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New Power Generation

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The term considered most apt by the nuclear industry to describe the next 20 to 30 years for their business is "renaissance". Not growth, or revival; these words are not large enough. In terms of scale and cultural associations, as a transformation from what came before, this is going to be a rebirth.

For several reasons, "the global nuclear renaissance", to use the full, preferred title, is well named. To be born again, you need to have died; and from Chernobyl onwards, with exceptions such as France, Japan and South Korea, the nuclear power industry has been impressively still. The last time planning permission was granted for a nuclear reactor in the UK was 1987. No new reactor has been built in the US since 1979, when an accident at the Three Mile Island power plant caused the reactor core to melt. Of the 439 nuclear power plants in the world today, 70 per cent are more than 20 years old. While global electricity demand grew by more than 60 per cent from 1980 to 2004, the number of new nuclear reactors being built halved every 10 years. During the 1990s, early developers of nuclear power such as Italy and Germany promised to phase out their nuclear energy altogether, while the United Kingdom Atomic Energy Authority became a decommissioning body.

Compare this slow death with the promise of the years ahead. Almost by process of elimination, nuclear power has emerged, once again, as the energy of the future. With world electricity demand forecast to double by 2030 – and about 25 per cent of all existing power stations due for replacement in the same period – nuclear power stands alone in its ability to deliver massive quantities of energy without carbon emissions. For countries without oil and gas supplies, it offers energy security; and for those with their own natural resources, it provides a way of diversifying their energy mix while preserving their fossil fuels for export. After years of not doing very much, the nuclear industry is now looking forward to building reactors on every inhabited continent. In Europe, Finland is leading the way: its first new plant since 1982 is scheduled to open in 2011. Britain is considering 10 new reactors, and the US Nuclear Regulatory Commission is expecting as many as 32 applications for new reactors by 2010 – after a 20-year pause.

And if that still sounds like a mere revival, then it is in India and China, as well as in countries still outside the pale of atomic technology, that something grander is starting to stir. India, despite being outside the Non-Proliferation Treaty, making it unable to trade in nuclear wares, plans to quintuple its nuclear capacity by 2020. China, which has 11 reactors, wants 10 times that number. And then come countries hoping to go nuclear for the first time. According to the World Nuclear Association, these include: Chile, Nigeria, Vietnam, Ireland, Turkey and Indonesia. In the past few years, nearly 30 governments have announced their intentions to launch peaceful nuclear programmes and most of them (not including Yemen) are being taken seriously. There is little doubt, for instance, about the likelihood of nuclear power in the Middle East. Between

February 2006 and January 2007, no fewer than 13 governments in the region announced a need for nuclear reactors.

But does a lot of activity constitute a renaissance? And will nuclear power and all the concerns attached to it be any different this time round? Right now, there is no way of knowing, but there are certainly some doubts. One of these centres on the fact that technology changes slowly in the nuclear world. Most of the reactors built in the first half of the 21st century will look a lot like the ones built in the 1970s and 1980s. The long-promised "fourth generation" of nuclear plants – with "breeder" and "fast" reactors that use recycled fuel and make less waste – remains a distant promise. Only one such reactor currently operates on a commercial scale. Of the 34 reactors under construction in the world, 26 of them are based on designs largely unchanged since the 1960s.

This caution reflects how expensive nuclear power plants are – about £1bn each – and a reluctance to tinker with something that has been rendered largely safe. But it also means that some of the problems bound up in traditional nuclear technology will remain. The first of these is waste. Even after 51 years of commercial nuclear power, Britain has no long-term strategy for dealing with the concoction of unburned fuel and radioactive isotopes that emerge from conventional reactors. Likewise the US, which in 1977 suspended "reprocessing", in which plutonium and other valuable elements are separated from waste to be burned again. Instead, America decided it would bury all its nuclear waste deep underground, within Yucca Mountain, 100 miles north-west of Las Vegas. But even that hasn't happened: nine years after the site was supposed to open, the plan is still stuck in Congress.

The reason the US halted nuclear-fuel reprocessing was that the products can also supply the ingredients needed for nuclear weapons. In 1974, India used spent fuel from a Canadian-built reactor to detonate a nuclear bomb. This is the second great awkwardness of nuclear power, and its legacy from the military-industrial complexes of the 1950s: the overlap between what you need to have a peaceful nuclear programme and what you could be using to make a bomb. It's the ambiguity currently personified – not very convincingly – by Iran.

Resolving the questions of waste and proliferation will help make the second life of nuclear much happier than its first. But there is plenty of scepticism about whether the existing companies, technologies and international institutions can achieve it. "The people who say they are going to bring us this renaissance are the people who brought us the Dark Ages," one industry critic told me. "This is Torquemada bringing us the idea of the Renaissance."

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Where, then, is nuclear's Leonardo da Vinci? What if there was, say, a small technology company that claimed there was a different way of doing things? What if it was developing a nuclear fuel that produced 70 per cent less waste and nothing that you could use to make a bomb? Let's say it was chaired by one of the world's leading non-proliferation experts and advised by Hans Blix, former head of the International Atomic Energy Agency (IAEA) and UN weapons inspector. What if it had just been appointed consultant to the United Arab Emirates, which is expected to be the first Middle Eastern country, after Iran, to generate nuclear power? That might sound promising. But it would also probably sound too good to be true.

The company is called Thorium Power, and I met Seth Grae, its president and CEO, on a damp April morning in Moscow. Grae is a lawyer from Staten Island, New York, who became a

nuclear entrepreneur in his late twenties after studying Soviet law and representing a Russian refusenik scientist in the late 1980s. Now 45, he has wavy, receding hair and, although not tall, stands with a slight hunch that gives him a permanent urgency, as if he is forever on the point of saying something or darting somewhere.

Thorium Power has been working in Moscow since the mid-1990s, when it was part-funded by the US Department of Energy as a way of keeping former Soviet scientists occupied. Now privately funded, it is testing a new nuclear fuel, based on the chemical element thorium, in a research reactor on the edge of the city.

In the back seat of a car on the way to the company's laboratory, Grae explained what Thorium Power was trying to achieve. He compared its work, which has cost more than $20m so far, to the development of unleaded petrol in the 1980s. The company is not trying to build a new kind of reactor or power plant, he said, just a new fuel element that can be retro-fitted or placed into conventional uranium-run reactors, which make up about 80 per cent of the world's nuclear power stations. Once the technology is proven and its benefits shown, the plan is to license it to the world's big nuclear manufacturers.

"When you try to develop a new nuclear technology, it's a lot like drug development," said Grae. "You can't just leap to the latter stages, to human testing. You have to start with the lab work, years of experiments." Now just two years away from using its fuel technology in a commercial Russian reactor, the company is beginning to sense the rewards.

Grae is aiming his hopes at the furthest edges of the nuclear renaissance: those countries going nuclear for the first time. According to Thorium Power's calculations, one-third of the new light water reactors expected to be built by 2027 – or about 40 – will be in countries that have not had atomic energy before. It is in these countries, which do not have weapons programmes but may have sceptical neighbours or international lenders, that Grae thinks a proliferation-proof nuclear fuel will be attractive, a guarantee of good intentions. "The issue of weaponisation relates to financing," he said. "People need to know the political risk. Is a country's reactor going to get bombed because its neighbours think it is trying to develop a bomb?"

After half an hour, we arrived at the Kurchatov Institute, where the thorium fuel cycle is being tested. Glowering over the car park was a bust of Igor Kurchatov, the father of the Russian nuclear weapons programme, who grew a beard in 1941 and swore not to cut it until the Nazis were defeated. ("The Beard", as he became known, ended up sticking with it.) Because of a problem with my paperwork, I was not allowed inside IR-8, the 50-year-old nuclear reactor where the thorium fuel cycle has been running for the past five years. Instead, an in-house photographer was sent to take pictures, and I was introduced to Yaroslav Shtrombakh, the first deputy director of the Kurchatov Institute, who agreed that the great potential for thorium lay in new nuclear settings. "We must not give these new countries dangerous toys like uranium and plutonium to play with," said Shtrombakh. "In this case, thorium is a very promise-able thing."

Over lunch, Grae described the early days of Thorium Power, which was incorporated just outside Washington in 1992. As he spoke, it became clear not only that the group's non-proliferation idea had been around for some time, but that it had an unlikely first proponent.

The founding myth of Thorium Power is a meeting organised 25 years ago by the reputed model for Dr Strangelove, Edward Teller, the maker of the hydrogen bomb. Teller is not a familiar pin-up for the non-proliferation movement; he is better known for his decade-long labours that led to

the explosion of his 65-ton "super" bomb in 1952, offering a glimpse of Armageddon and catalysing the cold war.

But by 1983, a 75-year-old Teller had undergone a change of heart. He arranged to meet a former student, Alvin Radkowsky, one of America's most prolific reactor designers, to talk about his fears about the next age of nuclear power. Teller foresaw more and more countries adopting atomic energy and the spread of uranium-fuelled reactors to all corners of the world – and with them their by-product: plutonium.

Teller had contacted Radkowsky, an Orthodox Jew from New Jersey who designed reactors for the world's first nuclear submarine and America's first commercial nuclear power plant, because Radkowsky had worked with an element called thorium. A radioactive metal long considered a possible alternative fuel to uranium, thorium does not produce nearly as much plutonium when it is irradiated in a reactor. At their meeting, Teller suggested that Radkowsky use it to design a proliferation-proof fuel cycle.

After eight years of work, Radkowsky, who was by now in his seventies, was ready to set up a nuclear technology company. He approached Grae, then recently qualified in international commercial law. Grae initially refused the quiet scientist. "It didn't sound like billable hours," he recalled, "even if he was who he said he was."

Radkowsky died in 2002, Teller a year later. Grae now believes their conversation in 1983 was highly prophetic. A standard uranium light water reactor produces about 200kg of plutonium a year. Although far from being ideal for use in a nuclear weapon, reactor-grade plutonium can be reprocessed or at the very least used to make a "dirty bomb". It is the prospect of dozens of plutonium-producing reactors in countries and regions of the world where there has never before been nuclear power that alarms Grae, despite the safeguards and inspections of the International Atomic Energy Agency.

But the wider nuclear power industry disagrees about the risk of proliferation. Before I went to Moscow, I spoke to John Ritch, director general of the World Nuclear Association, which represents the industry. He told me that the vast majority of reactors built in the 21st century would be in countries that already had nuclear power, and that the IAEA regime was well equipped to monitor new nuclear players. "I do not think the global nuclear renaissance carries with it an inherent proliferation risk," he said. "Weapons do not arise by accident, and we can expect IAEA safeguards to give early warning of any illicit programme."

But when I mentioned this to Grae, he asked why the plutonium had to be there in the first place. "It's the same as if these plants were producing massive amounts of arsenic. [Ritch's] argument would be that it is controlled. That we are in a world that knows how to handle this... How would you feel about hundreds of new plants in tens of new countries making massive amounts of arsenic? This [plutonium] is much more dangerous. This can destroy cities."

It was not until that evening that I learned more about the science of Radkowsky's thorium fuel cycle. Back at Grae's hotel, I met Alexei Morozov, the Russian physicist who has been testing the technology since 1994. Morozov, who is 62, worked for 25 years on the Soviet nuclear ice-breaker programme and other advanced reactors before being hired by Thorium Power. For most of our conversation, he sat rigidly in his chair, but he relaxed when I asked him to choose a Russian word to describe Radkowsky's designs. "Elegantni," he replied.

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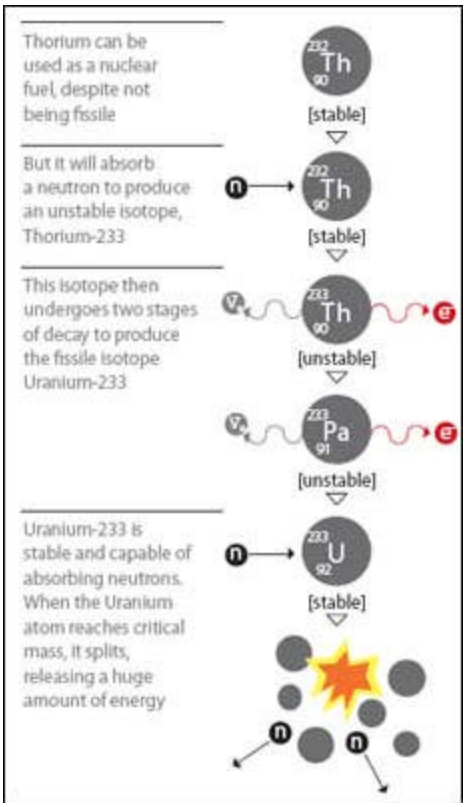
Thorium has always intrigued nuclear physicists; the question has been how best to use it. A silvery metal, it has similar radioactive properties to Uranium 238, the isotope which makes up the bulk of all nuclear fuels. But it is thought to be between three and four times more abundant in nature. Named after the Norse god of thunder by Jons Jacob Berzelius, the Swedish chemist who discovered it in 1828, thorium occurs in mineral-rich monazite sand, of which the world's largest deposits are in Australia, North America, Turkey and India.

Thorium and fission



Since the early 1950s, when uranium was in short supply, physicists have designed fuel cycles to run on thorium. Like U-238, thorium (T-232) will absorb neutrons from another fissile material, such as enriched uranium (U-235), and start to break down, releasing huge amounts of energy. The difference comes in the family of radioactive elements and isotopes that are created as a result. The key absence from the thorium reaction is large quantities of the manmade element plutonium, particularly in the Pu-239 form favoured as a weapons material.

Instead, thorium breaks down into several unstable uranium isotopes, chief among them U-233, and, to a lesser extent, U-232, an unpleasant, gamma-radiating by-product. These provide what physicists call thorium's nuclear "burn" – a process made attractive by U-233, which degrades efficiently, and by thorium's high boiling point (about 500°C higher than uranium's) which has potential safety advantages.

Thorium's behaviour has enticed scientists for a variety of reasons – not all wholesome. John Simpson, a historian and non-proliferation expert at the University of Southampton, believes that Britain first experimented with thorium in the 1950s because of mistaken rumours that it had been used in the hydrogen bomb. The intentions of India, the only country to have maintained long-standing research into thorium because of its large domestic supply, are also viewed as ambiguous: it focused on breeding as much U-233 as possible, reprocessing it for use elsewhere. U-233 on its own is considered a proliferation risk.

According to Thorium Power, Radkowsky's fuel cycle design is unique because it is intended to use up as much of the fuel as possible in a single stage, making it impossible to extract any weapons-usable isotopes afterwards. "It's not the thorium, it's the design that matters," said Grae. A "seed" of enriched uranium starts a chain reaction in a "blanket" of thorium, which is then "spiked" with U-238 to prevent the U-233 from being easily separated afterwards.

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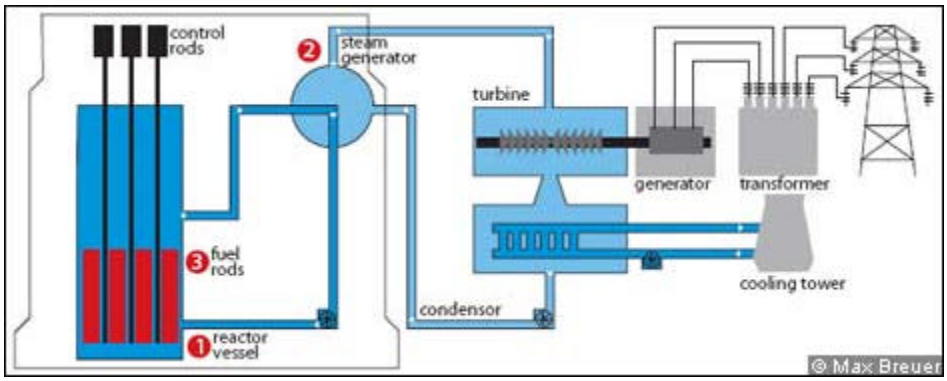
How a nuclear reactor works



*1. **The heating unit** The nuclear reactions take place in the fuel rods. In traditional power plants, this involves uranium. In Thorium Power's model, a "seed" of plutonium kick-starts a nuclear reaction in a "blanket" of uranium and thorium surrounding it.*

*2. **The steam** Thorium Power's Kurchatov reactor is not attached to a steam generator or turbine. But the technology is designed to fit into existing power plants, so a thorium-fuelled plant would look much like this one: only the fuel rods would be different.*

*3. **The waste** Traditional uranium reactions – which take place in a power plant's fuel rods – produce a range of isotopes, many of which don't break down for hundreds of thousands of years. Thorium produces similar material but in smaller quantities – and in forms that can't be used to create nuclear bombs*

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Morozov told me that, with the fuel arranged this way, he has achieved a yield of 100MW days per kg of fuel, which compares with an average of about 60MW days in most uranium-run reactors. As well as being more efficient, Morozov repeated the company's central claims about the fuel: that it produces 70 per cent less waste by weight (50 per cent by volume) and 85 per cent less plutonium than standard light-water reactors, none of it viable for making a weapon.

Because of rising uranium demand and the long time that the thorium "blanket" can be burned in a reactor – up to nine years, as opposed to three for ordinary uranium fuel – the company also believes that a thorium cycle could be as much as 10 per cent cheaper than a uranium-run process. I asked Morozov if his experiments could really work on a commercial scale. "This is not an unrealistic idea," he replied.

Still, Thorium Power faces a sceptical public. According to Grae, once the fuel has run for three years in a Russian VVER-1000 reactor (the standard Russian uranium reactor), it will be commercially proven. That should happen in 2013. But this is the cautious world of nuclear. Mujid Kazimi, the director of MIT's Center for Advanced Nuclear Energy Systems, is one of the few scientists to study the Radkowsky design in detail, and he believes the company must do more publicly to demonstrate its claims. "They should be reporting on it more in the open

literature than there has been thus far," he said. "I think that's obviously the dilemma here. How do you gain the confidence [and] at the same time retain the commercial edge?"

Kazimi said his own experiments show the Radkowsky design to be feasible and support its central claim – that it reduces the amount of plutonium generated in the reactor. But he said there were other complications, particularly related to the smaller but highly radioactive quantities of waste, that were yet to be resolved. "This is an arena where the risk of the unknown is taken very seriously," he said.

If scientific support for the fuel is one thing, political support is another. Just as Grae has tended Thorium Power's team of Russian scientists, so he has spent years nurturing politicians on Capitol Hill and assembling a group of non-proliferation experts to sell thorium to the world. He hired Tom Graham, the American diplomat who led the indefinite extension of the Non-Proliferation Treaty in 1995, to be the company's executive chairman in 1997. Hans Blix joined the company as a consultant in February. Since last year, the company has also been working with opponents of the Yucca Mountain repository plan, including Harry Reid, the US Senate majority leader, on placing a bill before Congress supporting more research into thorium.

Not everyone appreciates this assertiveness. The argument for thorium, particularly on non-proliferation grounds, can sound like an argument against the dangers of the nuclear industry as a whole. Ritch, of the World Nuclear Association, stopped short of accusing Thorium Power of scare-mongering, but not by much. "People who are commercially active in the area of thorium will of course advertise the non-proliferation characteristics of their technology as an advantage," he said. "That's fair enough, but I don't like to grant that a fundamental problem exists." And even Blix stressed that building a nuclear weapon is more than just a crime of opportunity – it takes more than a spare pile of plutonium. "The basic thing that drives proliferation, I think, is not the possession of fuel or spent fuel but fear and perceived security risks," he said. "And so, while in Washington they might feel that practically anyone outside the Beltway is a proliferation risk, the world does not look that way."

Nonetheless, it is Thorium Power's spotless non-proliferation credentials – enhanced by Graham and Blix – that are winning its first commercial work. Earlier this month, the company announced that it was advising the United Arab Emirates on how to implement what a senior US State Department official described to me as "a model civilian nuclear programme", just 50 miles from Iran. Thorium Power has already collected about $10m in consulting fees on the deal and is advising the Executive Affairs Authority of Abu Dhabi, which is overseeing the programme, as it aims to build its first reactor by 2017. Although there is no guarantee that the reactor will run on thorium, Grae insists the technology will be ready to install. "Given that we started with a vision that seems to be coming true," he had told me in Moscow. "There's no reason for us to stop now, to not seize this."

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