A Supersafe Reactor

The steel pressure vessel of the PBMR (see **Figure 1**) is six meters in diameter and about 20 meters high, inside a building that is 21 meters below ground. The walls of the vessel are lined with 100-cm thick graphite bricks. Inside the vessel are 310,000 fuel balls ("pebbles") which are the size of tennis balls, plus 130,000 graphite balls, which moderate the reaction.

Each fuel ball contains about 15,000 fuel particles, and about nine grams (about one-quarter ounce) of uranium. The total uranium fuel in the reactor is 2.79 tons. Each fuel pebble generates about 500 watts of heat, when the reactor is in full operation. The reactor is continuously refuelled, with new fuel balls added at the top, and spent fuel balls removed at the bottom. Each fuel ball passes through the reactor about ten times. The continuous refuelling eliminates the weeks-long down-time necessary for large light-water reactors, when they are refuelled.

The fuel particles, which were pioneered by General Atomics in the United States in the 1950s, are constructed with a tiny particle (0.5 millimeters) of uranium dioxide at the center, surrounded by several concentric layers of temperature-resistant materials—porous carbon, pyrolytic carbon, and silicon carbide. These coatings "contain" the fission reaction of the uranium, even at very high temperatures (up to 1,600°F). In fact, the fuel pebbles can withstand temperatures at which the metallic fuel rods in conventional light-water reactors would fail.

How It Works

To produce electricity, helium gas, at a temperature of about 500°C, is inserted at the top of the reactor, and passes among the fuel pebbles, leaving the reactor core at 900°C. From there it passes through three turbines, the first two driving compressors, and the third the generator. There, its thermal expansion is transformed into rotational motion to generate electricity. The expanded helium is then recycled into the reactor core by two turbocompressors. The helium leaves the recuperator at about 140°C, and its temperature is lowered further to about 30°C in a water-cooled precooler.

The helium gas is then repressurized, and moves back to the heat exchanger to pick up heat before going back to the reactor core.

This direct-cycle helium turbine, with a highly efficient recuperator, simplifies the reactor operations, eliminating the need for heat exchangers and secondary cycles, which are required in conventional light-water reactors.

The net thermal efficiency of the PBMR is 45%, compared to 30-35% for conventional light-water reactors. This is one of the main reasons that the PBMR is projected to produce electricity so cheaply.

The outlet temperature of 900°C is far higher than that of conventional light-water reactors (280°C to 330°C), which gives this type of reactor its name: high-temperature reactor.

Safety Systems

The inherent and passive safety systems of the PBMR are designed to make it "meltdown proof." The physical characteristics of the reactor are such that it shuts itself down, without any additional safety systems, in any imaginable accident scenario. As in the GT-MHR operation, there is a self-stabilizing temperature effect. If the temperature of the reactor core should heat up, the large amount of U-238 in the fuel particles absorbs more neutrons without fissioning. Thus, if the core heats up, the reaction slows down and stops, automatically stabilizing the temperature of the core.

The spent fuel from the PBMR also has built-in safety features. Because it is encapsulated in several coatings, including silicon carbide, the radioactive fission products which remain when the fuel has been burned, are fully captured and contained inside the same fuel pellets, and can be stored relatively inexpensively.

Interview: Walter Simon

Russia's GA Reactor To Burn Weapons Plutonium

Mr. Simon is a nuclear engineer and Senior Vice President for Reactor Projects at General Atomics (GA) in San Diego. He is in charge of the joint program GA has with Russia to build a high-temperature gas-cooled nuclear reactor, which will use weapons-grade plutonium as fuel. He was interviewed by 21st Century Science & Technology *managing editor Marjorie Mazel Hecht at the end of 2001.*

Q: What is the status of the General Atomics project to build the Gas Turbine-Modular Helium Reactor, the GT-MHR, with the Russians?

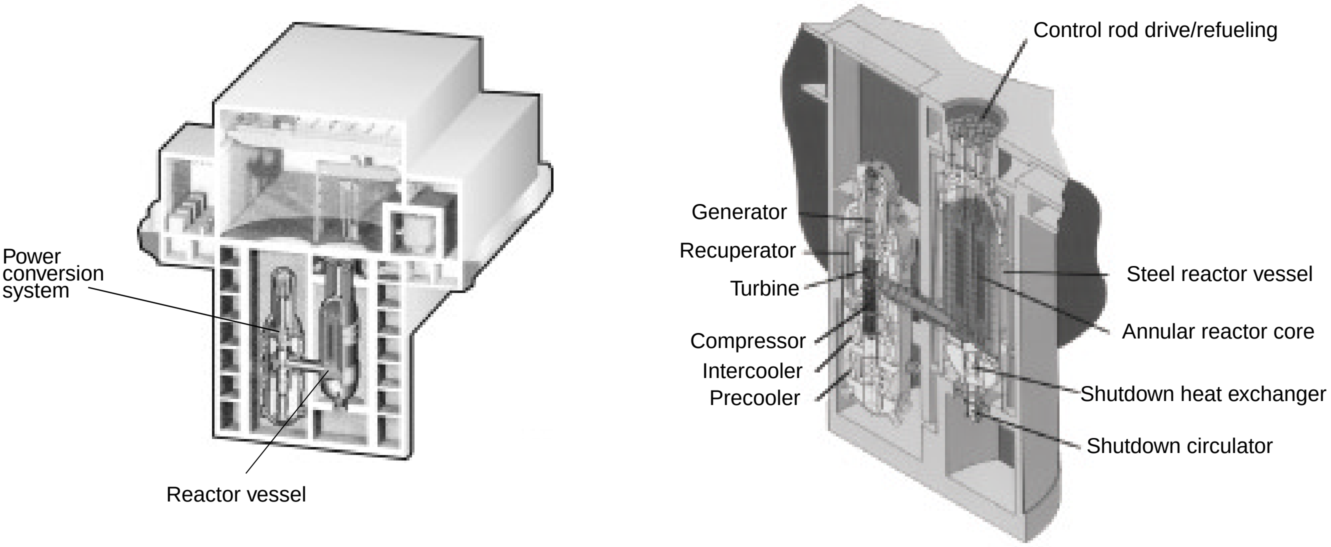
Simon: Our schedule right now is that by early 2002 we will have completed the preliminary design. The Russians have been working on it. There are somewhere between 700 and 800 people in Russia working on this program right now.

Q: Can you describe the reactor design?

Simon: The design itself hasn't changed much [see **Figure 2**], but we have much more detail on it than before. It is a

FIGURE 2

Cutaway View of the GT-MHR Reactor and Power Conversion Systems



Source: General Atomics.

This is the current design for a 285 MW-electric power plant (600 MW-thermal), and shows how the layers of hexagonal fuel elements are stacked in the reactor core. The helium gas passes from the reactor to the gas turbine through the inside of the conducting duct (vessel system), and returns via the outside.

The reactor vessel and the power conversion vessel are located underground, and the support systems for the reactor are above ground.

high-temperature gas-cooled reactor coupled to a gas turbine. The gas turbine drives the generator, as well as the compressors that circulate the gas. That is basically what we are working on. In addition to that, we need to do fuel development, since we are talking about plutonium fuel.

Q: Because you will be burning weapons plutonium in Russia?
Simon: Yes, weapons-grade plutonium. That is the purpose of the project in Russia. They have started to do some testing on reactor components, and we are marching on; the next step is to go into the detailed design, what we call the final design, and then, when that is done, we'll make the plans to start getting the construction work done.

Q: When do you expect a demonstration reactor to be completed?
Simon: The goal is still to have the first module on line in 2009.

Q: Is the site in Russia already selected?
Simon: Yes, the site that we've discussed with the Russians is Seversk. This is the former Tomsk-7, about 10 or 15 miles out of the city of Tomsk in Siberia. This used to be a closed city, but it is not closed any more. The Russians still have two plutonium production reactors running there, because they need the power, to heat the city and provide electricity. These reactors will be shut down soon.

Q: So, the GT-MHR, when it is built, will begin burning up the surplus weapons plutonium, of which there is a great deal.
Simon: There are many tons of weapons-grade plutonium on both sides—U.S. and Russian. The two governments—actually Presidents Boris Yeltsin and Bill Clinton—each had declared a total of about 34 tons of weapons-grade plutonium as surplus, and now, after the recent discussions that President George Bush had with Russian President Vladimir Putin, they want to reduce the whole weapons inventory further—I haven't seen any specific numbers yet.

Q: It would take a long time for you to get through 34 tons of plutonium fuel.
Simon: Yes, the history of that goes way back. The alternative to burning plutonium as fuel (which we continue to work on), is the use of MOX fuel (mixed oxide fuel). The idea was to use MOX fuel in Russian light-water reactors, as well as—they have a fast breeder reactor—doing it with the fast breeder. The number that came out was that the capacity is

somewhere between 2 to 2.5 tons per year that could be burned as MOX.

Now, of the material that has been declared surplus, the 34 tons all will be burnt.

Q: Who is funding this part of the project now?
Simon: Our project has one unique characteristic: that in the beginning, GA and the Russian nuclear agency, Minatom, shared the cost. That's how we started.

When the U.S. Congress began to support this program, starting in fiscal year 1999, the Congress required that of the first money it made available (a total of $5 million), $3 million would have to be spent in Russia, but under the condition that the Russians match the amount of U.S. money going into the project.

Well, the Russians have done that, and I'll have to say right now, that this is the only plutonium destruction program with the Russians (and there are several; the light-water reactor program with MOX is still ongoing) where the money is being paid 50-50. The gas-cooled reactor program is, and will continue as, a joint program, which means that for every dollar that the United States puts in, the Russians put in an equal amount. This goes back to the contract we negotiated in 1994-95.

Q: What are the prospects here in the United States for the gas-cooled reactor?
Simon: Earlier this year, GA decided that after the electricity problems we had in California, and the energy plan that came out, spearheaded by Vice President Dick Cheney, that we should move forward here with the GT-MHR on the commercial side. First of all, the U.S. Department of Energy started looking at what to do to get nuclear power back on track. Clearly in the long term, and even in the relatively short term, this country is going to need more power, and this means that new power generation sources will have to be built. Even though a lot of coal and gas will have to continue to be burned, the renewables (solar and wind) will not be able to close the gap.

Q: Hardly.
Simon: And so, nuclear power has to come back. I'm sure you have seen the numbers. They are talking about 100,000 more megawatts in the next 20 years. And so, we decided that we should also follow a parallel branch here, to what we are doing with the Russians. Even though the Russian design is mainly focussed on the plutonium disposition, in the end, it will be the prototype for a commercial unit. That's the way we look at it.

And we have now started to go in a commercial direction, in parallel to the Russian program.

There will have to be some design changes made relative to the plans we are designing with the Russians. One example is that we would not use plutonium, particularly not weapons-grade plutonium, as the fuel for commercial U.S. applications.

We will put together a consortium of companies which, hopefully, will work together and modify the design as may be necessary. The plan is really now to march on toward a commercial unit.

We formed a utility advisory committee, led by Entergy, and including Omaha Public Power District, Nuclear Management Corp., Dominion, PSE&G, and Constellation. We have several additional companies that have joined, but which have not yet been announced.

The bottom line of all this, is that the Utility Advisory Committee represents about 35% of the U.S. nuclear-generating capacity. These people are active. These people are in Washington, D.C., fighting for the gas reactor, together with us, or by themselves. It is quite clear that Entergy, for instance, is very interested in getting the gas-cooled reactor moving.

Q: Is the plan, that you would move forward here in parallel, and perhaps have another prototype built in the United States?
Simon: Yes, in the end we will have to have a prototype in

General Atomics' GT-MHR

The GT-MHR produces higher process heat (1,000°F, compared to the 600°F limit of conventional water-cooled nuclear reactors). This makes it more efficient for a wide range of industrial applications, from making fertilizer to refining petroleum. It uses a direct conversion gas turbine to produce electricity from the flow of superheated gas, thus simplifying the reactor system and increasing efficiency.

The 285 megawatt-electric (MW-e) reactor is small enough to be mass produced in standardized units, thus making the cost very competitive.

How the GT-MHR Works

The GT-MHR reactor consists of two steel pressure vessels, one for the reactor system, and the other for the power conversion system, both of which are housed about 100 feet underground in a concrete building (**Figure 2**). Above ground are the refuelling machine for the reactor and the auxiliary systems for operating the reactor.

Fuel system: Tiny fuel particles that are shaped into finger-sized rods are stacked into a column, and then inserted into the hexagonal fuel element block (**Figure 3**). The GT-MHR is designed to burn uranium fuel, or plutonium.

The cylindrical reactor core is made up of stacks of hexagonal fuel element blocks of graphite (each about a the United States However, the prototype we are talking about for the United States is about a year or so behind the Russian plan. We would go ahead and build the Russian plant, and then, after that, we would start construction on a U.S. plant.

There are certain things that we would just take over and utilize. For example, the fuel element here would be loaded with enriched uranium rather than with plutonium. And there will be a few other things that will have to be modified: for example, the whole documentation structure that has been adopted in this country for a nuclear plant. Basically there is a common way of doing that, no matter what type of reactor you build. The Russian rules are different, and the information that will be there, will have to be reworked to meet our requirements.

Secondly, of course, we'll have to start talking with the Nuclear Regulatory Commission (NRC).

Q: Have you begun to do this?

Simon: We had our kickoff meeting in December 2001 in Washington; it's what we call the pre-application kickoff meeting, the first dialogue with the NRC to get this whole thing moving.

Q: The pebble bed modular reactor [PBMR] design has already been brought before the NRC by Exelon, which is working with the South Africans, and it seems to me, just from observing from the outside, that the reaction on the part of the NRC is favorable to these new reactors.

Simon: Fundamentally, I agree with you. These are different types of reactors—the PBMR and GT-MHR. They are quite different from the traditional light-water reactors. I can only go back—and I'm putting a little bit of caution in here—in the sense that we had been dealing with the NRC some years ago on the early modular HTGR [high-temperature gas-cooled reactor], and we had submitted a preliminary safety information document on the design, and we asked for a safety evaluation report and we got all that.

But when the NRC came down in the end, there were maybe something like ten items or so on the table that would apply for both the conventional light-water reactors and the

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foot wide and three feet long), into which fuel rods are inserted in vertical columns. The core is ring shaped (annular). It has 61 columns of graphite reflector blocks at the center, 102 columns of fuel blocks surrounding the center, and a ring of unfuelled graphite blocks near the outer rim. There are also helium coolant channels in the fuel elements.

In the three-year fuel cycle of the GT-MHR, refuelling takes place for half the core every 18 months. (In the Pebble Bed design, the refuelling is continuous.)

Helium coolant: The helium gas flows down through the coolant channels in the fuel elements, mixes in a space below the core, and then carries the reactor heat through the inside of a connecting duct to the power conversion system. It circulates through the power vessel, and returns back to the reactor vessel via the outside chamber of the connecting duct. The helium enters the reactor core at 915°F, and is heated by the nuclear reaction to 1,562°F.

Safety systems: Control rods at the top of the reactor vessel regulate the fission reaction. The rods are lowered into vertical channels in the center and around the rim of the core. If the control rods fail, gravity-released spheres of boron automatically drop into the core to stop the fissioning.

There is a primary coolant system and a shutdown coolant system. If these systems both fail, the reactor is designed to cool down on its own. First, there is a passive back-up system, whereby coolant on the inside of the reactor walls uses natural convection to remove core heat to an external sink. The concrete walls of the underground structure are also lined with water-cooled panels to absorb heat, and should these panels fail, the concrete of the structure alone is designed to absorb the heat. The natural conduction of heat to the underground structure surrounding the reactor will keep the core temperature below 2,912°F (1,600°C), which is far below the temperature at which the fuel particles can break apart, releasing fission products or other radionuclides. The graphite blocks retain their strength up to temperatures of 4,500°F.

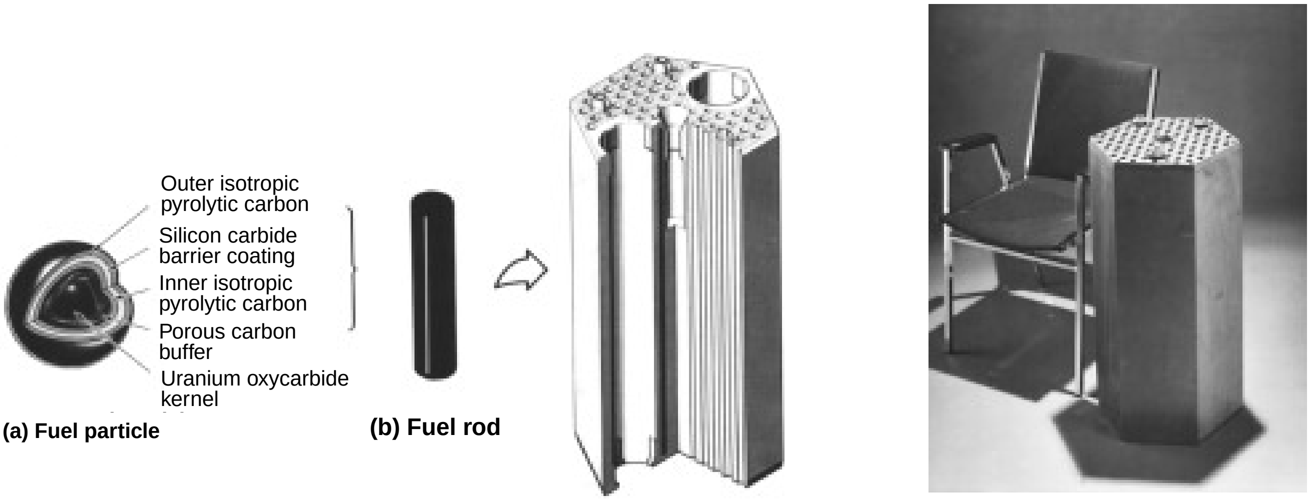
In any type of loss-of-coolant accident, the reactor can withstand the heat without any human operator intervention.

Increased Efficiency

The GT-MHR system efficiency is about 48%, which is 50% more efficient than the conventional reactors in use today. Its increased efficiency comes from its use of recent technological breakthroughs: new gas turbines developed for jet engines, like that of the Boeing 747s; compact plate-fin heat exchangers that recover turbine exhaust heat at 95% efficiency; friction-free magnetic bearings, which eliminate the need for lubricants in the turbine system; and high-strength, high-temperature steel vessels.

A more detailed description of how the new fourth-generation nuclear reactors work can be found in the Spring 2001 issue of 21st Century Science & Technology *magazine, which is available at $5 per copy from* 21st Century, *P.O. Box 16285, Washington, D.C. 20041, or online at http://www.21stcenturysciencetech.com.*

FIGURE 3
GT-MHR Fuel Components



(a) Fuel particle
(b) Fuel rod
(c) Fuel block element
(d) Fuel block element

Source: General Atomics.

The tiny fuel pellet (a) is about 0.03 inch in diameter. At the center is a kernel of fissile fuel—uranium oxycarbide. This is coated with a graphite buffer, and then surrounded by three successive layers of pyrolytic carbon. The coatings contain the fission reaction within the fuel kernel and buffer.

The fuel pellets are mixed with graphite and formed into cylindrical fuel rods about two inches long.

The fuel rods are then inserted into holds drilled in the hexagonal graphite fuel element blocks. These are 14 inches in diameter and 31 inches long. The fuel blocks, which also have helium coolant channels, are then stacked in the reactor core.

advanced reactors, in which I would count the liquid metal reactor (LMR), which at that time was on the table, and the HTGR. The NRC spent quite a bit of time on these items, but in the end they came out with rulings whereby it turned out that if there was any doubt of how to do something, they always favored the existing methods for light-water reactors. And we were not enthused about that.

These issues will have to be revisited. But I think the attitude of the NRC, in the meantime, really has changed. They recognize that these machines—the GT-MHR and the PBMR—have passive safety characteristics that make these reactors literally meltdown proof, and there are no other reactors that can do that. This is an example of the things that we will have to discuss and work on with the NRC.

Q: These new designs are really a completely new concept. It's been around for a while, but is very different from the existing conventional reactors.

Simon: That's right. For example, there is the fact that we have in both of these designs only ceramic material for the reactor. This is all material that can tolerate fairly high temperatures. From a safety standpoint, we have chosen our reactors in terms of physical size and physical shape, such that even if you lose all the cooling, you get fuel temperatures which can basically not exceed 1,600°C, and that compares to a fuel particle that can take at least 2,000°C.

So, we have chosen design parameters, from the geometry to the material, in such a fashion, that you may attack the fuel particle's integrity, but you can never destroy it.

Q: So the fuel particle's coating is an impermeable containment.

Simon: That's correct. The coated particles are one of the barriers [to a fuel meltdown], but of course they are the most significant one.

Q: To go back to the NRC—

Simon: In December, we had a whole day meeting with the NRC. That's something that the PBMR already has started.

I would say that we have one advantage, and that is, GA had the experience of the Fort St. Vrain HTGR. This nuclear plant operated in Colorado, and had a steam cycle [not a direct conversion gas turbine], and had hexagonal block fuel elements—about 14 inches across the flats and about 70 inches tall.

We are going to use the same graphite fuel element configuration for the Russian design as well as the U.S. design. Why? Well, we have irradiated in total about 2,500 fuel elements in this reactor, where we found only two blocks which had a hairline crack, just two webs.

We had a lot of discussion about this with the NRC at that time, but in the end, the NRC accepted that there was no reason for serious concern, that we could continue to operate with the cracked blocks, because the cracks just relieve the stresses. That's what it came down to.

So we are going to use the same fuel elements, the same shape, with the only difference being that in the United States we'll use uranium fuel instead of plutonium.

The other part that we had the NRC look at in the late 1980s and early 1990s, was the large-scale modular gas-cooled reactor, which had the same fuel elements. In the big scheme of things, in terms of design philosophy, as well as the design itself, things haven't changed that much, although there have been changes in details.

And so, my point is that the NRC already has familiarity with our kind of reactor design, but in the case of the pebble bed reactor, the NRC has never reviewed a pebble bed design. And so I think they may have to do more things for the NRC.

Q: In general, in terms of the PBMR, your design has an advantage in terms of the power density. Can you say something about that?

Simon: Maybe the simplest way to talk about that is historically. The Germans started out with the modular pebble bed design, and there were some very simple rules that they began with. Number one, there should be no control rods in the reactor. This was an experience from the AVR, a smaller research reactor at the Jülich Research Center, and the THTR [thorium high-temperature reactor], a 300-megawatt electric power reactor, both pebble beds. I did not work on them, but I am reasonably familiar with them.

In the larger reactor, to keep the reactor under control, they had to push the control rods into the pile of pebbles, and this actually damaged pebbles, so therefore, they decided that in the next plant they wanted to build—a modular reactor—they didn't want to have any control rods that had to go into the pebble bed. So, that means, basically, that you have to control the reaction with control rods in the reflector [which surrounds the reactor core], which means that you have to control the reaction by its neutron leakage—because you catch the neutrons in the reflector outside the reactor, and if you catch more, they can't come back [to make more fissions]. This is how you deal with the reactivity.

So this is rule number one. To do that, however, you'll find that the size limit is somewhere around 10 feet—3 meters—in diameter for the reactor core.

The next item is the power density. In a graphite reactor core that is 3 meters in diameter, you do not want to exceed the 1,600°C (the limit in case you lose all coolant), and these parameters basically determine the power density in terms of kilowatts per cubic foot, or watts per cubic centimeter, whichever way you want to do it. It turns out that you come up with something that is about 3 watts per cubic centimeter, and so now you have fixed the diameter and you have fixed the power density.

The only way you can make more power is to make the core taller. Typically, if you look at these numbers, they come out between 8 to 10 meters, and so you have a tall, skinny core. Well, we at GA went through this too. And now comes the question of how you choose your parameters, specifically, by the condition of not having control rods in the core, nor exceeding the 1,600°C temperature during an incident where you lose all your coolant, at which point the reactor would shut itself down, all by itself. However, in such an incident, the decay heat will still build up. And that can only be removed by conduction from the inside of the reactor to the reactor vessel surface, and then radiated away from the reactor vessel surface to cooling panels which surround the cavity in which the reactor has been placed.

So, if you look at the PBMR, I think the commercial modular version of the design was somewhere around 10 meters high and 3 meters diameter, and if you multiplied this out and then figured the efficiency to convert the heat to electricity, the design should have come out at around 100 or 110 megawatts power.

Later, the word came out that the South Africans actually went to an annular core. And I have to say, that whether it's a pebble bed or a prismatic block-type core, if you apply these rules that I mentioned, they are equally restrained by the power level. You have exactly the same problem. You can only go to a certain reactor diameter, because that's all you can control. And once you have that, you can only choose the same power density. So, there is literally no difference in the design limitations.

It turned out, that when GA started working on the modular high-temperature reactor, at the suggestion of Congress, we actually started with the pebble bed reactor. However, we realized within the first few months, that from our vantage point from this part of the world, these plants were too small.

Q: Was this back in the early 1980s?

Simon: Yes. We got a letter from Congress in 1984 suggesting that we look at reactors that would be much safer. It took us less than a year, before we said that with this small reactor, we will not be competitive against these big 1,000-megawatt light-water reactors. And so we were looking to go to higher power levels.

The first thing we went to was an annular core. The whole trick with the annular core, is that you keep the path short from where the heat is generated to the place where you can radiate the heat off. That is basically the whole idea behind the annular core.

The AVR experimental pebble bed reactor in Jülich, Germany, came on line in 1967 and operated successfully for 22 years. It demonstrated many safety effects of the high-temperature reactor. One test with the AVR showed that in a total sudden shutdown, the plant cools down and the fuel pebbles remain intact.

Sometimes people ask, why don't you fill the inside of the annular core with fuel, rather than putting in graphite blocks. Well, if you do that, you would have to reduce the power, for temperature reasons, to the same size that we would have to go to for a much lower power density, and the total power level would be the same as that of a fully loaded pebble bed reactor without an annular core.

In other words, if you make a larger core, and you want to meet the requirements mentioned earlier, you'll get the same power level you would get if you had a smaller core with a higher power density. And in that case, if there was a loss of coolant, the heat would have to go from the center of the core to the outside, and that heat path is much longer. To drive that heat, the temperature in the center will have to meet the 1,600°C criterion, and you don't gain anything. You do gain, however, when you go to an annular core.

Q: Is that because the space between where the heat is produced and where it gets taken off, is very short in the annular core?
Simon: That is correct. That's the bottom line of this. And it turns out that if you go to an annular core, in the annulus, where the fission takes place, we now have a power density over 6 watts per cubic centimeter.

Q: So that's twice the power density of the PBMR.
Simon: Well, if the PBMR is just a cylinder, that is correct. But the PBMR has also done something here, and has gone to an annular core.

Q: So is their power density now better?
Simon: I think that the power density in the PBMR annulus has gone up to about the same level as our design. They are now talking about 120 to 150 MW electric for the small core.

Q: As opposed to their previous 100 to 110 MW electric?
Simon: Yes, and this is a 10 to 30% increase in power. They basically took that path. Now, I'm really speculating, because I don't know the facts in that detail, but my assumption, is that they did this because they wanted to get the cost down; meaning, if you think in terms of dollars per kilowatts, if you have more kilowatts in the denominator, then the cost comes down. And also, of course, the additional power that you get out helps.

Q: So, your design is larger.
Simon: Our design has 600 MW thermal, 285 MW electric.

Q: This size, as I understand it, is about the limit of what can be mass produced. For example, if you wanted to turn out several modules in a factory assembly line, if the reactor were much bigger than 285 MW, you couldn't do it.
Simon: I think there is only one company in the world that can at this time give you the steel forgings for the flanges, etc., for such a reactor, and that is a Japanese company.

Q: So that's the limitation on size right now.
Simon: That's where we are right now. We are up to something that's about 26 feet in diameter, which is not so easily transportable. Theoretically, you could build a 1,000 MW annular core. But then you have other manufacturing and assembly issues that will have to be dealt with.

Q: I think that the United States has completely dismantled any of its capacity to build a large reactor vessel. The same is true for the fusion reactor program. So what we need is a renaissance to get this program off the ground, and not have just one reactor—we're talking about a need for many reactors in the United States.
Simon: That's right, and I wouldn't mind having 10, or 15, or 20 under construction at the same time.

Q: I think that's the direction we have to go in. I don't know how familiar you are with the concept of the Eurasian Land-Bridge. This is a development program, a rail-vectored development corridor, for the Eurasian land mass, which stretches from the east coast of China to the west coast of Europe. The design for this was proposed by Lyndon LaRouche, and is now being undertaken by many of the countries involved—China, Russia, Iran, for example. As developed by LaRouche and his wife, the design includes industrial corridors, and the model nuclear plant selected to power those corridors is the HTGR—either the pebble bed or the GT-MHR. The development area is vast enough so that we would need both designs. So we are very interested in getting mass production capabilities for these reactors.

Simon: There is room for both of them. And, in the end, the question is really the cost of the electricity that comes out.

Q: I would also look at it another way, not the cost-accounting way: What is the cost of *not* doing this for our society and for the world?
Simon: I was rather referring to the stuff that will be built in the end, the machines that will be built will be the ones that produce the lowest-cost electricity.

Q: Yes, but, I also think that in looking at that formulation, one also has to consider what will happen if we don't do this, where the cost will be incalculable if we don't proceed.
Simon: Absolutely. We have to proceed. And I think it may take a little bit longer than we would like to see, but in the end, there is just no way around building these new reactors.

Q: I hope we do it within our lifetimes, and I—and you—have probably been saying that for at least 20 years.
Simon: Make it 40.

Q: How did you get started as a nuclear engineer?
Simon: I graduated from the University of Aachen in Germany in 1961, and in those days we were still part of the Mechanical Engineering Faculty. I always wanted to come to the United States, at least for a few years, and General Atomics had an office in Zurich and one in Düsseldorf. I applied there, and after an interview, I was hired, in 1961.

Then, in June 1964, they sent me to the United States for a year, for training. I always say that I'm a slow learner, and that's why I'm still here.

Q: So now you direct the joint GA program with Russia for the development of the GT-MHR.
Simon: As a matter of fact, I negotiated the program and put it all together.

Peach Bottom [in Pennsylvania] was GA's first reactor. I was there, during the initial physics tests—after the first criticality, all sorts of tests have to be made—and I was out there for about a month. Then, shortly thereafter, I became responsible for the nuclear design of the Fort St. Vrain plant. And then, later on, for the start-up program. I was the guy from the GA side, who took the reactor critical for the first time.

Then, we had sold ten large HTGR reactors that we were designing in those days, and I was responsible for the entire core design, not just the fuel and physics part, but the thermohydraulics and the structural design, and all of that. That was in the mid-1970s, when everything went down.

Q: In the mid-1970s, with the oil crisis.
Simon: Then the utilities cancelled their reactor orders. As a matter of fact, it's an interesting oddity, in the sense that the day we got a license, a construction permit, for the first of these big ones, the order was cancelled.

Q: It was a very sad time. I don't know if you saw our article on this [Marsha Freeman, "Who Killed U.S. Nuclear Power," *21st Century Science & Technology*, Spring 2001]. Although people think these nuclear plants were cancelled because of Three Mile Island, in 1979, it actually had started long before that, with the Wall Street interest rates and the environmentalist demands in combination making it impossible for the utilities.
Simon: That's exactly right. The last reactor that was sold in this country was in 1974.

Anyway, after that, I kept watch on gas reactors on the international side, trying to get things going there, with the Europeans and the Japanese, and I did a few other things in between, but basically I spent my life on the high-temperature gas-cooled reactor.

Q: Let's hope that this current effort succeeds, so that before your career ends you will see many of these reactors in operation.
Simon: I don't mind looking at them even if I'm retired.

Q: Your career with the HTGR has really spanned a cultural shift, from the optimism of the 1960s to the cultural pessimism of today. In the 1960s, you assumed that you could do the impossible, that you would simply solve every problem that came up. And now, this attitude is gone. The environmentalism that has taken over has brought a total scientific pessimism, that we have to protect the birds and the bees, even at the expense of human beings, and that these are insurmountable problems, and people are a nuisance, as opposed to being the solution.
Simon: Yes. I have nothing against the environment. I think we should do everything to protect the environment.

Q: Yes, but what is "protection"? You want to protect it against real things. Not against phony ideas. And, of course, nuclear would protect the environment.
Simon: Definitely, it's about the only source, certainly, that can do that, other than the renewable resources, like solar and wind.

Q: And they will never have any power density, to speak of.
Simon: That's correct. If people would do the arithmetic, they would find out, literally, that they would have to build forests of windmills. . . . The other thing that is not new, is that the Sun doesn't shine at night.