Nuclear Power and NAWAPA: What Will It Take?

by DeWitt Moss

The North American Water and Power Alliance, proposed in the 1960s, is a program to truly green the United States, and uplift the nation and world in the process. For a brief video overview of the project, see www.larouchepac.com/node/15570. Other NAWAPA maps, videos, and interviews are available at www.larouchepac.com.

DeWitt Moss is a retired nuclear engineer and former director of the National Water Resources Association (NWRA) for Idaho. He also was involved with the fuel selection and testing of the Fast Flux Test Facility at Hanford, Washington. His article also includes excerpts transcribed from his interviews on the subject.

The North American Water and Power Alliance (NAWAPA) is a very impressive, almost overwhelming project: It would take 17 percent of the nearly 800 million acre/feet of runoff water out of northern Canada and Alaska, and bring it south, distributing it across some of the plains provinces of Canada, and much of it down through Idaho, Montana, other Western states, and Mexico.

In the course of recent discussions and technical news, I have reflected on the monumental task confronting us with the NAWAPA program. The concerns may be surmountable and solved with extensive and expert management, but we should be aware of the issues in order to address them in the NAWAPA context.

Since NAWAPA was first conceived in the early 1960s, and relooked at in the 1980s, the United States has gone from 160 million people to 311 million people today. There is not one state in the Western part of the United States that is not struggling for water—for agriculture, for fish and wildlife, for hydropower, and communities. To the extent that there can be a feasible way to get this water down, without the destruction of the wild and scenic areas and critical habitat, through Canada and through the northern part of the Montana-Idaho region of the United States, there is probably nothing more valuable to the nation than getting water into Utah, Nevada, Idaho, New Mexico, Texas, California, and so on, and also Mexico.

Mexico would be allocated almost 20 million acre-feet under NAWAPA. Right now, Mexico is getting just 1.5 million acre-feet from the Colorado River, but that water is inherently salty, because of runoff, and is probably too saline to use in producing crops. The addition of 20 million acre-feet will give Mexico adequate water at enough dilution for agricultural production.

In California, the upper San Joaquin Valley and the westlands irrigation district had to idle upwards of 500,000 acres last year, and NAWAPA would provide an alternate source of water for these people. When you move farther on down into the Central Valley, the number I read 20 years ago, is that some of that land in the middle of the valley had subsided 20 to 50 feet because of the overpumping of ground water. So, there is an opportunity in that area to provide new water and use the excess water for aquifer recharge.

The same is the case in the state of Idaho. We are not desperate in Idaho, but we are gradually depleting our 200-400 million acre-feet Snake River aquifer, by pumping out of it. Our aquifer in Idaho is probably 50 percent of what it was just 40 years ago. We can tell that exactly—it's not a mystery: This water comes out through the canyon walls of the Snake River, and it's measured. At one time it was 7,000 cubic feet per second, and it's now getting down to 4,000 to 5,000 cubic feet per second. We are pumping it out to irrigate more agricultural land.

In the Tucson/Yuma/Blythe area of Arizona, the ground water there has been pumped out to the point that it's uneconomical to pump any more. There, 300,000 to 400,000 acres are idled; the water is now down too deep. In the Central Arizona Project and those areas, the water from NAWAPA would supplement the water supply and any extra could be put back into the aquifer. This would be an absolute boon.

Probably the picture doesn't differ at any major U.S. aquifer that you look at, which services agriculture and municipalities. Industry can generally get by with river-type water—industry generally doesn't need that pure type of water. But because industry needs so much water, it heats up the streams, and then you get the problems for fish and wildlife that come with that reduced flow, heat pollution, and algae.

If we talk about 50 million acre-feet of water coming south, down through the mountain states area, it has the potential to provide adequate water for 50 million additional people. If it takes an average of 5 or 6 acre-feet of

The Rio Grande at White Rock, N.M. The United States and Mexico share the water of the river, but there is now not enough river water to supply all the users—a condition that NAWAPA will alleviate.

City of Jerome

The Northside Canal Company canal in Jerome, Idaho. Idaho, like other Western states, is depleting its underground aquifer.

FAO

A farmer works on an irrigation canal in Mexico. NAWAPA would provide 20 million acre-feet of usable water to Mexico.

water to irrigate an acre of land to grow one crop, or two crops a year, we would have the ability to grow 8 to 10 million more acres of land.

I know the Western water problems relatively well. I was a director for the Northside Canal Company, which manages 165,000 acres of surface-irrigated water. We were changing then from gravity irrigation to sprinkler systems, which are much more efficient: Sprinkler systems only put the amount of water on the crop that it needs, and there is not much percolation down to the underground aquifer. The sprinkler system uses about 2 acre feet per acre, compared to 4 to 5 acre feet of water per acre used by a gravity system.

As part of this program, I was involved with the National Water Resource Association. I served on that for approximately 10 or 12 years, which gave me the opportunity to see many of the water issues throughout the Western states.

NNSA

Yellowcake, the milled uranium ore used to produce uranium fuel for nuclear reactors. We have enough uranium for now, but to provide adequate fuel for the numbers of new nuclear reactors required, we need to reprocess spent nuclear fuel, not bury it. The spent fuel from one 1,000-MW reactor over 40 years would yield the equivalent of 5 billion gallons of oil.

Somewhere around 80 percent of the rural and small city population rely on groundwater for their municipal water supplies, so NAWAPA would directly impact them. There is another aspect to this also. It is typical of rural America today that there are few industries, few challenging jobs, so the young people move away when they grow up, because there is no work for them. This is now the most difficult time in the last many decades for a young person to get a job, and develop a profession. It's one of the most difficult times I ever envisioned. You can get an education, and you still can't get a job. NAWAPA can change this.

NAWAPA's Power Requirements

The NAWAPA program, as presented by the Parsons Engineering Company in the 1960s, will require copious quantities of power to provide for pumping, railways, cities and communities, resource and infrastructure development, and other related needs. Nuclear and hydropower are viewed as the most environmentally preferred and readily available to minimize the carbon impact of the energy required. The hydro contribution should be incorporated where the water quantities and head justify such use—but the opportunities may have their limits.

In some instances of unpopulated and remote areas, natural gas may be an option, if it is readily available to a given area. However, natural gas power plants still have a carbon impact to the atmosphere, about one-half that of a coal-fired plant. A policy decision will need to be made regarding that carbon impact versus the cost of a power transmission line connecting to a larger proposed nuclear complex. Natural gas plants could also be considered, as required, for back-up power supply during normal nuclear outages for maintenance and repairs.

Let us consider the following: NAWAPA may require 30 or more nuclear stations to be operable, some as early as 10 to 15 years from the start and others up to 10 to 15 years later. These reactors will average out at 600 to 1,200 megawatts electric. Add to this nuclear plant requirement the projections that the United States will need 46 or more new nuclear plants by 2030 to meet U.S. power demand and Washington's target for reducing greenhouse gases. The question is, does this country have the industrial infrastructure, including the manufacturing-fabrication capacity, to do this?

In my assessment, probably not, without a Manhattan Project-type of commitment from the U.S. government and industry, in addition to cost guarantees to utilities.

Proven and tested technical expertise, quality assurance and control practices, material standards, operating and maintenance procedures, reliable equipment, operations and safety procedures and systems are paramount. These plants are massive, complex, and expensive, requiring demonstrated proven technology. In the case of new untested concepts, such as the PRISM, LMFBR, or IFR, discussed below, a demonstration plant is definitely in order.

Another question is, does the United States have the available uranium and plutonium to fuel a planned 70 to 80 nuclear reactors in a 20-year period, or do we have to consider reprocessing some existing inventory of spent fuel? Reprocessing facilities or new fuel enrichment facilities may be required. We possibly have weapons-grade material that could be blended for fuel. Also, the French company Areva plans to start building an enrichment plant in Idaho Falls in 2012.

In addition to the above-mentioned manufacturing capability, do we have in this country the necessary and qualified engineering talent to assure that these plants are built to the rigid required standard, on schedule and within the required costs? If not, we need to develop this expertise via training and education.

The cost burden of nuclear plants is definitely impacted by the recent surge of building material commodity prices. I quote from the *Global Energy Reporter* of Jan. 16, 2011. "In 2009,

The Sawtooth Lift

A crucial inflection point in the 1964 NAWAPA design of the Ralph M. Parsons Co. is the transfer function, where flows from the collection function exiting the Rocky Mountain Trench are transferred from the Columbia Basin up into the Great Basin and on through the distribution network. This transfer function hinges on the Sawtooth Lift, consisting of six pump lifts, for a total of 2,450 feet, with a flow rate of 85,500 cubic feet per second.

This would require 26 gigawatts of power. Powering this 26-GW pumping system with the most advanced nuclear power plants can serve as a trigger for a long-awaited nuclear renaissance in the United States.

—Michael Kirsch,

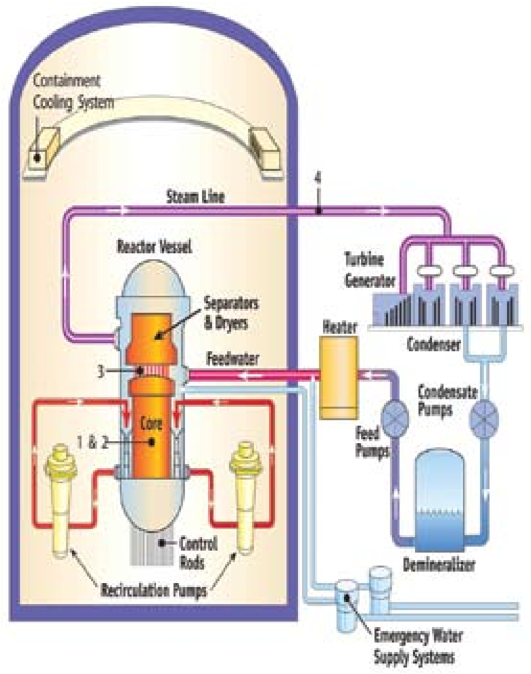


Figure 1
BOILING WATER REACTOR
The Boiling Water Reactor is the second most common commercial reactor type. In the BWR, water circulates through the reactor core, where the fission process heats it to boiling, converting it to steam. Steam separators remove water droplets from the steam, and the steam then goes to the turbine generator, which produces electricity. After it passes through the turbine, the steam goes to the condenser, where it is condensed into water. The cooled water is pumped from the condenser and sent back to the reactor core to begin the cycle again. The BWR has only two loops: the first one, which goes from the reactor core to the generator, and a second loop from the condenser to the cooling tower.

The control rods in the BWR come up from the bottom, instead of from the top. There is also a Torus or Suppression Pool below the reactor, which is used to remove heat in an emergency.

Source: NRC

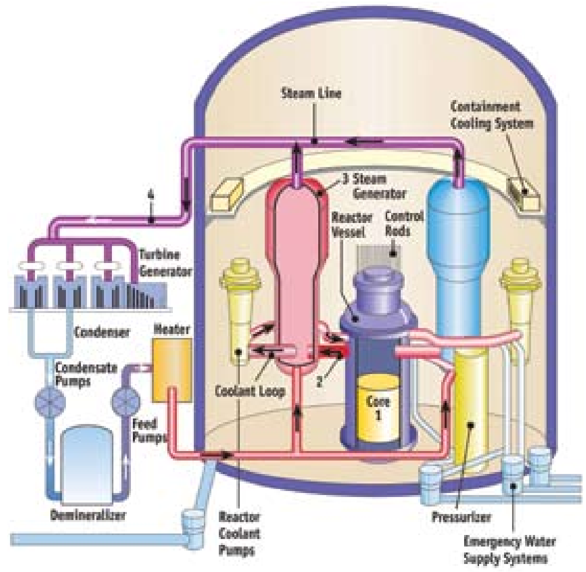


Figure 2
PRESSURIZED WATER REACTOR
The Pressurized Water Reactor is the most common commercial reactor type, and is similar to the BWR. The fission process in the reactor core heats pressurized water in a primary loop, which carries the heat to the steam generator. There it is vaporized and moves into a secondary coolant loop, where the resulting steam turns the turbine generators. The unused steam passes to a condenser, and is recycled back to the reactor core. A third loop, between the condenser and a cooling tower, cools the water in the condenser. High pressure keeps the water from boiling.

Source: NRC

MIT doubled its forecasted construction costs of new nuclear plants, while the U.S. Information Administration increased its 2009 estimate by 37 percent just this past December. All cost estimates have a huge amount of uncertainty—there is a big unknown in how reliable the contractors are going to be in coming through with their estimated costs. And similarly, how good they'll be at constructing them on time."

These are some of the major issues and obstacles that will confront NAWAPA tomorrow and into the foreseeable years to come. They probably are resolvable with adequate program planning and resources applied. It won't be simple, but with expert leadership, it is doable!

The Nuclear Options for NAWAPA

There are many nuclear power options to be considered. It is recognized that some of the concepts, discussed briefly here, will require an in-depth, independent evaluation, together with policy considerations to determine the preferred concept. Three engineering firms come to mind: Bechtel, Battelle Memorial Institute, and Fluor; there may be others.

The status of the nuclear and materials technology, availability of demonstrated fabrication expertise, safety and license approval, waste generated and disposal, economy of size and numbers of plants, capital and operating costs, and any required R&D will all need to be considered in choosing the preferred nuclear concept to be employed. Rigid quality assurance and quality control must be demonstrated through all phases of construction, equipment, materials, and operations. The significant number of plants involved may elicit some development and financial assistance from the chosen nuclear plant vendors.

Here are some of the nuclear power concepts available:

BWR—Boiling Water Reactor. The technology and operating experience are well proven for these light-water-cooled reactors, in sizes from 60 megawatts-electric to more than 1,000 megawatts-electric. Spent fuel is stored at reactor sites, as is the case for any operating U.S. nuclear power plant. Ad-

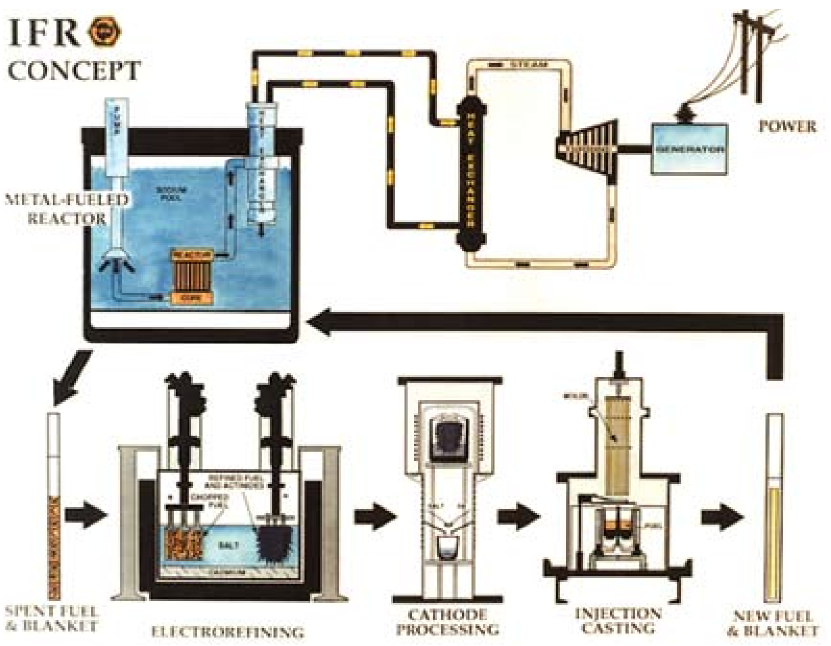


Figure 3
INTEGRAL FAST REACTOR
The Integral Fast Reactor uses fast neutrons (there is no moderator) to breed new fuel in a blanket. It completes the nuclear fuel cycle at the reactor site, reprocessing its spent fuel using electrorefining, and reusing it. The coolant is liquid sodium and the fuel is metallic. Developed at Argonne National Laboratory in the 1980s, the IFR was based on prior research with the EBR-II. The concept was cancelled in 1994, under pressure led by Energy Secretary Hazel O'Leary and Sen. John Kerry, allegedly for reasons of "proliferation."
Source: ANL

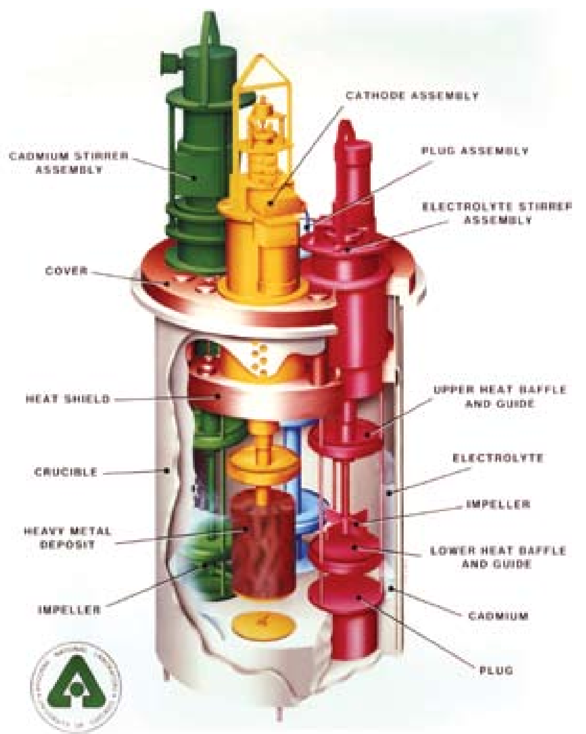


Figure 4
IFR ELECTROREFINER
The unique feature of the IFR concept is its electrorefiner (shown here in an artist's concept), which recycles its spent fuel, returning the long-lived "wastes" to the reactor to be burned up.
Source: DOE

vanced designs provide safer, long-lived mechanically improved plants.

Because thermal reactors produce small amounts of plutonium as a by-product of fission in uranium dioxide, any conventional-chemical reprocessing that separates the plutonium is cause for proliferation concerns. Also, it is an inefficient burner of its 4-6 percent enriched uranium, as is the Pressurized Water Reactor described below. High capital costs and lengthy construction times are a factor, similar for any nuclear concept.

PWR—Pressurized Water Reactor. Approximately 70 percent of the operating nuclear power reactors in the world are the PWR concept. The operating mode, plant equipment, and reactor component materials are similar to those of the BWR. France currently supplies 80 percent of its electrical needs, primarily with PWRs. The experience of PWR successful operation is bolstered by the fact that more than 100 nuclear naval submarines employ the PWR concept.

IFR—Integral Fast Reactor. The IFR concept is a sodium-cooled, pool-type, fast reactor with a closed fuel cycle employing uranium and/or plutonium metal fuel. The EBR-II (Experimental Breeder Reactor-II), a similar concept, was operated successfully for about 20 years. With the proper core and blanket design, the IFR can be configured to breed new fuel. With an attached fuel reprocessing cell, only chemical wastes are generated; plutonium is never outside the hot-cell reactor complex and is, therefore, unavailable for proliferation.

The IFR's design with metal fuel and pool sodium coolant makes it very safe in all modes of operation. Double-walled heat-exchanger tubing is generally used to avoid sodium-water contact, adding to its capital cost. The IFR can be designed to have a high power density, which requires smaller cores to produce a given amount of electricity, when compared to PWRs and BWRs. Because of its lower operating pressure, containment structures are less massive. Operating temperatures are

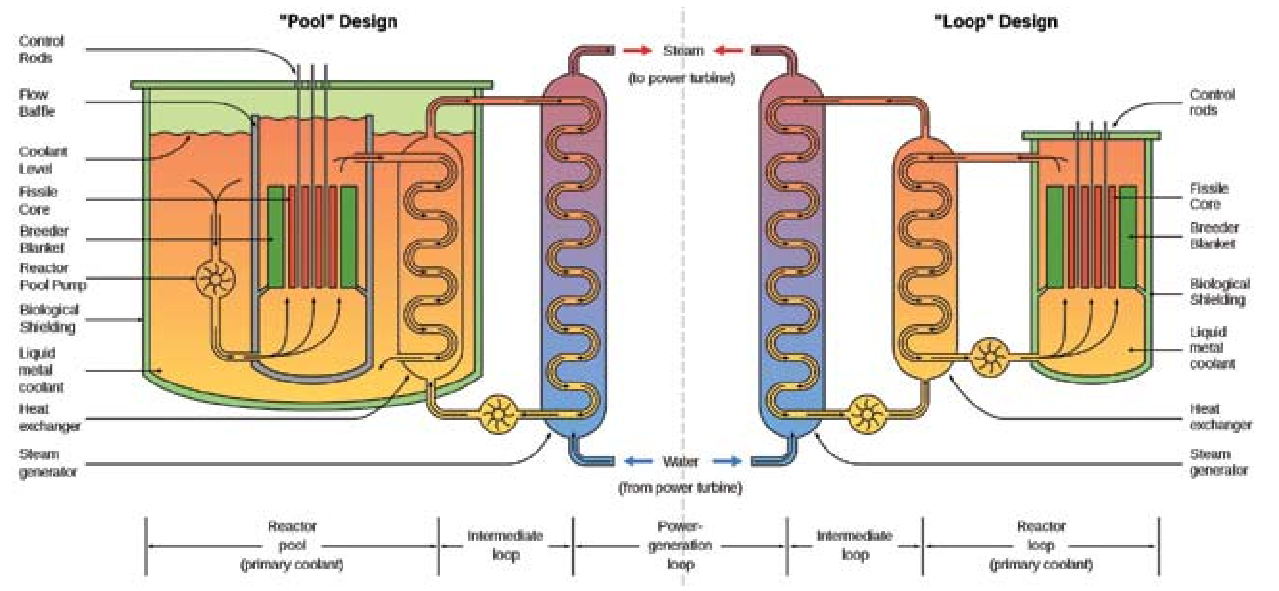


Figure 5
LIQUID METAL FAST BREEDER REACTORS
Liquid metal reactors usually use liquid sodium as the primary coolant that transfers heat from the reactor core to steam, which then is used to power a turbine to generate electricity. In the pool-type reactor (left), the primary heat exchangers and pumps are located inside the reactor tank. The loop-type reactor circulates the primary coolant through heat exchangers located outside the reactor tank. The LMFBR can be operated at much lower pressures and higher temperatures, because of the heat transfer properties of the liquid metal. The U.S. shut down its fast breeder program in the 1970s, for political reasons.

very nominal for the fuels and materials used.

Sodium melts at 208 degrees F and boils at 1,621 degrees F, while the metal-fueled core operates between 640 and 905 degrees F.

LMFBR—Liquid Metal Fast Breeder Reactor. The LMFBR concept is a sodium-cooled, mixed-oxide-fueled (generally) fast flux facility. Alternately, it could be a metal-fueled core. Demonstration plants exist in England, France, Japan, and Russia. Many have been in operation 10 years or so, and most experience is reportedly positive.

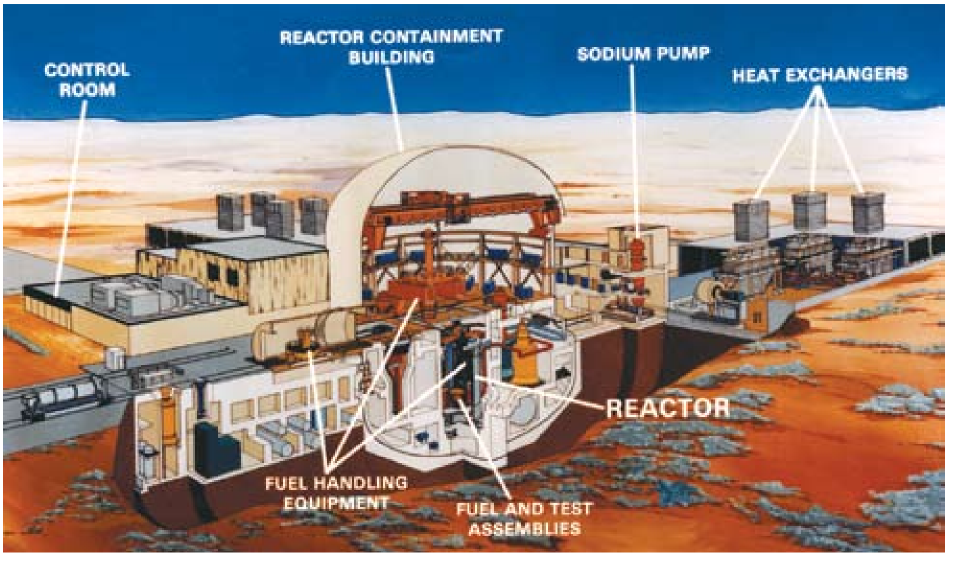


Figure 6
SCHEMATIC OF THE FAST FLUX TEST FACILITY
The FFTF at the Hanford Site in Washington state is a 400-MW sodium-cooled reactor that was designed to test breeder reactor fuels, materials, and components, and also to produce medical isotopes. The reactor was started up in 1980, and despite its very successful operation, political forces shut it down. The FFTF is now in limbo, but could be restarted.
Source: DOE

The largest fast breeder reactor was built in France, the 1,200-megawatt-electric Superphénix. It was shut down in 1998, for political reasons.

The concept was developed to breed plutonium, in order to use it as new fuel, which would extend our uranium resources for hundreds of years. Plutonium fissioning produces more neutrons per fission than uranium, resulting in a better output of energy. It's a fantastic resource. If we didn't ever find another pound of uranium, we could last another 1,000 years!

In my view, we stopped our breeder program when we were the leader in the world. We stopped, and every major country in the world proceeded, based on our developed technology..

The materials technology and nuclear characteristics are well established. In a closed cycle, like the IFR above, plutonium concentration for proliferation would not be a problem; it is recycled into new fuel for the reactor(s).

Metal fuel lends itself to the closed cycle, but the refabrication of irradiated, mixed oxides in a hot-cell complex is relatively undemonstrated. It would be a new concept to license, hence time-consuming and expensive. The United States had a design and construction under way at Clinch River, Tenn. for a demonstration LMFBR plant, but this was cancelled in the early 1980s, for political and economical reasons, and the perceived "lack of need" for a breeder reactor at that particular time.

The FFTF (Fast Flux Test Facility), a sodium-cooled fast flux test facility was built in the late 1970s-early 1980s at Hanford, Wash. It was fueled with mixed oxides of uranium and plutonium to test and evaluate materials, operating characteristics of the equipment and core, and reliability of equipment and other related purposes of a new concept. Although it operated successfully for several years, it is shut down now—but could be restarted.

PRISM—Power Reactor Innovative Small Module. A new concept with significant attributes, the PRISM is a pool-type sodium-cooled fast reactor with four components: a reactor core and associated pumps and heat exchanger, a hot cell to fabricate fuel, an Advanced Recycling Center (ARC) to recycle spent nuclear reactor fuel, and an electrical steam generator producing 622 megawatts-electric. As proposed, one nuclear site would have one, two, or three generators.

The reactor core is fueled with a metallic alloy of uranium, plutonium, and zirconium, which are easily fabricated in an attached hot cell. The proposed reactor core design and shutdown mechanisms make the reactor super safe.

Probably the most innovative and attractive attribute is the ARC. The Advanced Recycling Center would take spent nuclear fuel, now stored at the 100 or so operating nuclear power plants, and expose it to a molten lithium-chloride pool, with an adjacent electroplate anode. The uranium-based fuel would be dissolved, deposited and collected on the anode, and made into new metallic fuel.

If employed, the ARC could extract and burn up 90 percent of the uranium, compared with the 1-2 percent burn-up in light water reactors. Proliferation of uranium and plutonium are nonexistent in this concept because the fuel never leaves the reactor, hot cell, and ARC complex.

In the United States, 100 nuclear power plants produce 20 tons of spent fuel per plant per year for a 60-year lifetime, a total accumulation of 120,000 tons of spent fuel. Twenty-six PRISM-ARC plants can consume 120,000 tons of spent fuel, while producing 50,000 megawatts-electric—thus avoiding the emission of 400,000,000 tons of carbon dioxide every year. It would, also, consume our spent fuel inventory, avoiding expensive and time-sensitive storage. Only small quantities of radioactive "waste" would need storage at a site such as Yucca Mountain.

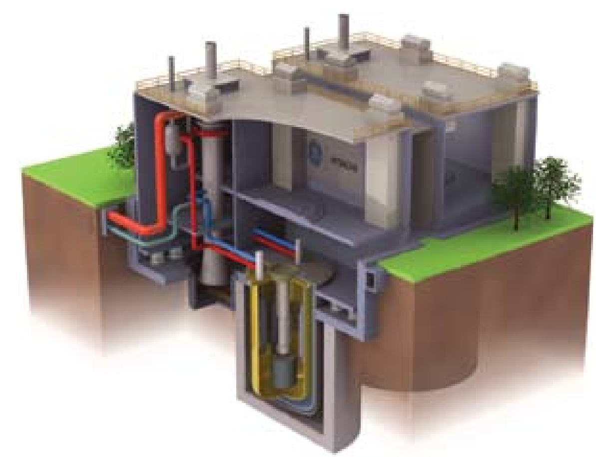


Figure 7
PRISM

The PRISM (Power Reactor Innovative Small Module) is a GE-Hitachi design similar to the IFR concept. It is a liquid-metal-cooled fast breeder, located below ground, which has an Advanced Recycling Center on site.

GE-Hitachi has initiated preliminary licensing steps for a single reactor and a 50 ton/year ARC separations facility. Its estimate for a demonstration plant to be available by 2020, would cost $3.2 billion over a 10-year period. This is an extremely safe concept, with proven reactor materials and equipment, and it could be a most reasonable and practical method to dispose of the tremendous spent fuel inventory now stored at U.S. reactor sites. The ARC concept is a patented, electrometallurgical process—but it needs to be demonstrated and verified.

We have adequate uranium available for fuel for the foreseeable future. A pound of uranium, as found in nature, has an energy equivalent of about 7,500 barrels (bbl) of oil, or 1,500 tons (3,000,000 pounds) of coal. Uranium in nature is 0.7 percent U-235 (fissionable), and 99.3 percent U-238. Commercial reactor nuclear fuel is normally enriched to about 4-6 percent U-235.

We now store the 40- to 50-year spent fuel inventory of our commercial nuclear power plants at the power plant sites, because we have no fuel reprocessing plants operable. Jimmy Carter came along as President and said “I do not want to reprocess fuels,” because of proliferation concerns. Spent fuel represents a wealth of energy, and basically money, that is sitting there idle. We only use about 1 percent of that fuel in a once-through cycle. So you have 95-plus percent of that spent fuel that can be used to fuel another reactor, *if you reprocess.*

Why would we want to process this spent fuel? The spent fuel of a 1,000-MWe plant over a 40-year lifetime, contains the equivalent energy of 5 billion gallons of oil, or 37 million tons of coal. And we have the equivalent of 60 to 80 of these plants in the United States.

HTGR—High Temperature Gas Cooled Reactor. The concept is not well tested in the United States. Two reactors, Peach Bottom (100 megawatts-thermal) and Fort St. Vrain (330 megawatts-electric) operated successfully, between 1967 and 1989. Both have been shut down. Their high temperature operation of 700 degrees C made for efficient electrical production, probably in the 50 percent range. Both concepts

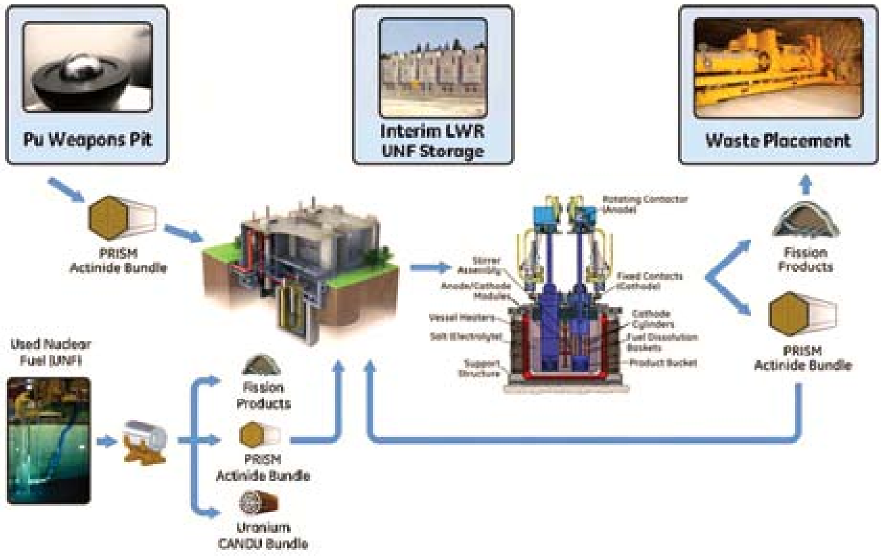


Figure 8
ARC—ADVANCED RECYCLING CENTER
The GE-Hitachi ARC is designed to recycle spent fuel, and also to process used weapons-grade nuclear materials to be used as new fuel for the PRISM or other reactors.

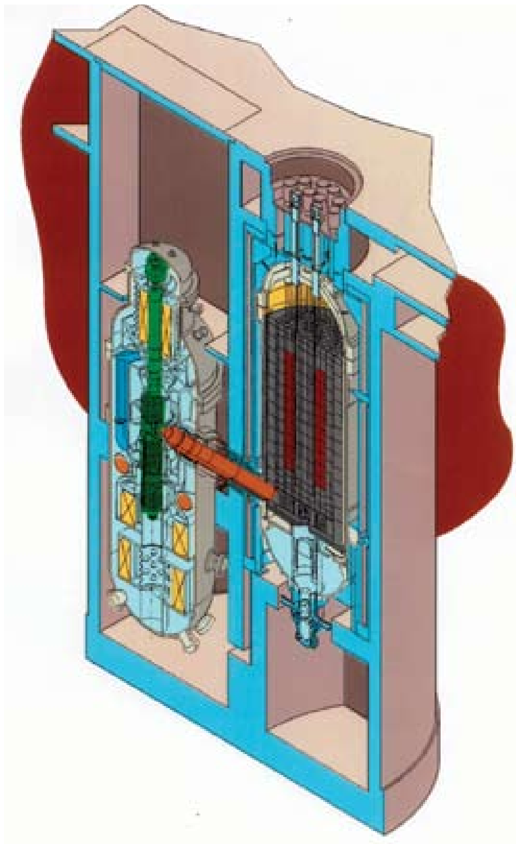


Figure 9
HIGH TEMPERATURE GAS-COOLED REACTOR
Cutaway view of General Atomics’ modular GT-MHR power plant, showing the reactor vessel (right) and power conversion vessel. The helium gas is used both as a coolant and to directly drive a gas turbine generator, which gives the reactor nearly a 50 percent increase in efficiency. Both modules are located below-ground.

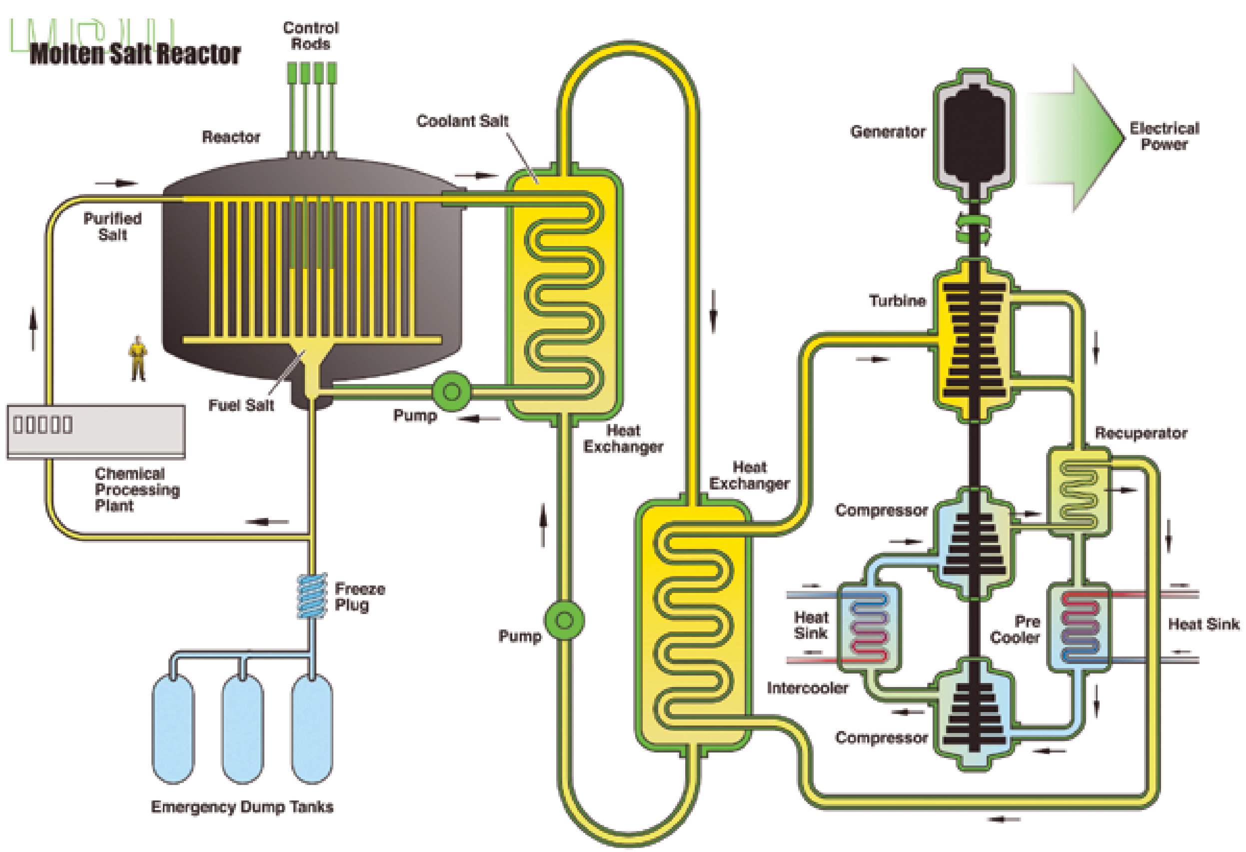


Figure 10
MOLTEN SALT REACTOR

The Molten Salt Reactor, which was researched at Oak Ridge National Laboratory in the 1960s and 1970s, uses a molten salt mixture as coolant, which can operate at high temperatures and low pressure. The molten salt mixture is less reactive than a liquid sodium coolant. The Liquid Fluoride Thorium Reactor (LFTR) is one promising type of MSR design. The thorium fluoride fuel is dissolved in the molten salt.

were helium-cooled and graphite moderated. Their design of a "dilute" core made for enhanced, safe operations.

The United Kingdom has many gas-cooled reactors operating, while the United States currently has none. It is anticipated that the operating and capital costs would be similar to that of the BWR and PWR. Licensing approval is probably not much different from the existing light water reactors' process.

MSR—Molten Salt Reactor. This concept circulates nuclear fuel in a molten salt, without any external coolant in the core. The primary circuit runs through a heat exchanger, which transfers the heat from fission to a secondary salt circuit for subsequent steam generation. It was studied in depth in the 1960s at Oak Ridge National Laboratory, but nothing has occurred beyond the laboratory stage.

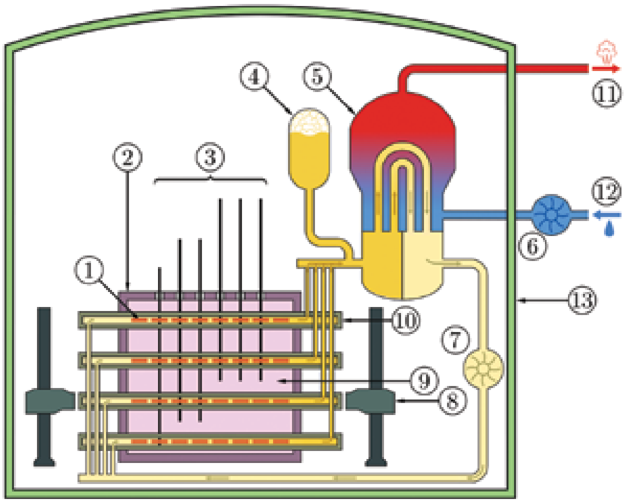
CANDU Reactor. This is Canada's preferred pressurized reactor concept, fueled with natu-

AECL

Canada has exported several CANDU reactors. These two 728-MWe Candu-6 reactors are operated by the Third Nuclear Power Company, Ltd., at Qinshan, China.

Figure 11
SCHEMATIC OF THE CANDU REACTOR
The CANDU (CANada Deuterium Uranium reactor) uses natural uranium as fuel and heavy water as a moderator. The primary heavy-water loop is in yellow and orange, the secondary light-water loop in blue and red. The heavy water moderator in the calandria (reactor vessel) is pink.

CANDU reactors can also use thorium and processed spent fuel.



Key
1. Fuel bundle
2. Calandria
3. Adjuster rods
4. Heavy water pressure reservoir
5. Steam generator
6. Light water pumps
7. Heavy water pump
8. Fueling machines
9. Heavy water moderator
10. Pressure tube
11. Steam going to turbine
12. Cold water returning from turbine
13. Containment building of reinforced concrete

ral uranium, and moderated and cooled with heavy water. The CANDU design allows for on-line refueling, thus minimizing downtime for improved operating efficiency. Since the spent fuel is never reprocessed, and only natural uranium is used, proliferation is not a concern. The heavy water coolant and moderator would allow the production of an insignificant plutonium by-product.

Canada has used this concept for the past 40 years. The CANDU spent fuel can be buried and/or stored with little or no economic penalty. Since some of the NAWAPA power requirements exist in Canadian provinces, Canada may prefer the CANDU reactor because of their construction, operating, and licensing experiences. Operation of these reactors is very safe, based on considerable experience with 10 or so reactors.

SAVANNAH RIVER NATIONAL LABORATORY/HYPERION POWER GENERATION, INC. Savannah River and Hyperion recently proposed the development of a "mini" nuclear power reactor, referred to as the Hyperion Power Module (HPM). As NAWAPA will most probably have requirements for some small modular nuclear plants to be used in the numerous proposed pumping stations, I will describe the plant design, as discussed by Hyperion.

The proposed HPM would produce 70 megawatts-thermal energy, and 25 megawatts-electric when connected to an electricity-generating system

According to Hyperion, "The reactor features uniquely stable uranium nitride fuel, an environmentally secure lead bismuth eutectic coolant, and robust HT-9 stainless steel construction. Scientists on the HPM project believe they have selected the safest combination of materials studied over decades of the nu-

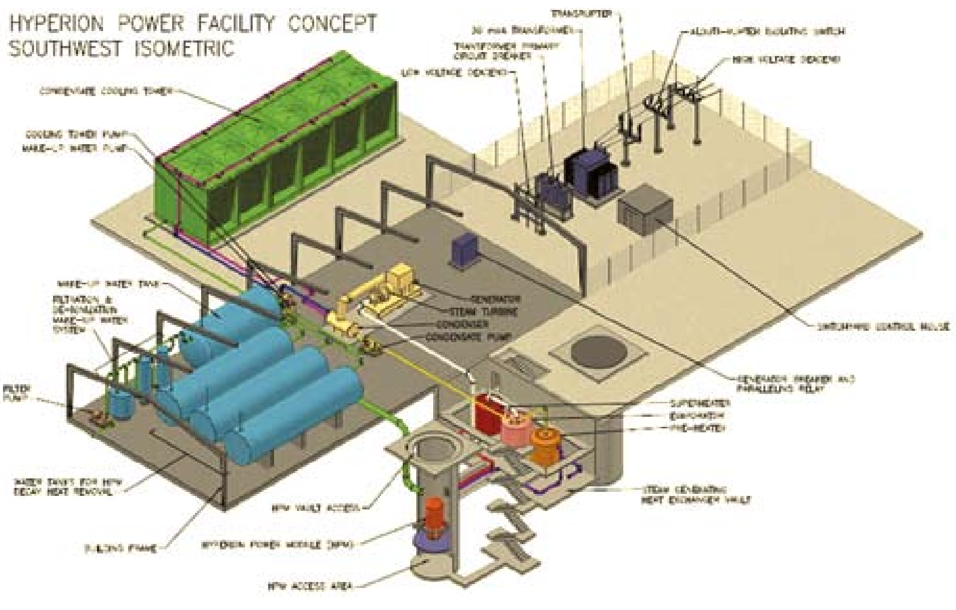


Figure 12
HYPERION'S MINI REACTOR LAYOUT
The Hyperion Power Module is a 25-megawatt-electric modular reactor design, which has been proposed for development at the Savannah River National Laboratory. The design would use uranium nitride as fuel with a lead bismuth coolant, and the whole module would be located underground.

Hyperion Power Generation

Its small size makes the Hyperion reactor easily transportable and suitable for remote locations.

clear age to create the most proliferation-resistant designed reactor thus far.

"The reactor vessel itself is about the size of a refrigerator and buried below grade for an extra measure of security. The complete plant, including the electrical generation system, takes up less than an acre. Transportable, permanently-sealed small reactors providing localized distributed power can be ideal for isolated locations that require an uninterruptible source of power, but they also have the potential to give utilities greater flexibility to add generation in a way that's comparatively inexpensive."

Future plans include testing and evaluation "to show how and where it can work," under the management of Savannah River Nuclear Solutions, LCC, a Fluor-Daniel Partnership, comprised of Fluor, Northrop Grumman, and Honeywell, which are responsible for the management and operation of the Savannah River Site.

Obviously, the HPM, if successfully developed, could be viable for NAWAPA. Development needs to proceed soon to demonstrate the concept.

Thorium-232 and Uranium-233 Cycle Reactors. In concepts discussed above, uranium and plutonium are the primary nuclear fuels. Thorium exists worldwide and is used extensively in India, where it is plentiful. The United States has done minor testing of thorium fuels in the Peach Bottom HTGR, the Fort St. Vrain HTGR, and at Shippingport, and India has had extensive experience with thorium.

Thorium oxide absorbs neutrons to produce U-233, which is fissionable. Some advantages of thorium-oxide are: The fuel has 10-15 percent better thermal conductivity than uranium dioxide and a melting point of 500 degrees C higher than uranium dioxide, thus giving an additional safety margin. The U-233 produced gives a higher neutron yield per fission than U-235 and/or Pu-239—and thus is more efficient in a fissioning and/or breeding cycle.

Based on the design of the reactor core, heavy water or light water can be used as the coolant. High temperature gas, probably helium, is also a coolant option.

"The difficulties in developing the thorium fuel cycle include the high cost of fuel fabrication," according to critics of the cycle, who cite the high radioactivity of U-233 and its contamination with traces of U-232, and contamination of Th-232 with highly radioactive Th-228. Also cited is the "weapons proliferation" risk of separated U-233.

Natural Gas, Hydro, and Electricity Transmission

The water for the NAWAPA project will need to flow continuously, requiring reservoirs, pumping stations, and the necessary back-up power and equipment. An engineering analysis will be required to determine where power is needed, including the hydropower available and the specific locations. Hydropower and gas-fired electrical plants seem logical for remote locations, because the strong technical workforce required for nuclear plants might limit available and willing personnel in the numbers required.

What's needed is an energy analysis that would evaluate the power requirements and the hydropower potential, to determine whether small modular plants with minimal transmission lines, or large nuclear plants with an extensive transmission connection would be most cost efficient, appropriate, reliable, and environmentally acceptable.

In establishing the overall energy made available along the NAWAPA water route, advanced planning should consider resource development power requirements. The Canadian Tar Sands are currently being developed. The current oil extraction from the tar sands requires an estimated 400,000,000 cubic feet of natural gas per day to heat the water needed to accomplish this oil separation. Nuclear power could provide the energy for

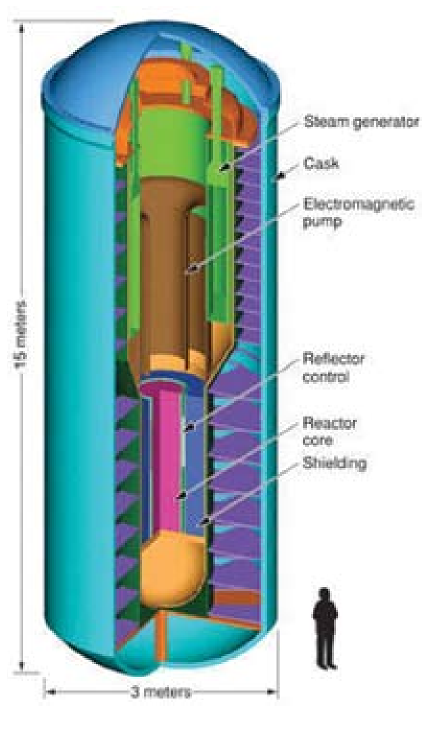


Figure 13
THE SSTAR THORIUM REACTOR

There are many nuclear reactor designs for using thorium fuel. India, which has large thorium reserves, has considerable experience with thorium, and is working on a thorium-fueled Advanced Heavy Water Reactor and an Advanced Thorium Breeder Reactor.

Shown here is the SSTAR (small, sealed, transportable, autonomous reactor), under design by the Lawrence Livermore, Los Alamos, and Argonne national laboratories. The reactor is here enclosed in a transportation cask.

heat requirements, saving the natural gas for purposes unique to natural gas, such as home heating, fertilizers, and so on.

It is also possible that oil shale development in the Western United States could be enhanced with the separation energy requirements provided by nuclear power.

Powering Lift Pumps

BWRs and PWRs have demonstrated operating experience with considerable industrial capacity in the United States. The fabrication capability of the large pressure vessels required may need to be re-established domestically. The Westinghouse PWRs, generally, are a loop-type design, with two, three, or four loops of 300 megawatts-electric each, thus allowing individual sizing to meet the requirements of a specific power site.

AECL

NAWAPA's power requirements will need both conventional nuclear plants, which can be built quickly, and advanced reactor designs, which must first be built as demonstration models. Here, the Bruce Power Plant in Canada.

Other PWRs and BWRs are of a single rating of about 1,200 megawatts-electric. Economy of size is important for nuclear plant construction and operation.

In my opinion, these plants could be built on today's well proven experience. No demonstration plant is required. The newer, safer plants are not dissimilar to the existing 100 nuclear commercial plants operating in the United States. Reprocessing, waste disposal, and some plutonium proliferation issues remain. If one had to choose today for a plant(s) to be operable in a 10- to 12-year period, without further developmental costs, the BWR and PWR concepts would suffice.

If we look to advance the U.S. nuclear program beyond the existing water reactors, liquid metal (primarily sodium) fast reactors should be considered, because they can breed new fuel, they have much higher power density per unit volume of core, and their fuel can be processed on-site, which significantly reduces proliferation concerns.

One concept, PRISM, as proposed (and discussed above), would use a dissolving and electroplating concept to reprocess spent stored fuel.

The three advanced concepts that I would consider for the pumping requirement are the PRISM, the IFR, and the LMFBR. These concepts each have pluses and minuses. Many concerns would be addressed via a vigorous demonstration plant program. A demonstration plant of intermediate size, 300 to 500 megawatts-electric would be in order.

Reflecting on the above sodium-cooled concepts, I offer the following personal views for further review and discussion.

Argonne National Laboratory (ANL) has extensive reactor design experience of a pool type, sodium-cooled, and metal (uranium and plutonium) fueled cores, attached to a hot cell fabricating facility; that is, the EBR-II facility. Metal fuel was chosen for the core for testing a high density fuel, high power density, high fast flux, and breeding capability. Metal fuels originally had a problem with swelling, thus limiting their core lifetime and affecting costs. To my best knowledge, the swelling issues have been made manageable by fuel alloying and fuel element design. However, I am not currently aware of the tested and verified maximum burn-up achievable with metal fuels.

Industry and utilities, initially, did not embrace the sodium-cooled metal fuel concept because of their extensive experience with uranium dioxide fuel and water-cooled reactors. The design and maintenance of equipment and water-cooled reactor operation was perceived as a better proven concept than the sodium-cooled concept.

ANL designed and operated EBR-II. Westinghouse designed and operated the FFTF, because it was the operator of the Hanford facility when the FFTF was constructed. General Electric was a prime contractor to the government for testing mixed-oxide fuels in a sodium-cooled reactor environment. This occurred during a 20-30 year period commencing in the 1960s. GE also has extensive experience with uranium dioxide-fueled water-cooled reactor concepts for the next generation of water-cooled thermal reactors.

It, therefore, is of significant note that GE is proposing as an advanced reactor concept a sodium-cooled metal-fueled fast reactor with an attached reprocessing hot cell. This PRISM concept addresses both proliferation and spent fuel reprocessing issues. Also, it implies that a major industrial vendor is endorsing a metal-fueled, sodium-cooled fast reactor. The GE choice, with its significant experience and resources, should be a major factor in the selection of an advanced reactor design.

ANL still exists to assist (if required) in the design of equipment and components of a sodium pool-type reactor, where most fuel handling is accomplished in a non-transparent sodium pool with argon, an inert gas.

In my view, the PRISM concept, with GE's formidable technical experience and resources, may be a preferred concept for NAWAPA to advance the U.S. nuclear program. As proposed, the PRISM concept with its Advanced Recycle Center is probably the most complex of the concepts considered above. Without an ARC, the PRISM is similar to the IFR, but the ability to reprocess spent stored fuel is lost.