Safe pebble-bed nuclear reactors are just what Russia needs

Professor Lidsky is professor of nuclear engineering at the Massachusetts Institute of Technology. He was interviewed on May 25 by Jonathan Tennenbaum, director of the Fusion Energy Forum in Germany.

Q: I understand that you have been involved in organizing a cooperative effort between the United States and Russia in the field of "inherently safe" nuclear power stations. What exactly does that project involve?

Lidsky: The idea is in fact to provide the first commercial version of a technology that has been discussed worldwide for the last decade or so, and which a number of countries are interested in. The idea is to provide the inherently safe pebble-bed reactor, which was developed in Germany, with a gas turbine power conversion system. The result of doing that is that we end up with the inherent safety of the gas-cooled pebble-bed reactor and the great economy and small size of the gas turbine. The combination turns out to be a very attractive commercial source of nuclear power. As it happens, the Russians have, distributed over a number of sites, all of the technology needed to develop the system very well. And they have, as a result of their weapons effort, the fuel that would be needed to fuel a great number of these systems around the world. In fact, the installation of these systems would be one of the best ways you could think of to use up, in a socially beneficial way, the great Russian stock of weapons-grade uranium.

Q: How much is that?

Lidsky: There is an extraordinary amount, probably greater than 500 tons of very highly enriched uranium. With each reactor system that you build, you commit about three tons of that uranium for the first 30 years of its lifetime. So one could, in principle, by selling the reactor and committing fuel, account for a very large fraction of the Russians' weapons stockpile.

Q: What are the advantages of this type of reactor for commercial use?

Lidsky: The gas-cooled reactor is one that was developed quite a while ago to take advantage of the very favorable high-temperature properties of the fuel. Shortly after the Three Mile Island accident, some researchers in Germany realized that you could take advantage of this fuel and produce a reactor that was limited in size, but had an inherent safety, in the sense that there is nothing you could do to cause a release of radiation from this reactor. You could draw out the control rods, you could release the coolant, you could do all the things that would cause extraordinary difficulties in the classical light water reactors which are used everywhere, and it would have no effect whatever, with respect to the safety of the public or, in actuality, even to the survival of the plant.

This is a very interesting concept, because what one really wants to do with nuclear power is to spread it to developing countries, which in the course of the next half a century or century would burn massive amounts of fossil fuel. One really wants them to have an alternative, and it is hard to imagine that the current light water reactor, with its great cost and great size and its extraordinary complexity, furnishes that alternative. So one would have in principle a reactor that one can, with a light heart, distribute around the world. Furthermore it uses a fuel cycle that does not lend itself well to proliferation of nuclear materials. So in terms of safety and in terms of nuclear proliferation it is a marvelous reactor type.

The down side is the fact that this reactor is limited to about 200 MW or possibly at most 300 MW electric power, which is very much smaller than the current light water reactors. In the ordinary course of events, that would make the electricity from such a reactor very expensive, because there are economies of scale which favor big generating plants. It turns out that the use of the helium gas turbine with these reactors makes it possible to overcome those drawbacks. First, it is possible to build small gas turbines without paying a penalty with respect to larger ones. Secondly, the system can yield a very much higher efficiency than is ordinarily the case with nuclear power plants—efficiencies of the order of 45% to over 50% are possible. Whereas the ordinary nuclear power plants have efficiencies from the low to middle 30% range. The combination of the small size and high efficiency balances the higher unit cost for small nuclear power plants, and the combination becomes very attractive. It achieves the dual ends of inherent safety, so you can distribute it around the world, and low cost. Also the small size matches very well to the needs of the developing countries, where the transmission grid is not very well developed.

Q: These units could be produced in series—

Lidsky: In fact, since these are very much smaller than existing reactors, the idea would be to build them in a central factory and ship them around. They have a very much simpler installation. The present reactors are larger and you have, effectively, to build each one on site, because there is so much material outside the reactor core itself. This particular reactor has exactly the opposite situation. The reactor and the power conversion system can be built in a central factory, and merely assembled on site.

Q: So building the reactor would come out being extremely economical.

Lidsky: That's right. It's very hard to obtain very large economies of scale, but there are great economies of serial production, and if you get into a production-line mode—and you will with reactors of this sort, because with their lower power levels you will need a lot more of them—there is no question that you gain great economies.

Q: What is the historical background of the Russian project you mentioned?

Lidsky: Some very interesting things happened. In the late 1980s, there was a very strong program that had developed between Russia and Germany, to produce a prototype of this reactor and begin production of them. An extraordinary amount of money was spent on setting up to build that prototype. It was somewhere between half a billion and a billion dollars spent in developing and transferring the German-developed pebble-bed fuel-making technology to the Russians. For their part, the Russians developed the biggest high-temperature, high-pressure helium test loop existing in the world. That project was very close to fruition when, almost simultaneously, the German reunification put a great strain on the Germans' ability to finance that project, and developments in Russia took attention and money away from their ability to complete their half of the project. So the project, which came very close, fell apart.

On the other hand, all of the pieces are still there, in many cases still unused, and so there is an enormous infrastructure in place, in Russia, to develop and produce reactors of this sort. There is a great desire on the part of many large Russian

The 'pebble-bed' reactor

The key to the type of high-temperature reactor (HTR) technology developed in Germany lies in the use of novel spherical fuel elements (the "pebbles" or "potatoes") that prevent the release of radioactive fission products up to extremely high temperatures. The fission fuel (typically a mixture of enriched uranium and thorium) is prepared in the form of tiny particles of approximately 0.5 millimeter diameter, which are coated with multiple layers of carbon and a special form of the high-temperature ceramic material, silicon carbide (SiC). Several tens of thousands of these "coated particles" are embedded in a ball of graphite—the "pebble"—about the size of a tennis ball. In advanced versions now under development, the outside surfaces of the spheres are coated once more with multiple, chemically bonded SiC layers, for foolproof protection against corrosion.

The core of the reactor is simply a pile of these "pebbles" sitting in a cylindrical container with a funnel-shaped bottom. Unlike light water reactors, which must periodically be shut down for refueling with the familiar fuel rods, the "pebble-bed" reactor is continuously fueled; new "pebbles" are fed in at the top while used ones flow out through the bottom. Because of this, the reactor contains at all times only as much fuel as is necessary for normal operation, avoiding excess reactivity, which is a safety concern in other reactors.

A crucial feature of the "pebble-bed" HTR is its very strong "negative temperature effect": If the temperature rises above a certain level, the fission chain reaction shuts down immediately. This is due to the temperature dependence of neutron interactions in the system, and occurs independently of any outside interventions. The combination of this feature, the high-temperature tolerance of the fuel elements, and a modular reactor providing for a large heat capacity and "passive" heat conduction to the environment, ensures that this system is "inherently safe"—a serious accident with major release of radioactivity is ruled out physically, even in the event of sudden loss of coolant and failure of pumps, control systems, or other components.

The high-temperature gas-cooled reactor (HTGR) and modular HTGR developed by General Atomic in the United States share many of the advantageous features of the "pebble-bed" design. In the American designs, the "coated particles" are embedded in prismatic fuel elements which are periodically changed, instead of being cycled as in the case of the German reactor.

laboratories to do just that, because it would be a very good use for much of their technology. The gas turbine, for example, would be an ideal thing for the people who have been building their aircraft engines, to be involved in. The fuel supply, as I mentioned previously, would be a great use of the Russian stockpiles of uranium, and the fuel production facilities are very well developed. As it happens, in Russia they have done extensive fuel testing. In many ways they carried the development of the fuel further than in fact had been done in Germany. So the Russians had, just before the project fell apart, some of the world's very best fuel for reactors.

Q: These are the so-called pebbles?
Lidsky: These are the pebbles for the pebble-bed reactor. This is all based on a reactor that operated in Germany for more than 20 years, the AVR reactor. It was meant as a test bed for a much larger reactor, and was then converted to a test bed for smaller, modular, inherently safe reactors late in its life. Pebbles were developed for that use, and literally millions of pebbles had been developed and tested in that device. That technology has been transfered, in one form or another, to Russia, to China, to Japan, and other countries.

Q: What happened after the Russian-German project shut down?
Lidsky: The program stagnated. For four or five years nothing further developed. The people who worked on it remained intensely enthusiastic about it, but it is very hard to get a project for nuclear power to happen anywhere in the world. The reason for that is that most people view nuclear power as one extension or other of existing light water technology, which has taken up all the available niches in the countries where it evolved, and is not at all suitable for installation in developing countries, and knowledge about this sort of system is not widespread, and governments tend to view nuclear power with the drawbacks of the light water reactors. And so there is a combination of problems involving education and economics, that need to be solved.

Q: What are the more recent efforts that you have been involved with?
Lidsky: I was involved in an effort put together by a company called Advanced Physics Corp. in San Diego, California, that attempted to match private funding with a consortium of Russian laboratories and manufacturing firms, to build the reactor. It would be built in Russia for initial use in Russia, but could in principle provide Russia with a very valuable source of hard foreign currency if they exported these reactors. But the initial goal was to provide for a reactor built in Russia by Russians, for Russian use. If it worked out, this could be distributed much more widely. This had clearance at the very highest levels in Russia, including Minister of Atomic Energy Mikhailov, who was very enthusiastic about this project. Mikhailov was very insistent about the fact that this reactor would meet the very highest world standards for safety—including the German standards and IAEA [International Atomic Energy Agency] standards—and was convinced that this reactor could do that. The reason for this is, of course, the Russian sensitivity about nuclear power safety; they would have to show they could meet the world's highest standards. It is also an expression of the fact that they expected to be able to export this reactor anywhere in the world after it had been developed.

Q: How long would that development take, if the project went full speed ahead?
Lidsky: The prototype would take a while, because some things need to be developed and some things that had fallen into disrepair would have to be put together. But one could have that done within probably six years, very realistically, if in fact it were funded at the initial level. The succeeding reactors of course take much less time than that, because they can be factory built. But the very first one, considering that parts have to be designed in detail, would probably take six years.

Q: Did this involve the Kurchatov Institute?
Lidsky: This involved a number of institutes in Russia. It involved the Kurchatov Institute; it involved Energomash, which participated in most of their rocket engine development; it involved another major manufacturer responsible for a number of crucial developments; it involved Chelyabinsk 70, a weapons laboratory, and a group in Novosibirsk which was the factory responsible for the reactor fuel production plant. So there is a group of five or six major Russian laboratories involved in this—Kurchatov having the lead but with all very actively involved.

Q: What is the situation now?
Lidsky: The present situation is stasis. The Russians have come together with a design and a plan for this reactor. It was a remarkable effort done in a very short period of time. The funding is proving to be just a little bit too high for the private funding that Advanced Physics had put together. So the program is waiting now to see whether additional input can be made of funding from some other source, or some way can be found to bring the price down in Russia. It is a great shame, because it is something that the world needs. It is something that if carried to fruition, the Russians could do as well as anyone in the world. And because of their very large stock of weapons-grade uranium, it could supply fuel at an advantageous cost to the whole world for quite a period of time. So it really is something that the Russians would like very much to be able to do, and they find themselves caught short by a funding shortfall.

Q: Why shouldn't this kind of project have enthusiastic support from the U.S. government? Vice President Gore, when he was in Russia, spoke of the need to preserve the scientific manpower and capabilities in Russia, and I know that people in the United States are concerned that the scientists in Russia, especially scientists who were involved in the military domain, be given reasonable things to do in the civilian domain. So it would seem to be a perfect way to realize what many people inside and outside the U.S. administration want, to have projects which would really benefit the Russian economy. Everyone knows that to the extent the economy deteriorates further, the political situation will also deteriorate.

Lidsky: You are absolutely right. It is hard to imagine a project that would better use the capability of the Russian weapons laboratories and the Russian military establishment, at the same time provide power for Russia, and draw down their weapons stocks. Rationally, this should be given support at the very highest levels. But, in fact, the current U.S. administration, as a matter of principle, has stated that it will provide no money whatsoever to advanced nuclear power research in any form. The only item which was singled out by name in President Clinton's first State of the Union address, was the cancellation of all work on advanced nuclear power systems. So rationality does not really enter into the discussion. . . .

Q: But the administration must have in some way been willing to have it happen.

Lidsky: Yes. This was cleared, for example, with the State Department and with other responsible agencies. But at the very highest levels in the Clinton administration there is absolute unwillingness to have anything whatsoever to do with this, to support it in any way or even to facilitate in any way whatsoever work on advanced nuclear power systems.

Q: Even if it would be done in Russia?

Lidsky: Apparently so.

Q: What would you like people to do about this?

Lidsky: The issue is quite clear. The Russian capability is there, the Russian interest is very high, the results of having the Russians develop this technology would be very good for Russia and for a large fraction of the developing world. This technology could be well established and we would cut down enormously on the burning of fossil fuels as the developing countries develop in the course of the next half-century. The only thing standing in the way of a successful Russian program, if it could be done before Russia collapses even further, is money.

The issue is putting together sufficient funding, by one route or another, to make the project possible. After that, everything comes easily. The goal is the production of a prototype, to prove to everyone the potential of this technology.

Q: I would like you to comment on an area where nuclear energy has a decisive role to play in providing for peace through economic development: the peace process in the Near East. On the background of negotiations between Israel and the Palestine Liberation Organization, Israeli Foreign Minister Shimon Peres, as well as various Arab spokesmen, referred repeatedly in public statements to the potential of nuclear-powered desalination of seawater. These statements echo the "Oasis Plan" proposed in the July 1990 by Lyndon LaRouche, which envisages the construction throughout the Near East region of a network of agro-industrial centers powered by modular nuclear reactors of the high-temperature reactor (HTR) type, which would be linked together by modern rail systems, water canals, and pipelines, and would apply desalinated water to high-tech agriculture and related activities for "greening the deserts." What do you think of this perspective for the region?

Lidsky: The goal is admirable. The technology exists. The idea is a sound one. Clearly what the region needs is energy and water. This technology provides both in a safe form that is suitable for installation in that part of the world. Now the particular technology we are talking about is high temperature, compared to the light water reactor technology. The trick is to produce both electricity and water. As it happens, water production is almost a crude by-product of the development of power by the gas reactor system. In a reactor of the more conventional sort, the light water reactor, one has to choose between producing power and producing water; if you do more desalination, you produce less electrical power. With the gas reactor, you don't have to make that choice. The heat that is thrown away after being used at high temperature in the gas-cooled reactor, is still of sufficiently high quality as to be useful for desalination, without at all affecting the process of electricity generation. Water generation is thus a low-cost by-product of power generation. It is my belief that you need both, to make the desert bloom.

Q: What about the issue of proliferation?

Lidsky: Proliferation is a problem when nuclear fuel is reprocessed. When the nuclear fuel is not reprocessed, the plutonium which is an inevitable effect of producing nuclear energy, is locked up in a form that is totally unusable for weapons and is totally untouchable. The fuel elements of the gas-cooled reactor are far more difficult to reprocess for removal of plutonium than in the light water reactor. In fact, one of the reasons why the light water reactor gained its ascendancy early on, was because there was a great desire to do reprocessing for a number of reasons that are no longer valid. So it is far more difficult to reprocess the HTR fuel, albeit not impossible. It would certainly be very difficult for any group smaller than a large national group even to think of attempting such a thing. So, it is not proliferation-proof, but is far more proliferation-resistant, than any of the existing nuclear reactor types that people are considering.