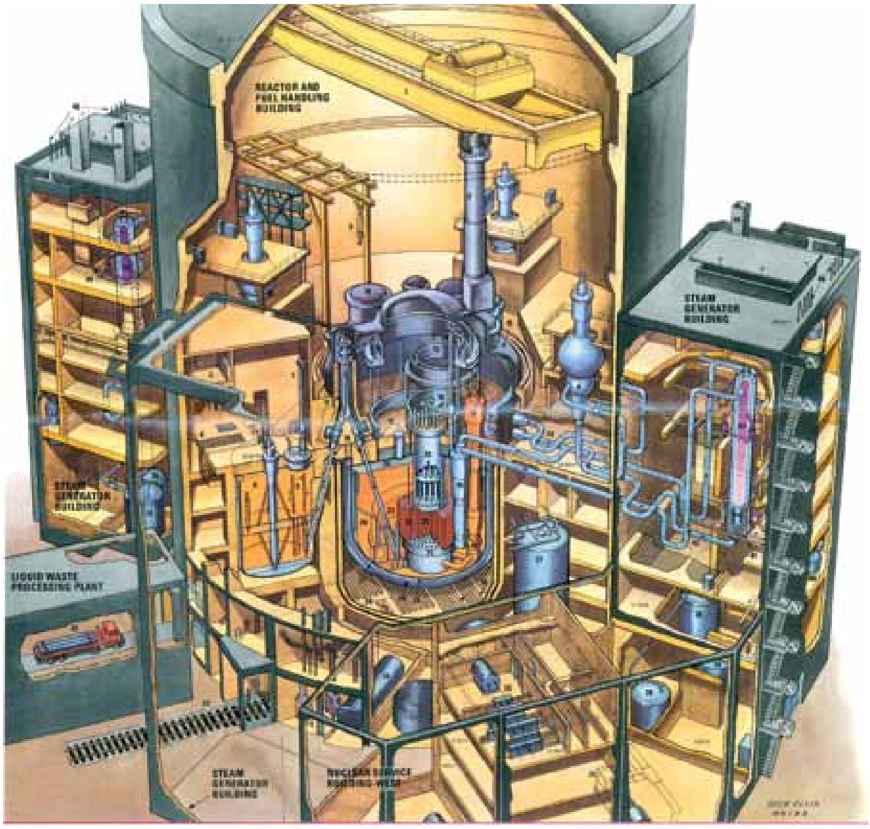
The very heavy forging capacity in operation today is in Japan (Japan Steel Works), China (China First Heavy Industries and China Erzhong), and Russia (OMZ Izhora). New capacity is being built by JSW and JCFC in Japan, Shanghai Electric Group (SEC) and subsidiaries in China, Doosan in South Korea, Le Creusot in France, Pilsen in the Czech Republic, and OMZ Izhora and ZiO-Podolsk in Russia. New capacity is at a planning stage in the U.K. (Sheffield Forgemasters) and India (Larsen & Toubro, Bharat Heavy Electricals, Bharat Forge Ltd). In China, the Harbin Boiler Co. and SEC subsidiary SENPE are increasing their capacity as well.

Nothing in North America currently approaches these enterprises. The changed position of the United States is remarkable. In the 1970s, both US Steel and Bethlehem Steel had 8,000 ton presses and could handle 300 ton ingots. U.S. forging capacity has not been significantly upgraded since. In the 1940s, it manufactured over 2,700 Liberty ships, each 10,800 tons DWT. In the 1970s, it had substantial heavy infrastructure. But today, China, Japan, South Korea, India, Europe, and Russia are all well ahead of it. Steelmaker ArcelorMittal, based in Luxembourg, now owns the American company which built the most U.S. reactor pressure vessels in the 1970s-80s.

It must be noted that the need for nuclear power reactors in China, India, and Russia is bound to grow at a faster pace than in the rest of the world. These three countries, when they increase their NPP sets manufacturing capacity to the desired level, they will find it difficult to export a large number of reactors to other countries that will be in need of nuclear reactors.

That means that many other nations in Asia, Africa, and South America have to prepare for rapid development of a nuclear future now. This entails training of manpower using a large number of research reactors, development of heavy engineering capability to forge NPP sets, and other basic infrastructure that would enable them to enhance their power generation. The focus on developing human resources is two-fold: 1) generic capacity-building at the national level in nuclear sciences and technology, to support the government and other stakeholders in making informed decisions on nuclear power; and 2) developing personnel in stakeholder organizations to implement the nuclear power program.

Moreover, the commitment to nuclear power also entails developing manpower in all nations, including those that have nuclear power plants, or even just nuclear research reactors. There is already a significant gap between the number of nuclear engineers that are being produced and those that are retiring, which needs to be addressed just to keep the world's existing nuclear reactors running. Therefore, in order to speed up nuclear generation, countries, one and all, require large-scale training programs to fulfill this need. Developing the right skills base is a priority for the industry to grow to the level that it demands.



The French Super-Phénix was the world's first large-scale breeder reactor. It was put in service in 1984, and ceased operation as a commercial power plant in 1997. It was the last fast breeder reactor operating in Europe for electricity production—as the result of Green protests.

Why Nuclear?

The world does not have any choice but to go with nuclear fission now and prepare to introduce nuclear fusion at the earliest possible date. Since nuclear power has the highest energy-flux density of all power-generating sources, it generates a vast amount of power using very little fuel. In addition, although the world will run out of other power-generating natural resources, it will never run out of nuclear fuel, because nuclear fuel is renewable: Fast Breeder Reactors (FBRs) produce more fuel than they consume, making nuclear fuel inexhaustible.

Under appropriate operating conditions, neutrons given off by fission reactions can "breed" more fuel from otherwise non-fissile isotopes. The most common breeding reaction is that of plutonium-239 (Pu-239) from non-fissionable uranium-238 (U-238). This becomes possible because the non-fissionable U-238 is 140 times more abundant than the fissile uranium-235 (U-235) and can be efficiently converted into Pu-239 by the neutrons from a fission chain reaction. Pu-239 is a fissile material that can be used to generate power.

For instance, the Liquid-Metal Fast Breeder Reactor (LMFBR) is a Pu-239 reactor, commonly identified as a fast breeder reactor. In this system, cooling and heat transfer is done by a liquid metal. The metals that can accomplish this are sodium and lithium, with sodium being the most abundant and most commonly used. Construction of this type of fast breeder requires higher enrichment of U-235 than a light-water reactor, typically 15 to 30%. The reactor fuel is surrounded by a "blanket" of non-fissile U-238. No moderator is used in the breeder reactor, since fast neutrons are more efficient in transmuting U-238 to Pu-239.

France's Super-Phénix (SPX) was the first large-scale breeder reactor that was built; it was put into service in 1984, and ceased operation as a commercial power plant in 1997. The reactor core consisted of thousands of stainless steel tubes containing a mixture of uranium and plutonium oxides, about 15-20% fissionable Pu-239. Surrounding the core was a region called the breeder blanket, consisting of tubes filled only with uranium oxide. The entire assembly was about 3x5 meters and was supported in a reactor vessel in molten

IAEA

India's prototype fast breeder reactor at Kalpakkam. The reactors use natural gas as fuel during the current first stage of operation. The third stage reactors will use thorium as fuel.

sodium. The energy from the nuclear fission heated the sodium to about 500°C, and it transferred that energy to a second sodium loop, which in turn heated water to produce steam for electricity production. Such a reactor could produce about 20% more fuel than it consumed. Enough excess fuel could be produced over about 20 years to fuel another such reactor. Optimum breeding allowed about 75% of the energy of the natural uranium to be used, compared to only 1% in the standard light-water reactors.

India is now developing a fast breeder reactor which will produce fissile uranium-233, which will then be loaded to generate power through fission. Fuelled with uranium-plutonium oxide, these reactors will have a thorium blanket to breed fissile U-233. The plutonium content will be 21% and 27% in two different regions of the core. Initial Indian FBRs will have mixed oxide fuel, but these will be followed by metallic-fuelled ones, to enable a shorter doubling time.

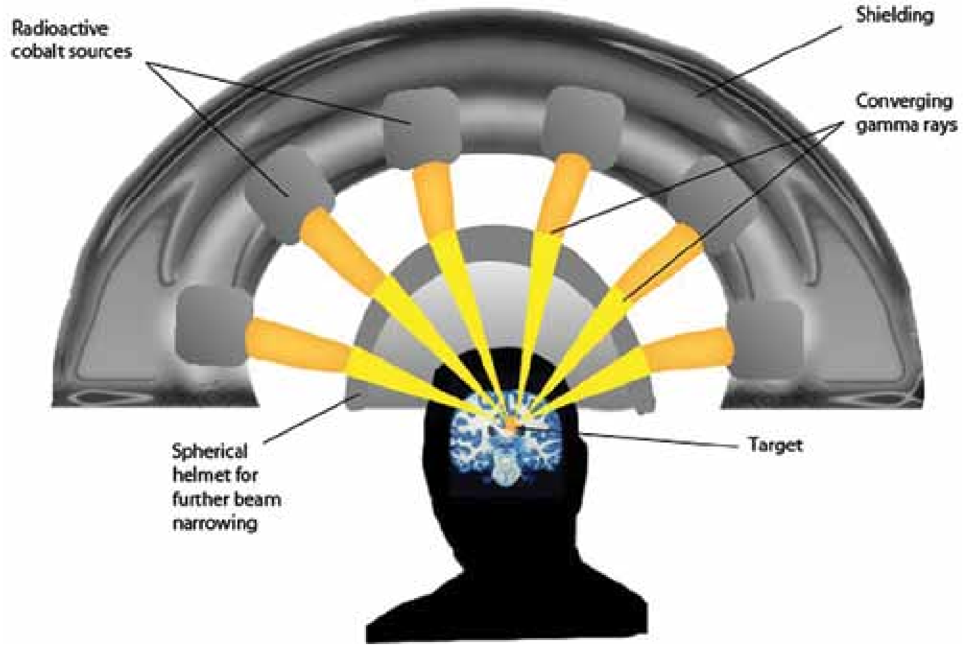
By contrast with nuclear fuel, the most frequently used fossil fuels are not renewable. A 1,000 MW coal-fired power plant needs about 6,600 tons of coal daily—the amount varies slightly according to the quality of coal used. On the other hand, a nuclear power plant requires very little fuel—a tiny fraction of what a coal-burning power plant requires. Used nuclear fuel still contains an immense amount of energy—over 95% of the potential energy contained in that small amount of material is not even used. Advanced reactors will one day routinely recycle this waste.

In the case of thorium-fueled nuclear power plants, the fuel requirement will be even less. Why? Because, unlike the pressurized and boiling water reactors that burn about 1% of their fuel before going non-critical and require refueling once every 18-24 months, thorium-fueled power plants can burn more than 90% of the loaded fuel and would thus require refueling once every 30 years or so. This means that the overall waste in a reactor's lifespan would be a fraction of what we have to deal with in the present generation of uranium-fueled reactors.

Other Benefits

But beyond its low fuel consumption, nuclear power provides mankind with a number of other benefits. Nuclear byproducts are used in some calibration devices, radioactive drugs, bone-mineral analyzers, imaging devices, surgical devices, teletherapy units, and diagnostic devices used in dentistry and podiatry. Some cardiac pacemakers are powered by nuclear batteries. Source material is also used for counterweights in medical devices and for radiation shielding.

Nuclear medicine, developed in the 1950s by physicians using iodine-131 to diagnose and treat thyroid disease, now uses radiation to provide diagnostic information about the functioning of many of a person's organs, or to treat them. In most cases, the information is used by physicians to make a quick, accurate diagnosis of the patient's illness. The thyroid, bones, heart, liver, and many other organs can be easily imaged. In some cases, radiation can be used to treat diseased organs or destroy tumors. Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99, with some 40 million procedures per year (16.7 million in the United States in 2012), accounting for 80% of all nuclear medicine procedures worldwide.



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The Gamma Knife concept of stereotaxic radiosugery. Radioactivity is used for treatment of brain tumors, among many other medical applications.

Diagnostic techniques in nuclear medicine use radioactive tracers, which emit gamma rays from within the body. These tracers are generally short-lived isotopes linked to chemical compounds that permit specific physiological processes to be scrutinized. They can be given by injection, inhalation, or orally. The first types are where single photons are detected by a gamma camera, which can view organs from many different angles. The camera builds up an image from the points from which radiation is emitted; this image is enhanced by a computer and viewed by a physician on a monitor, for indications of abnormal conditions.

Radiotherapy can also be used to treat some medical conditions, notably cancer, using radiation to weaken or destroy targeted cells. Rapidly dividing cells are particularly sensitive to damage by radiation. For this reason, some cancerous growths can be controlled or eliminated by irradiating the area.

Many radioisotopes are made in nuclear reactors, some in cyclotrons. Generally neutron-rich ones and those resulting from nuclear fission need to be made in reactors; neutron-depleted ones are made in cyclotrons. There are about 40 activation product radioisotopes and five fission product ones made in reactors. Tens of millions of nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing rapidly. Sterilization of medical equipment is also an important use of radioisotopes.

Food Preservation and Industrial Use

Food irradiation is a technology that improves the safety and extends the shelf-life of foods by reducing or eliminating microorganisms and insects. Like pasteurizing milk and canning fruits and vegetables, irradiation can make food safer for the consumer. The process is important in all countries, particularly in the Tropics, where food perishes within a very short period of time, endangering health and raising health-care costs.

Food irradiation can serve many purposes. It can be used to effectively eliminate organisms that cause foodborne illness, such as salmonella and *Escherichia coli* (*E. coli*). It can be used to destroy or inactivate organisms that cause spoilage and decomposition, and to extend the shelf-life of foods. It can destroy insects in or on fruits and decreases the need for other pest-control practices, which might harm the fruit.

One of the methods widely used to irradiate food and enhance its shelf-life is the use of gamma rays. Gamma rays, which contain cobalt-60 and caesium-137, have been used routinely for more than 30 years to sterilize medical, dental, and household products. They are also used for radiation treatment of cancer. High-energy gamma rays can penetrate foods to a depth of several feet. They do not make anything around them radioactive. Both cobalt-60 and caesium-137 are produced in nuclear reactors

Modern industry uses radioisotopes in very many ways to improve productivity and, in some cases, to gain information that cannot be obtained any other way. The continuous analysis and rapid response of nuclear techniques, many involving radioisotopes, mean that reliable flow and analytic data can be constantly available. This results in reduced costs, with enhanced product quality.

Neutrons from a research reactor can interact with atoms in a sample causing the emission of gamma rays which, when analyzed for characteristic energies and intensity, will identify the types and quantities of elements present. The two main techniques are Thermal Neutron Capture and Neutron Inelastic Scattering. TNC occurs immediately after a low-energy neutron is absorbed by a nucleus, NIS takes place instantly, when a fast neutron collides with a nucleus. A particular application of this is where a probe containing a neutron source can be lowered into a bore hole where the radiation is scattered by collisions with surrounding soil. Since hydrogen (the major component of water) is by far the best scattering atom, the number of neutrons returning to a detector in the probe is a function of the density of the water in the soil.

Since the amount of ash in coal is an additional headache, gamma ray transmission, or scattering, can be used to determine the ash content of coal on a conveyor belt. The gamma ray interactions are dependent on atomic number, and the ash is higher in atomic number than the coal's combustible matter. Also the energy spectrum of gamma rays which have been inelastically scattered from the coal can be measured to indicate the ash content.

Radioisotopes are used as tracers in many research areas. Most physical, chemical, and biological systems treat radioactive and non-radioactive forms of an element in such a way that the system can be investigated with the assurance that the method used does not itself affect the system. An extensive range of organic chemicals can be produced with a particular atom or atoms in their structure replaced with an appropriate radioactive equivalent.

Governmnet of India/Dept. of Atomic Energy

India has been engaged in desalination research since the 1970s. This demonstration plant was set up in 2002, at the Madras Atomic Power Station in Kalpakkam.

Desalination

Another major contribution to mankind from the waste heat generated by nuclear fission is the desalination of sea and brackish water. Freshwater makes up a very small fraction of all water on the planet. While nearly 70% of the world is covered by water, only 2.5% of it is fresh; the rest is ocean-based. Even then, just 1% of our freshwater is easily accessible, with much of it trapped in glaciers and snowfields.

The lack of clean drinking water is a major problem worldwide. The World Health Organization says that more than 1 billion people live in areas where renewable water resources are not available. The problem is especially serious in Africa, followed by Asia and the Pacific, according to a UN report. The lack of clean drinking water around the world forces millions of people to drink unsafe water. This leads to an increase in diseases like diarrhea, the second leading cause of death in children under five. Unsafe drinking water takes the lives of hundreds of thousands of children every year.

Yet we have the technology to desalinate sea and brackish water and provide each and every individual with potable water. But no real effort has been made to make water available to all.

Nuclear fission-created waste heat has been used sparingly for desalination. Nuclear reactors that help desalinate water will also produce electricity. An example of a nuclear reactor producing both electricity and desalinated water is the BN-350 fast reactor at Aktau in Kazakhstan, which supplied up to 135 MW of electric power while producing 80,000 m^3/day of potable water for some 27 years, about 60% of its power being used for heat and desalination. Japan, Russia, and Canada all have experience with nuclear reactors employed in the desalination of water, and the International Atomic Energy Agency (IAEA) strongly promotes this use of nuclear energy.

Early in the 1960s, foreseeing a time when freshwater needs would outstrip supplies, the U.S. Department of the Interior's Office of Saline Water (OSW) authorized funding for five research facilities to develop desalination technologies for the country. The Wrightsville Beach facility on Harbor Island, N.C., set up in the early 1960s, was dubbed the "world center for experimental development in saline water conversion," by OSW director C.F. McGowan. It was non-nuclear. The plan did not move forward.

In essence, nuclear desalination uses the excess heat from a nuclear power plant to evaporate seawater and condense the steam into pure water. It can also make brackish inland water potable. The feasibility of integrated nuclear desalination plants has been proven with over 150 reactor-years of experience, chiefly in Kazakhstan, India, and Japan. Large-scale deployment of nuclear desalination on a commercial basis will depend primarily on economic factors. One obvious strategy is to use small reactors in clusters, running at full capacity, but with all the electricity applied to meeting grid load when that is high, and part of it used to drive pumps for reverse osmosis (RO) desalination when the grid demand is low.

In Japan, some ten desalination facilities linked to pressurized water reactors operating for electricity production yield some 14,000 m^3/day of potable water, and over 100 reactor-years of experience have accrued. The water is used for the reactors' own cooling systems.

India has been engaged in desalination research since the 1970s. In 2002, a demonstration plant coupled to twin 170 MW nuclear power reactors (PHWR) was set up at the Madras Atomic Power Station, Kalpakkam, in southeast India. This hybrid Nuclear Desalination Demonstration Project (NDDP) comprises a reverse osmosis unit with 1,800 m^3/day capacity and a multi-stage flash (MSF) plant unit of 4,500 m^3/day, plus a recently added barge-mounted RO unit. This is the largest nuclear desalination plant based on hybrid MSF-RO technology, using low-pressure steam and seawater from a nuclear power station. The plant incurs a 4 MW loss in power.

China academy of Machinery Science & Technology

The gear box used in the seawater circulating pump at the Hongyanhe nuclear power station in China. The waste heat will provide water to cool the reactors.

A low temperature (LTE) nuclear desalination plant using waste heat from the nuclear research reactor at Trombay, near Mumbai in India, has operated since about 2004, to supply water for the reactor.

Pakistan in 2010 commissioned a 4,800 m^3/day multiple-effect distillation MED desalination plant, coupled to the Karachi Nuclear Power Plant (KANUPP, a 125 MWe PHWR) near Karachi. It has been operating a 454 m^3/day RO plant for its own use.

China General Nuclear Power (CGN) has commissioned a 10,080 m^3/day seawater desalination plant using waste heat to provide cooling water at its new Hongyanhe project at Dalian, in the northeast Liaoning province. Much relevant experience comes from nuclear plants in Russia, Eastern Europe, and Canada, where district heating for commercial and residential use is a by-product.

The best way to develop large-scale nuclear desalination along the world's coastal areas will be manufacturing large numbers of small modular nuclear reactors of 100-200 MW capacity. These reactors, when put in a cluster, would provide adequate and reliable power to the burgeoning industry and commerce, while supplying the heat to desalinate abundant amounts of seawater.

South Korea has developed a small nuclear reactor design for cogeneration of electricity and potable water. The 330 MWt (thermal) SMART reactor has a long design life and needs refueling only every three years. The main concept has the SMART reactor coupled to four MED units, each with a thermal-vapor compressor (MED-TVC) and producing a total of 40,000 m^3/day, with 90 MWe.

Argentina has designed the CAREM, an integral 100 MWt PWR suitable for cogeneration or desalination alone, and a prototype is being built next to Atucha nuclear power plant. A larger version is envisaged, which may be built in Saudi Arabia.

China's INET has developed the NHR-200, based on a 5 MW pilot plant.

Russia has developed a floating nuclear power plant (FNPP), with two KLT-40S reactors derived from Russian icebreakers, or other designs for desalination. The ATETs-80 is a twin-reactor cogeneration unit using KLT-40 and may be floating or land-based, producing 85 MWe plus 120,000 m^3/day of potable water. The small ABV-6 reactor is 38 MW thermal, and a pair mounted on a 97-meter barge is known as the Volnolom FNPP, producing 12 MWe plus 40,000 m^3/day of potable water by reverse osmosis. A larger concept has two VBER-300 reactors in the central pontoon of a 170-meter barge, with ancillary equipment on two side pontoons, the whole vessel being 49,000 DWT. The plant is designed to be overhauled every 20 years and have a service life of 60 years. Another design, PAES-150, has a single VBER-300 unit on a 25,000 DWT catamaran barge.

Thorium Reactors

The next wave of nuclear reactors that must emerge in large numbers are those fueled by thorium. Thorium has multiple advantages as a nuclear fuel. Thorium ore, or monazite, exists in vast amounts in the dark beach sands of India, Australia, and Brazil. It is also found in large amounts in Norway, the United States, Canada, and South Africa. Thorium-based fuel cycles have been studied for about 30 years, but on a much smaller scale than uranium or uranium/plutonium cycles. Germany, India, Japan, Russia, the United Kingdom, and the United States have conducted research and development, including irradiating thorium fuel in test reactors to high burn-ups. Several reactors have used thorium-based fuel.

India is by far the nation most committed to study and use of thorium fuel; no other country has done as much neutron physics work on thorium. The positive results obtained have motivated Indian nuclear engineers to use thorium-based fuels in their current plans for the more advanced reactors that are now under construction. It is therefore incumbent upon Indian policymakers to make thorium-fueled nuclear reactors their main workhorse and develop the engineering infrastructure to manufacture them in large numbers within a very short period of time.

In addition to thorium's abundance, all of the mined thorium is potentially usable in a reactor, compared with only 0.7% of natural uranium. In other words, thorium has some 40 times the amount of energy per unit mass that could be made available, compared with uranium.

From the technological angle, one reason that thorium is preferred over enriched uranium is that the breeding of U-233 from thorium is more efficient than the breeding of plutonium from U-238. This is because the thorium fuel creates fewer non-fissile isotopes. Fuel-cycle designers can take advantage of this efficiency to decrease the amount of spent fuel per unit of energy generated, which reduces the amount of waste to be disposed of. In addition, the fissionable thorium-232 (Th-232) decays very slowly (its half-life is about three times the age of the Earth).

There are some other benefits as well. For example, thorium oxide, the form of thorium used for nuclear power as fuel, is a highly stable compound—more so than the uranium dioxide that is usually used in today's conventional nuclear fuel. Also, the thermal conductivity of thorium oxide is 10-15% higher than that of uranium dioxide, making it easier for heat to flow out of the fuel rods used inside a reactor. Furthermore, the melting point of thorium oxide is about 500°C higher than that of uranium dioxide, which gives the reactor an additional safety margin, if there is a temporary loss of coolant.

The one challenge in using thorium as a fuel is that it requires neutrons to start its fission process. Thorium is not a fissile fuel like U-235; Th-232 absorbs slow neutrons to produce U-233, which is fissile. In other words, Th-232 is fertile, like U-238. Th-232 absorbs a neutron to become Th-233, which decays to protactinium-233 (Pa-233) and then to fissionable U-233. When the irradiated fuel is unloaded from the reactor, the U-233 can be separated from the thorium, and then used as fuel in another nuclear reactor. Uranium-233 is superior to the conventional nuclear fuels, U-235 and Pu-239, because it has a higher neutron yield per neutron absorbed. This means that once it is activated by neutrons from fissile U-235 or Pu-239, thorium's breeding cycle is more efficient than that using U-238 and plutonium.

Here is a summary of the advantages of using thorium as nuclear fuel:

1. Thorium fuel generates no weaponizable material in its waste profile; the waste consists of the radioisotope U-233, which is virtually impossible to weaponize;

2. Unlike uranium, thorium does not possess any fissile isotopes in its naturally occurring form; consequently, there is no material that can be enriched to weaponizable levels;

3. Thorium fuel can be used to safely incinerate the world's unwanted stockpile of plutonium waste and generate electrical power and heat to desalinate water;

4. Thorium fuel cycle waste has a radio-toxicity period of less than 200 years, which compares favorably with the more than 1 million-year radio-toxicity period estimated to exist for uranium fuel-cycle waste;

5. Thorium fuel has superior fuel economy in various respects; it will generate more energy per unit of mass than uranium fuel by a factor of approximately 30, which means thorium fuel-based power plants do not require re-loading for dozens of years;

6. Thorium fuel-cycle waste can be reprocessed and used as fissile material in a closed fuel cycle, meaning that eventually no new fissile material will be required to power the reactors; however the reprocessing technology (to separate U-233) does not yet exist.