The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Russia's Unique SVBR-100 Nuclear Reactor

Posted by Gail the Actuary on May 17, 2009 - 10:54am
Topic: Alternative energy
Tags: christopher babb, nuclear [list all tags]

This is a guest post by Christopher Babb. Until 2007, Christopher worked as a Ph. D. Economist. In 2007, he retired early to work on issues related the peak oil problem. His background in physics is from undergraduate coursework and from studying about it on his own.

The Significance of the SVBR-100 Modular Nuclear Reactor

Many analysts expect that societies in the post peak oil period will go through a “power down” scenario that will force their economies to be reconstituted using the primitive energy systems of the eighteenth century. However, not all analysts share this expectation. Since the accident at Chernobyl, an important group of Russian scientists has taken it upon themselves to rewrite the energy future of technically advanced civilizations.

Those scientists have chosen to turn away from the dangerous sodium cooled breeder reactor technology, and have turned instead to their own “home grown” “heavy metal” alternative. At present, the Russians are forging ahead to develop and build two different types of uranium fueled “heavy metal” reactors that have most of the favorable characteristics that engineers and policy makers would want in a nuclear reactor. In my opinion, those reactors have the potential to usher in a new era of almost unlimited low cost electric power.

The Russian’s SVBR-100 reactor, which is the subject of this short essay, is the first of those “heavy metal” reactors. (SVBR is the Russian acronym for “lead-bismuth fast reactor”). The first SVBR-100 will go critical and begin generating commercial electric power by around 2020.

The principal scheme of SVBR-75/100 is presented in Fig. 1, showing all basic systems of the reactor installation.

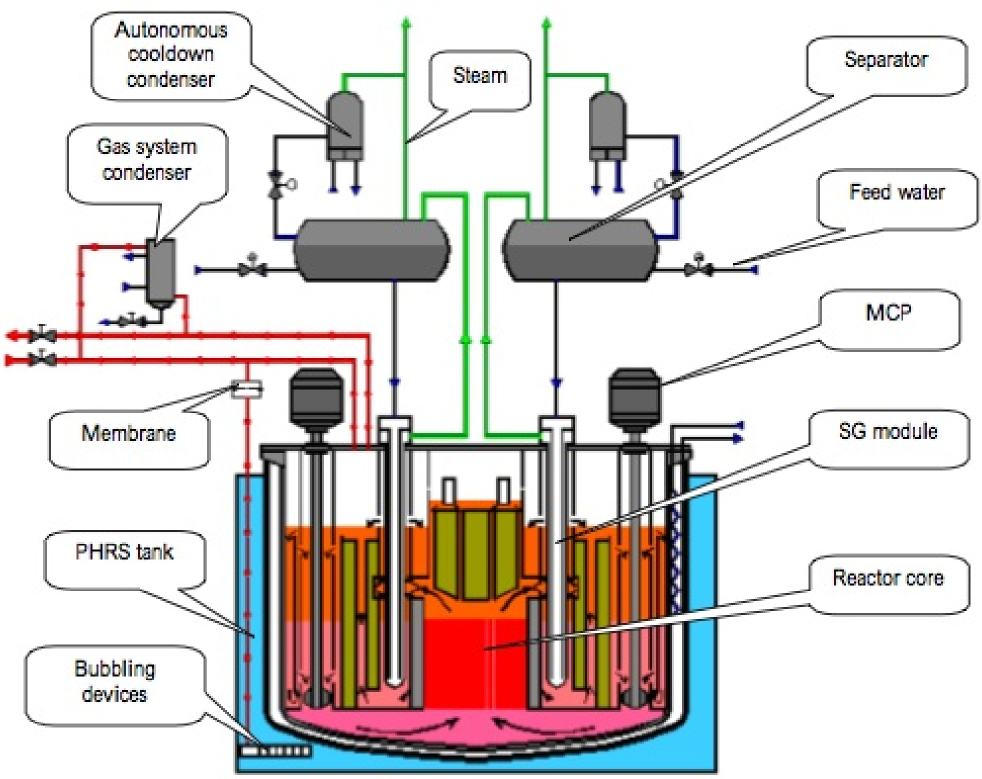

FIG. 1. The principal hydraulic scheme of SVBR-75/100.

The primary circuit includes core, steam-generator (SG) modules, main circulation pumps (MCPs) and in-vessel radiation shielding, all installed in a reactor mono-block vessel.

The secondary circuit includes SG modules, feedwater and steam pipelines, separators and autonomous cooling condensers.

The gas protection system includes condensers, protection membrane device, bubble device and pipelines.

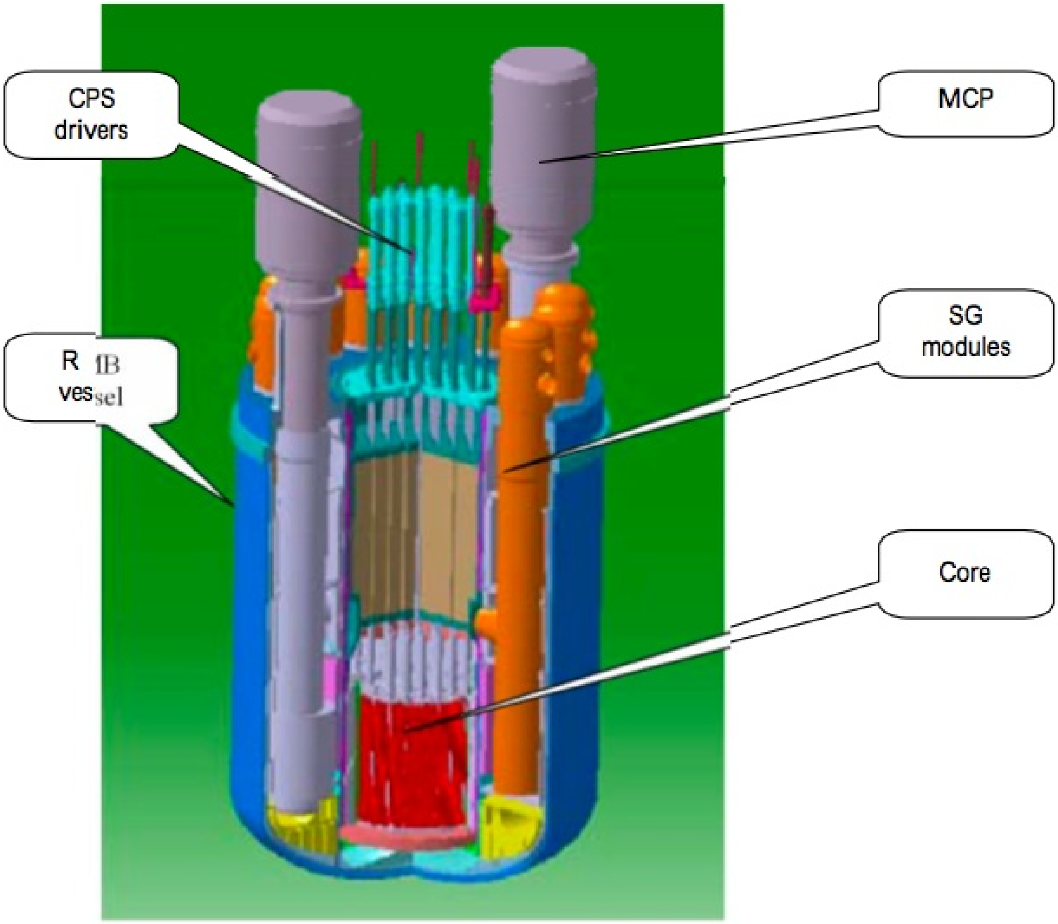

FIG. 3. Arrangement of the equipment in reactor mono-block vessel.

Images 1 and 3 from G.I. Toshinsky, et. al. Small modular lead-bismuth cooled fast reactor for multi-purpose use: SVBR-75/100, which is published in Innovative small and medium sized reactors; Design features, safety approaches and R & D trends, May 2005. – IAEA-TECDOC-1451, pp. 162 and 165

Background

On July 9, 2008, the company director of power machine engineering in the Russian Machines Company, Vladimir Petrochenko, announced that his company had made a commitment to invest US$400-500m in a joint venture with the State Corporation Rosatom to build the first SVBR-100 commercial power reactor in Obninsk which is in the Kaluga Region [Nuclear.Ru2008]. At that time the project was expected to take approximately seven years with a tentative completion date of 2015.

Subsequently, at the *2nd International Conference* **"Construction of Nuclear Power Plants "** which was held in Moscow in November 2008, Anna Kudryavtsev said that the total investments in the SVBR-100 project are currently estimated at 16bln Rubles. Updated estimates of the time line for the reactor's construction indicated that the design project should be ready by 2017 with a pilot reactor being installed by 2020. She noted that the SVBR-100 is likely to become the world's first commercial reactor cooled by liquid heavy metal. In this field, Russia is currently the world leader.

As the deputy director of the innovation science and technology policy department at

Atomenergoprom, Anna Kudryavtseva said that the SVBR-100 was a very promising project and that this type of reactor could be used at thermal power plants, floating nuclear power plants, in reconstruction of decommissioned nuclear power plants, desalination, production of hydrogen and petrochemistry [Nuclear.Ru2009].

Even before the July 2008 announcement of the SVBR-100 project, several Russian scientists had proposed that up to 300 of the SVBR-100 reactors should be built for installation in repowering several of the older VVER-440 and VVER 1000 series of pressurized water nuclear reactors [Toshinsky2005, 5]

Separate estimates developed by the IAEA suggested that by 2040 between 500 and 1,000 of the SVBR-100 reactors will have been built to accommodate growing market demands around the world.

The Unusual Properties of the SVBR-100

The SVBR-100 is a small "ultra safe" fast-breeder reactor with a heavy metal coolant. The modular design of the SVBR-100 makes it suitable for large scale production in a factory setting where high levels of quality control can be assured, and unit costs can be kept low. The SVBR-100 is cooled by a lead-bismuth eutectic alloy which is loaded into the reactor at the factory. After testing, the heavy metal coolant is allowed to "freeze", and the modular SVBR-100 reactor is transported to its power plant destination via railroad flat car for installation. The design of that reactor is both conservative and mature, being based on more than 80 reactor years of Russian operational experience with reactors of this heavy-metal type in the Project 705/Alfa nuclear attack submarines [Polmar2004, 140-146][Zrodnikov2003,117].

The thermal capacity of each individual SVBR-100 reactor is very small when compared to that of traditional "thermal" pressurized water reactors. Specifically, the thermal capacity of the SVBR-100 is only 280MW (thermal) which corresponds to 101.5 MWe [Zrodnikov2006, 1495]. When used in powering thermal electric plants, multiple units or batteries of SVBR-100 reactors are installed to satisfy the steam requirements of the power plant.

The societal implications of the technology embodied in the SVBR-100 are noteworthy. The SVBR-100 is the first in a class of "fast-breeder" power reactors that use a bootstrapping or breed/burn approach to multiply the energy extracted from a pound of uranium ore by a factor of 100 [Amer_Nuclear_Soc, 1]. Inside "heavy metal" reactors, the plentiful, fertile isotope U-238 is progressively converted to fissile Pu-239 which is then burned. As the U-238 gradually becomes depleted from the fuel mixture, more U-238 is added from stocks of un-enriched uranium.

The fuel cycle being developed for this new class of "heavy metal" reactors is also revolutionary. The ultimate waste products from those reactors will require storage times of less than 550 years [Lopatkin1999, 952-953] in contrast with that of the current pressurized water "thermal" reactors that generate plutonium wastes requiring storage times of between 100,000 to 500,000 years [Lopatkin1999, 949].

During scheduled reactor fuel reprocessing, a high proportion of the shorter lived radioactive waste products are extracted for placement in storage. However, enough of the dangerous nuclear actinides are intentionally retained in the reprocessed fuel to make it impossible to construct nuclear bombs from the plutonium component of the fuel. No plutonium is removed from the fuel, during reprocessing. The reprocessed fuel from each "heavy metal" reactor is returned for further burning in other "heavy metal" reactors. The conceptual shift embodied in this new fuel cycle is captured by the phrase: *"From clean fuel and dirty wastes towards dirty fuel and clean wastes."* [Adamov2006, 15].

The Russians Rethink Sustainable Nuclear Power After the Chernobyl Accident

Outside of Russia various proposals for quasi-sustainable nuclear power have been put forward that rely on using pressurized water reactors in combination with smaller numbers of "sodium cooled" fast breeder reactors and "accelerator driven" sub-critical reactors [Nifenecker2003,23-33,36-38]. However, problems with the reactor safety, nuclear proliferation and waste management issues created by that "standard approach" have been found to be close to insoluble.

In their efforts to "invent" a better approach to constructing a sustainable nuclear power system, those Russian scientists with the most cautious and critical view of nuclear power started out by reviewing five main categories of "risk" associated with the "standard approach". What they found strongly confirmed the societal unacceptability of the "standard" approach.

(1) The occurrence of a major fire in a sodium-cooled fast breeder reactor can easily lead to a Chernobyl level accident involving a massive release of radiation. [Adamov1999, 2].

(2) Because the breeding blankets in sodium-cooled fast breeder reactors produce near bomb quality plutonium, there is an unacceptable risk of the unlawful diversion of plutonium for bomb making. [Adamov1999, 2].

(3) The huge energy potential which exists in the fertile uranium U-238 isotope would be eliminated, if pressurized water reactors continue to be used, with the result that future generations would be deprived of an invaluable high-density energy source. [Adamov1999, 3].

(4) The economic costs of constructing and operating the technically complex sodium-cooled fast breeder reactors and accelerator driven sub-critical reactors would be extremely high, for all fuel cycles structured around the continued use of pressurized water reactors [Aastronomy2009, 2].

(5) The astronomically high costs resulting from the long storage times (100,000 to 500,000 years) of the plutonium and neptunium components of the waste streams generated by the "once-through" reactor fuel cycle would permanently burden future generations. [Lopatkin1999, 949]. Even the partial "burning" of "once-through" waste products creates storage times of up to 1,500 years [IAEA_2004, 12, 18].

A Competing "Heavy Metal" Reactor Design

In breaking new ground with heavy metal "breeder" reactors, the Russian scientists decided to proceed along two tracks. The first track involved the further development of lead-bismuth cooled reactors as embodied in the small modular SVBR-100 reactor. However, because the prevalence of bismuth metal in the earth's crust is well below that of lead, the Russian scientific community is also pursuing a second path which uses pure lead as a coolant. Currently, two lead cooled reactor designs are under development in Russia: the medium sized Brest-300 and the larger Brest-1200 [Gabaraev2003, 3-6][Saraev2007, 11, 14].

Unlike the lead-bismuth eutectic alloy in the SVBR-100 which melts at 125 degrees Centigrade, the lead used in the Brest series of reactors melts at the much higher temperature of 327 degree Centigrade. That higher melting point of lead presents various design challenges, relating to the temperature “floor” that must be maintained while circulating the reactor’s coolant. In addition, there is also a second design challenge based on an upper coolant temperature “ceiling” that is imposed because of the need to reliably control the corrosive effects of the lead coolant. Together those two restrictions require a reactor design where the core inlet and outlet temperatures are set at 417 and 537 degrees Centigrade, respectively [Adamov2001, 159-180]. Surprisingly, high thermal efficiencies can be achieved in a lead cooled reactor with that very narrow spread between inlet and outlet temperatures, if a high pressure turbine design is employed that uses supercritical CO_2 in a Brayton Cycle [Dostal2004, 294-296]. At the Sandia National Laboratories in the United States, preliminary work has been started on testing out supercritical CO_2 turbines [Wright2006, 9].

Assessing Risk

In considering the risk of a nuclear accident from a statistical perspective, it is revealing to find that some Russian scientists are inclined to view conventional estimates as not credible. One senior scientist has asserted that the conventional risk measures that fall in the range of 10^{-6} to 10^{-7} major accidents per year are unreliable, since they are developed using hypothetical arguments and are not grounded on actual real world experience [Adamov2001, 130-132].

When assessing the probabilities of accidents with “heavy metal” reactors that same scientist took the position that real world probabilities of the loss of a plant should be somewhere in the range of 10^{-3} to 10^{-4} major accidents per year.[Adamov2000,201]. However, those much larger accident probabilities do not need to cover collateral damage to people, land and structures which exist outside of the physical confines of the reactor building. All of the heavy metal reactors, including the SVBR-100, are engineered in such a way that the most dangerous accidents, such as fast runaway, loss of coolant, fire, steam and hydrogen explosions resulting from fuel failure and catastrophic radioactive releases, are excluded deterministically. So while the statistical likelihood of failure is higher, using the more realistic probabilities, the risks are nevertheless much lower due to the low impacts that any power plant failure would have on areas outside of the plant.

Adapting the SVBR-100 Reactor to Power Large Ships

In 2001, Shell ordered two LNG carriers to be built by Daewoo. The main steam turbines to be installed in each of those LNG carriers were rated at 32,400 horsepower [Tavinor2001]. In the coming decades when diesel fuelled engines are likely to be prohibitively expensive to operate, the SVBR-100 reactor could be readily adapted to propel large ships around the world at relatively low costs per nautical mile. The antecedent to the SVBR-100 which drove the Russian Alfa submarines had a 155 MWt lead-bismuth reactor that developed 40,000 horsepower [IAEA_2006, 4, 9-10]. (Note: The SVBR-100 generates 280 MWt.) As a consequence, it is not inevitable that International shipping will shut down in the post peak oil period, because of the high costs and limited availability of diesel fuel.

Using the SVBR-100 to Repower Coal Power Plants to Curtail CO_2 Emissions

Another application of the SVBR-100 reactor, which could have a very important impact on the World economy and environment, would be to adapt the reactor to repowering a high proportion of the World’s coal-fired power stations. This would be possible because the inlet and outlet temperatures of the SVBR-100 are very close to those of many coal fired power plants. Such a repowering operation would help mitigate the CO_2 emissions problem which arises from the operation of coal fired power plants. If the SVBR-100 reactors were used in that application, it would be necessary to greatly expand world bismuth production. That production expansion could only be accomplished with a combination of deep mining and a major run up in bismuth prices. Currently, bismuth is produced only as a bi-product of the mining and smelting of lead, tin and tungsten.

Prospects for Russia and the Russian Federation in the Post-Carbon Era

Based on the energy framework given in the "**White Book of Nuclear Power**" [Adamov2001, 229-235], the Russian leadership is working systematically to move toward a "post carbon" energy future to be secured by building several different types of breeder reactors. Those reactors will operate within a nuclear industry framework that will manage a numbers of different closed nuclear fuel cycles [Ratchkov2004, Sec. 3.3 & 5]. Currently, the idea of a "Nuclear Renaissance" is being used to market various elements of their program to interested foreign investors and governments [Nuclear_Ren2009]. Since Russia is a dominant oil exporter, and also has vast undeveloped reserves of natural gas, it is all but certain that Russia and the Russian Federation will succeed in their efforts to build a high tech "post carbon" future for their citizens.

It is a grand irony of history that a major support for the Russian plan to repower their economy using nuclear power will come from the run-up in oil prices that will occur as the world's oil importing nations scramble to purchase oil imports, during the "post peak" declining phase of world oil production.

References for Russia's Unique SVBR-100 Nuclear Reactor

Aastronomy2009, Aastronomy: *Subcritical reactor* http://www.absoluteastronomy.com/topics/Subcritical_reactor , pub 2009

Adamov1999, Adamov. E. "Supply of Fuel for Nuclear Power – Present Situation and Perspectives" *Uranium Institute – 24th Annual International Symposium* – Sep. 8-10, London, 1999

Adamov2000, Adamov, E., Ganev, I., Lopatkin, A., Orlov, V., Smirnov, V. – "Self-consistent model of nuclear power and nuclear fuel cycle" *Nuclear Engineering and Design*, no. 198, pp.199-209. – pub. 2000

Adamov2001, Adamov, E.O., et.al., **White Book of Nuclear Power**, Moscow, ***NIKIET***, pub. 2001

Adamov2006, Adamov, E., Muraviev, E., Orlov, V., "Vision of Nuclear Power Options for XXI Century" *N.A. Dollezhal Research and Design Institute of Power Eng*., Russia , pub 2006.

Amer_Nuclear_Soc, American Nuclear Society, Position Statement – 74 "Fast Reactor Technology: A Path to Long-Term Energy Sustainability" http://www.ans.org/pi/ps/docs/ps74.pdf , pub. (Nov.) 2005

Dostal2004, Dostal, V., Driscoll, M., Hejzlar, P. "A Supercritical Carbon Dioxide Cycle for Next Generation Nuclear Reactors" **MIT-ANP-TR-100** – pub. 2004

Gabaraev2003, Gabaraev, B., and Filin, A., "Development of a Brest-OD-300 NPP with an On-Site Fuel Cycle for the Belyarsk NPP Implementation of the Initiative by Russian Federation President V.V. Putin"., *11th International Conf. on Nuclear Eng.*, **ICONE11-36410**, Apr. 20-23, 2003.

IAEA_2004, IAEA_011604, "Implications of Partitioning and Transmutation in Radioactive Waste Management" **IAEA-TECDOC-xxxx**, 2004-01-16

IAEA_2006, IAEA_Brief_Paper_98, "Fast Neutron Reactors – Briefing Paper # 98 http://www.chumphon.mju.ac.th/mju_c/Data/Nuclear%20Power%20Plant/Nuclear... Pub. June 2006

Lopatkin1999, Lopatkin, A., Orlov, V., Filin A., - "Transmutation of Long-Lived Nuclides in the Fuel Cycle of Brest-Type Reactors" *Uranium Institute Annual Symposium 1999*, pp. 947-958.

Nifenecker2003, Nifenecker, H., Meplan, O., and David, S., **Accelerator Driven Subcritical Reactors**, Institute of Physics, Bristol, pub. 2003.

Nuclear_Ren2009, Nuclear Renaissance, a PDF weekly service by **Nuclear.Ru** with original information on Russia and CIS (Commonwealth of Independent States) nuclear industry., http://www.nuclear.ru/eng/nr/

Nuclear.Ru2008, "Rosatom and Russian Machines plans for JV to build brand-new-design reactors", http://www.nuclear.ru/eng/press/nuclear_power/2110145/
, posted Sept. 18, 2008

Nuclear.Ru2009, "SVBR-100 N-plant design to be ready by 2017"
http://www.nuclear.ru/eng/press/nuclear_power/2111220/
, posted Nov. 26, 2008

Polmar2004, Polmar, N., Moore, K., **Cold War Submarines: The Design and Construction of U.S. and Soviet Submarines**, Potomac Books, Inc., Wash. DC, 2004.

Ratchkov2004, Ratchkov, V. (Nigmatulin, B.), "Strategy of Nuclear Power Development in Russia", **Ministry of the Russian Federation for Atomic Energy**, Feb. 11, 2004.

Saraev2007, Saraev, O., "Prospects of Establishing a New Technology Platform for Nuclear Industry Development in Russia", Rosenergoatom, *International Congress on Advances in Nuclear Power Plants*, May 13-18, 2007.

Tavinor2001, Tavinor, C. – "Shell orders two more LNG carriers" , Shell International Media Relations – Press Release, May 14, 2001

Toshinksy2005, Toshinksy, G. "Concept of Small Power Reactor Installation without Refueling during lifetime (SVBR-75/100)", IAEA research Contract No. 13093 , pub. 2005

Wright2006, Wright, S., Vernon, M., and Pickard, P. – "Small Scale Closed Brayton Cycle Dynamic Response Experiment Results", *Sandia Report* (**SAND2006-3485**) – pub. 2006

Zrodnikov2003, Zrodnikov, A., Chitaykin, V., Gromov, B., Grigoriev, O., Dedoul, A., Toshinsky, G., Dragunov, Yu., Stepanov, V., "Multi-purposed Small Fast Reactor SVBR-75/100 Cooled by Plumbum-Bismuth", in IAEA-TECDOC-1348, also http://www.iaea.or.at/inisnkm/nkm/aws/fnss/fulltext/tecdoc1348_13.pdf , pub 2003

Zrodnikov2006, Zrodnikov, A., Toshinsky, G., Komlev, K., Dragunov, Yu., Stepanov, V., Klimov, N., Kopytov, I., Krushelnitsky, V., "Nuclear power development in market conditions with use of multi-purpose modular fast reactors SVBR-75/100" Nuclear Engineering and Design, vol 236 (2006), pp. 1490-1502