CENTRE FOR EUROPEAN REFORM
policy brief

Thorium: How to save Europe's nuclear revival

By Stephen Tindale

★ The Fukushima nuclear incident in Japan has reduced public and political support for nuclear power across Europe. Nevertheless, the EU should continue to support nuclear power as a low-carbon bridge technology until Europe can be 100 per cent reliant on renewable energy – which will take several decades.

★ As a general rule, European countries should use tried-and-tested technologies to make the transition to a low-carbon economy rather than spend money developing new technologies. But reactors which use thorium as a liquid fuel – which cannot melt down – should be an exception to this approach. Such reactors would reduce the amount of nuclear waste produced and help deal with existing waste stockpiles. They would also reduce the risk of nuclear weapons proliferation.

★ China and the USA are now taking thorium liquid reactors seriously. Europe is not, so risks losing out on the economic benefits of a safer form of nuclear power.

The best sources of energy, in both climate and energy security terms, are renewable. The EU is committed to obtaining 20 per cent of its total energy from renewables by 2020. This is a crucial objective, and must be met. But even if the EU meets that target, European countries will still need to construct an enormous amount of new energy infrastructure before they can be totally reliant on renewables. An effective large-scale means of storing electricity from intermittent wind, wave and solar power plants must also be developed. The transition to a fully renewable economy will therefore take several decades. So other low-carbon sources of energy are needed as bridge technologies.

Nuclear power stations produce only around a tenth of the carbon dioxide per unit of electricity of coal power stations.[1] (This takes account of the full life-cycle of nuclear generation, including mining and transport of the fuel and decommissioning.) Its ability to generate large amounts of low-carbon electricity makes nuclear power an essential part of Europe's transition to a low-carbon economy. The risks of uncontrolled climate change are greater than any of the risks presented by nuclear power stations.

[1] UK Energy Research Centre, 'Response to Treasury consultation on carbon capture and storage', May 2006.

Before the nuclear incident at Fukushima in March 2011, nuclear power's climate and energy security advantages were spurring an increasing political commitment to nuclear power among EU governments. The governments of Bulgaria, the Czech Republic, Italy, Lithuania, Poland, Romania, Slovenia and the UK had said that they favoured the construction of new nuclear stations. The German government did not talk about new nuclear stations, but Chancellor Merkel did say that existing nuclear stations would be allowed to operate for the period they were designed for, rather than being closed by 2022 as a law passed by a previous German government requires. Merkel correctly described nuclear power as a necessary low-carbon bridge technology, to be used until Germany can be 100 per cent renewable.

Since Fukushima, Merkel has backtracked. She now says that some of Germany's nuclear plants must close immediately, and all by 2022. The Italian government has announced a delay of at least a year before allowing construction of a nuclear reactor. The EU has announced that all EU nuclear facilities will be subject to 'stress tests' to check their safety. The tests will take into account local factors such as distance to the coast, levels of seismic activity and the plant's age. This is essentially political window dressing – regulators and governments already know how far nuclear power stations are from the coast, how seismic the areas are and when the plants were constructed. Europe's leaders should demonstrate greater leadership and imagination in overcoming public hostility to nuclear power.

In order to use nuclear as a bridge technology, the EU need not spend more money on unproven technological approaches such as nuclear fusion, which remains at least 30 years away. Advocates of fusion argue that this technology in theory provides limitless and sustainable energy. So it does – theoretically. The downside is best summarised in the quip that "nuclear fusion is 30 years in the future – and always will be". The budget for the international nuclear fusion project, ITER in France, has almost tripled since 2001. It is now €16 billion, although major construction has yet to start. The EU will have to pay €6.6 billion of this. The Commission awarded ITER €1.4 billion, from unspent parts of the EU budget and the research programme, in 2010.[2] Even if fusion works eventually (which is far from certain), it will not provide electricity soon enough to help Europe with its transition to a low-carbon economy. ITER itself accepts that the plant will not feed electricity into the grid before 2040.

2 European Commission, 'Commission proposes plan for financing ITER', July 20th 2010.

As a rule, therefore, European countries should use tried-and-tested technologies to make the transition to a low-carbon economy. France, which generates around 80 per cent of its electricity from nuclear, has essentially used only three generations of design for its nuclear stations. This has kept costs lower than they would have been if each station had been slightly different (which has been the UK approach).

Thorium molten salt reactors

There should, however, be one exception to the general approach of using established technologies and designs. The EU should invest in developing thorium-fuelled molten salt reactors. This is a proven technology: the US operated a molten salt reactor in the late 1960s.

Thorium is an abundant mineral: it is about three times as abundant as uranium. But this alone is not a strong reason to invest in developing thorium reactors. There are large enough proven reserves of uranium around the world to fuel nuclear power through the decades needed for the transition to renewables. The fact that they are in countries such as Australia and Namibia means that energy security is not a major concern. The case for thorium molten salt reactors rests on the fact that this technology is Europe's best bet to overcome public opposition to nuclear, by demonstrating that nuclear power can be made significantly safer.

Molten salt reactors use liquid fuel. When the liquid gets too hot it automatically flows out of the reactor core, so making meltdown impossible. Reactors using liquid fuel produce less radioactive waste than solid fuel reactors do. Thorium molten fuel reactors also reduce – though do not eliminate – the risk of nuclear weapons proliferation, as they do not produce plutonium.

Anti-nuclear campaigners often use the issue of radioactive pollution as a central plank of their argument – partly because radioactivity is invisible and so easy to scare the public about. High levels of radioactivity do have implications for human health. But the levels of radioactivity which result from the operation of nuclear power stations are not high enough to cause significantly increased health risk. There has been extensive research and assessment into this question, by bodies independent from the nuclear industry. For example, a recent report from a UK public advisory body concluded that rates of childhood leukaemia are not related to proximity to nuclear plants.[3]

3 Committee on the Medical Aspects of Radiation in the Environment, 'Further consideration of the incidence of childhood leukaemia around nuclear power plants in Great Britain', COMARE, May 2011.

The danger of meltdown is a much stronger anti-nuclear argument. The world's worst nuclear power incident, at Chernobyl in 1986, was caused by the meltdown of a reactor core. The 2011 Fukushima incident and the 1979 Three Mile Island accident in the US involved partial meltdowns. In a molten salt reactor, thorium is dissolved into hot liquid salts. This liquid is then poured into tubes which take it into the reactor core, where nuclear fission occurs and electricity is generated. If the liquid becomes too hot, it expands and so flows back out of the tubes, so reducing fission and removing the risk of meltdown.[4]

4 World Nuclear Association, 'Thorium', WNA information page http://www.world-nuclear.org/info/inf62.html, March 2011.

A third anti-nuclear argument is that nuclear power stations produce radioactive waste. Molten salt reactors use liquid fuel rather than solid fuel rods. Reactors with liquid fuel use all the fuel, whereas reactors with solid fuel use only part of the fuel, and the rods remain as spent fuel. So molten salt reactors produce a much lower volume of radioactive waste

[5] James Hansen, 'Tell Barack Obama the truth – The whole truth', Columbia University, 2008. http://www.columbia.edu/~jeh1/mailings/2008/20081121_Obama.pdf.

than solid fuel reactors do. James Hansen, chief scientist at NASA, has written that "thorium can be used in ways that practically eliminate build-up of long-lived nuclear waste."[5]

Whatever form of energy generation countries use in future, those which have, or ever have had, nuclear power plants have stockpiles of radioactive waste to deal with. Existing uranium reactors also produce plutonium, which could then be used for nuclear weapons and so needs to be safeguarded and managed. France and the UK also have plutonium from dismantled nuclear weapons.

The current approach to managing the stockpile of spent fuel in both France and the UK is to reprocess the spent fuel. France also reprocesses spent fuel from Germany, the Netherlands and Belgium. Reprocessing means that the fuel can be re-used. However, it also leads to the production of more plutonium. So France and the UK mix uranium and plutonium into mixed oxide fuel (MOx). French nuclear reactors use MOx fuel. British nuclear operators have chosen not to, because uranium fuel is cheaper. The UK spent billions of pounds constructing a reprocessing plant and an MOx plant at Sellafield, in the expectation that it would be able to sell the MOx fuel to Japan. But the contracts from Japan have not been forthcoming, and are looking even less probable post-Fukushima. So Sellafield has cost the UK taxpayer an enormous amount of money.[6] It has also caused considerable radioactive pollution of the Irish Sea – reprocessing causes much higher radioactive emissions than reactors do.

[6] Steve Connor, 'The nuclear industry must learn its lesson and stop building these white elephants', The Independent, May 9th 2011.

A more cost-effective way to deal with spent fuel and plutonium stockpiles would be to develop molten salt reactors. Spent uranium fuel and plutonium can be combined with thorium fuel and dissolved into the salt liquid, which can then be used to fuel the reactor. So molten salt reactors could be used as a means of recycling spent fuel and reducing the existing spent fuel and plutonium stockpiles

Reducing the risk of nuclear weapons proliferation

A fourth anti-nuclear argument is that nuclear power stations are closely linked to nuclear weapons. The US built nuclear weapons before it constructed nuclear power stations, but since then every country that has acquired nuclear weapons (except Israel) did so by building nuclear power stations. So concerns about proliferation are a valid and forceful argument against nuclear power.

One way to combine global expansion of nuclear power with stronger control on weapons proliferation would be to establish an international nuclear fuel bank. Nuclear fuel would be enriched at an internationally-controlled facility and supplied to different countries, with the spent fuel and plutonium then returned to that facility after the generation of electricity. This approach has been promoted by, among others, the Nuclear Threat Initiative, which includes among its leading participants former US secretaries of state Henry Kissinger and George Schultz, former US secretary of defense William Perry and former US senator Sam Nunn. However, there is not yet any agreement on setting up such an international nuclear fuel bank.

An alternative, and more achievable, approach to combining nuclear power expansion with weapons proliferation control would be to promote thorium molten salt reactors instead of uranium solid fuel reactors. Some uranium solid fuel reactors require that the uranium is enriched. (Uranium in which the isotope U-235 is more than 20 per cent of the total is referred to as highly enriched unranium (HEU). HEU can be use for weapons, although the term 'weapons-grade material' refers to uranium in which U-235 is 90 per cent. 30 countries use HEU in reactors. Modern uranium reactors can use low enriched uranium, in which U-235 is 3-4 per cent.) All uranium solid fuel reactors then produce plutonium. Thorium fuel does not require enrichment, and thorium molten salt reactors do not produce plutonium, so the threat of weapons proliferation would be substantially reduced. It would not, however, be removed completely. The thorium is transformed during the process into a form of uranium – U-233 – which could in theory be used in nuclear weapons. This has not yet been done, so thorium molten salt reactors represent a smaller proliferation risk than uranium hard fuel reactors do. However, the safest approach to proliferation prevention would be to combine development of molten salt reactors with the establishment of an internationally-controlled nuclear fuel bank.

'Too cheap to meter'?

A fifth anti-nuclear argument is that nuclear power is expensive, so that investment in new nuclear stations will divert money away from renewables and energy efficiency programmes.

Nuclear power is not cheap, as the cost overruns at plants currently under construction in Finland and France demonstrate. The nuclear industry remains scarred by its infamous claim in the 1950s that it would produce electricity 'too cheap to meter'. Companies involved in the uranium nuclear fuel cycle are now wisely refraining from claims about cheapness (although non-industry commentators are arguing that new nuclear stations will be cheaper than other low-carbon options such as carbon capture and storage or offshore wind).[7]

[7] Committee on Climate Change, 'The renewable energy review', May 2011.

Some commentators and companies are claiming that thorium molten salt reactors will generate electricity more cheaply than existing fossil fuel power stations do.[8] This is possible at some stage in the future, but not likely. The rational approach for policy-makers would be to assume that molten salt reactors will be expensive, and to assess whether the improved safety features and reduced waste management and proliferation risks justify the increased costs.

8 *For example, Robert Hargraves, 'Aim high, thorium energy cheaper than from coal', Booksurge Llc, February 8th 2009.*

The money to support research and development of molten salt reactors need not be taken from renewables or other low-carbon energy supply options. There is more than enough money available in the existing subsidies for nuclear fusion. And the argument that governments which support any form of nuclear power overlook or downplay renewables is disproved by the example of France. France gets over three-quarters of its electricity from nuclear power stations. Yet the French government has supported onshore wind farms and is now giving subsides to offshore wind. It is also subsidising an expansion of the district heating system in Paris, to distribute heat from power stations burning energy crops and waste wood which would otherwise be wasted.

The history of thorium as a fuel

Thorium molten salt reactors could produce nuclear electricity without the risk of meltdown and with less waste and lower risk of proliferation. They have been technologically proven since the 1960s. So why have they not been developed? Part of the answer is the link between the uranium nuclear fuel cycle and nuclear weapons outlined above. The US built a thorium molten salt reactor in 1965, but subsequently opted to develop only uranium reactors. Critics argue that this was because of the link between uranium reactors and nuclear weapons, though this has never been the publicly-acknowledged reason behind the choice of uranium.[9] The first three countries to construct nuclear power stations – the Soviet Union, the UK and the US – were all extensively involved in nuclear weapons programmes.

9 *For example, Richard Martin, 'Uranium is so last century – enter thorium, the new green nuke', Wired magazine, December 21st 2009. http://www.wired.com/magazine/2009/12/ff_new_nukes/.*

However, the link with nuclear weapons is not the reason why all countries that have developed nuclear power stations have opted for uranium. Some of them – notably Germany, Japan and South Korea – have never been involved in nuclear weapons programmes. The reason these countries adopted the uranium fuel cycle was economic: thorium molten salt reactors were substantially more expensive per unit of electricity produced than uranium reactors were. There has also been opposition from nuclear power companies involved in the uranium fuel cycle to any public investment in an alternative. By the time a thorium molten salt reactor had been demonstrated in the 1960s and was ready for widespread deployment, there had been major investment in the uranium fuel cycle. So the companies involved in uranium reactors were politically influential.

Since the 1970s, India has been the country most active in thorium research. This was partly for energy security reasons – India has extensive proven reserves of thorium but little uranium – and partly because its access to imported uranium was restricted by international sanctions following its explosion of a nuclear weapon in 1974. These sanctions were strengthened following further nuclear tests in 1998. They were removed in 2008 after an agreement with the US on civil nuclear co-operation, but India remains committed to thorium research in order to use its thorium reserves. However, India has focused on using thorium in solid fuel reactors which would otherwise have used uranium. As outlined above, solid fuel reactors could melt down.

Past European research into thorium has also mainly been on its use in solid fuel reactors. For example, Germany ran a 300 megawatt solid fuel reactor fuelled by thorium from 1983 to 1989. This was shut down on economic grounds, having already cost around €2.5 billion (so making the electricity generated around eight times as expensive as electricity from uranium reactors). Norway, which like India has large proven reserves of thorium, has also carried out extensive research into using thorium in solid fuel reactors. The French company Areva is currently working with the US company Lightbridge (formerly called ThoriumPower) to use thorium fuel in its European Pressurised Reactor (EPR). The EPR is an established nuclear design: the plants under construction in Finland and France are EPRs, though in these two cases they will use uranium fuel. Lightbridge is also working with Moscow's Kurchatov Institute to use thorium rather than uranium in some of Russia's existing nuclear reactors.

The European nuclear research organisation CERN applied to the European Commission for funds for thorium research in 1999, but was turned down. CERN staff claimed that the Commission had consulted its nuclear technical advisers, who were French, and opposed thorium because France had invested so heavily in uranium technology.[10]

10 *Professor Egil Lillestol of CERN, quoted in James Quinn, 'Obama could kill fossil fuels overnight with a nuclear dash for thorium', Daily Telegraph, August 29th 2010.*

Current interest in thorium molten salt reactors

Although thorium molten salt reactors have largely been off the energy policy agenda since the end of the

1960s, they are now making a comeback. There is considerable interest in them from energy companies and politicians in China and the US. The interest in the US is primarily driven by concerns about energy security (the US also has extensive quantities of thorium); in China, the main concern is to develop all forms of electricity generation to meet the needs of a rapidly expanding economy. There is much less interest in Europe.

The Chinese government is financing a recently established private company, International Thorium Energy & Moltem-Salt Technology Inc., which aims to produce a small molten salt reactor within five years. The funding will come via the Chinese Academy of Science, as part of a programme headed by Jiang Mianheng, son of former Chinese president Jiang Zemin.

In the US, political interest in thorium molten salt reactors is cross-party, having been led by Democratic Senator Harry Reid and Republican Senator Orrin Hatch. Reid and Hatch have introduced three bills to Congress, all of which identified thorium fuel cycle technology as a means to expand nuclear power without increasing waste or nuclear proliferation.

When he entered office, President Barack Obama set up a Blue Ribbon Commission on America's nuclear future, which is considering nuclear fuel cycles and nuclear waste against criteria of "cost, safety, resource utilisation and sustainability, and the promotion of nuclear non-proliferation and counter-terrorism goals".[11] The Commission will publish a draft report in July 2011 and a final report in January 2012. US Energy Secretary Steven Chu has already indicated that he thinks thorium and molten salt reactors are the way forward for nuclear energy:

11 *Blue Ribbon Commission reactor and fuel cycle technology subcommittee, 'Draft recommendations', May 13th 2011.*

"We cannot continue to improve the condition of people throughout the world without use of nuclear power. None of the renewable energy solutions can be scaled quickly enough to meet current and future energy needs. Safer, proliferation resistant, nuclear power without the long term high level waste storage problems is needed to power a growing world economy and to allow all nations to provide for and feed their growing populations in peace. These goals are available by changing the nuclear fuel cycle to a U-233/Thorium fuel cycle."[12]

12 *Planet Forward interview, 'Energy Secretary Steven Chu answers our energy question', March 1st 2011.*

Large US energy companies have not yet shown serious interest in molten salt reactors. However, Microsoft's Bill Gates has set up a company called TerraPower with the aim of developing a nuclear energy system which reduces the weapons proliferation risk and allows the re-use of spent nuclear fuel. TerraPower has identified thorium molten salt reactors as a promising means of achieving these objectives. Other US companies are part of a consortium, with Japanese and Russian companies, to develop a molten salt reactor. Japanese companies involved include Toyota, Toshiba and Hitachi.

Within the EU, there is no substantial or co-ordinated effort into developing thorium molten salt reactors. The most substantial current European research into thorium is in France (despite France having invested so greatly in uranium as the nuclear fuel of choice). A French nuclear research laboratory is building updated models of 1950s designs of molten salt reactors.

Environmentalist opinion

Opposition from green parties and environmental non-governmental organisations has played an important role in stopping the expansion of nuclear power in Europe and the US since 1979, when the partial meltdown of the US Three Mile Island reactor sparked off massive opposition to nuclear power. Taking a strong anti-nuclear line became a central tenet of being 'green'. In some countries, notably Germany and Austria, it still is. In other countries, including the UK and Sweden, concern about climate change has led some environmentalists to accept that nuclear power is a necessary low-carbon bridge technology.

Most of the green non-governmental organisations remain opposed to all forms of nuclear power, including thorium molten salt reactors. For example, Greenpeace International published an article by Amory Lovins, Chairman of the Rocky Mountains Institute, which dismissed thorium's advantages: "Thorium's waste, safety, and cost problems differ only in detail from uranium's."[13]

13 *Amory Lovins, 'New' nuclear reactors, same old story', Greenpeace International, May 2009.*

However, other non-governmental organisations are prepared to consider a role for thorium reactors. Friends of the Earth recognises the need for low-carbon bridge technologies, and supports carbon capture and storage for this purpose. Friends of the Earth England, Wales and Northern Ireland has also accepted that thorium reactors should also be supported. Mike Childs, head of that organisation's climate campaign, has written that "it's always handy to have something in the back pocket in case it is needed in the future. This is why it is useful to have research into new technologies such as creating transport fuels from solar energy, super cheap thin-film solar power and even thorium nuclear reactors."[14]

14 *Mike Childs, 'Thorium reactors and nuclear fusion', Friends of the Earth, March 24th 2011. http://www.foe.co.uk/news/thorium_30112.html.*

For a green organisation to speak approvingly of anything including the word nuclear represents a considerable step forward. European governments should take advantage of this opening. They should emphasise that thorium molten salt reactors are a form of nuclear technology which have much lower risk of accident because they cannot melt down, produce much less nuclear waste and can be used to reduce the existing stockpile of nuclear waste. Having stressed the environmental advantages, European governments and institutions should then invest in the development of thorium molten salt reactors.

Conclusion and recommendations

The EU has played a progressive role in climate change policy, though EU institutions have placed too much emphasis on targets and timetables and too little on specific policy and investment. The EU is right to focus on expanding renewable energy, which has substantial economic and energy security benefits as well as helping control climate change. Europe receives enough energy from the wind, sun, waves, tides and rivers to deliver all its energy requirements. But it will take at least four decades before Europe can be 100 per cent reliant on renewables. So other low-carbon bridge technologies are required.

Despite two of the EU's founding organisations – the European Coal and Steel Community and Euratom – having been about energy, the question of which energy sources countries rely upon remains a national competence. However, the European institutions play an important role in setting the framework for Europe's energy market. The Commission also spends considerable sums of money on energy research, development and demonstration.

The EU should continue its support for carbon capture and storage (CCS) large-scale demonstration projects. However, CCS has not yet been demonstrated at a large scale, so its cost is essentially unknown – though no one expects it to be cheap.[16] In addition, CCS is increasingly unpopular with the public in several member-states, notably Germany, where projects involve proposals to store carbon dioxide under land rather than under the sea.

16 *Stephen Tindale and Simon Tilford, 'Carbon capture and storage: what the EU needs to do', CER report, February 2010.*

Given the uncertainties surrounding CCS, it would not be sensible to rely on it as the only low-carbon bridge technology. Nuclear power should also be used. Tried-and-tested solid fuel reactors such as the EPR could be used as part of the low-carbon bridge. But solid fuel reactors, however well constructed, operated and regulated, always carry the potential risk of meltdown. This risk is a strong cause of public opposition to nuclear power. In the aftermath of the Fukushima incident in Japan, public opposition is one of the major obstacles to using nuclear power. Developing thorium molten salt reactors could make a substantial contribution to increasing public support.

Molten salt reactors are a proven technology. They would not provide cheap electricity. But they would provide low-carbon electricity, with lower amounts of radioactive waste than produced by uranium reactors. They would also make possible support for nuclear energy around the world with a lower risk of weapons proliferation. And they would provide nuclear power stations with a much lower risk of accident, because the reactor core could not melt down.

The EU should stop spending money on nuclear fusion. If the other partners in ITER – China, India, Japan, South Korea, USA – wish to continue giving money to fusion research, either in their own countries or at the ITER project in France, they are free to do so. The French government is also free to continue giving money to the ITER project. But there is no good reason for EU money to go to ITER. Due to the economic recession and slow growth in many European countries, the EU budget is under considerable pressure. EU institutions should not waste money on an unproven technology which, if it ever works, will not produce significant quantities of electricity soon enough to help with controlling climate change.

The EU should transfer funding from ITER to research and development into thorium molten salt reactors.

The EU should also invest in thorium molten salt reactors to avoid the risk of missing out on a major business opportunity. The US and China are taking this option seriously. Although the commercial opportunities related to thorium remain uncertain, Europe should stand ready to reap the benefits if and when they materialise.

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Thorium-based nuclear power generation is fueled primarily by the nuclear fission of the isotope uranium-233 produced from the fertile element thorium. A thorium fuel cycle can offer several potential advantages over a uranium fuel cycle â€” including the much greater abundance of thorium found on Earth, superior physical and nuclear fuel properties, and reduced nuclear waste production. One advantage of thorium fuel is its low weaponization potential; it is difficult to weaponize the uranium-233/232... Europe is not, so risks losing out on the economic benefits of a safer form of nuclear power. The best sources of energy, in both climate and energy security terms, are renewable. The EU is committed to obtaining 20 per cent of its total energy from renewables by 2020.Â The case for thorium molten salt reactors rests on the fact that this technology is Europeâ€™s best bet to overcome public opposition to nuclear, by demonstrating that nuclear power can be made significantly safer. Molten salt reactors use liquid fuel. When the liquid gets too hot it automatically flows out of the reactor core, so making meltdown impossible. How To. How To. Games. Games.Â Yet, nuclear energy could soon receive yet another shot in the arm that might significantly improve its standing in the eyes of the public: Substituting thorium for dangerous uranium in nuclear reactors. Thorium is now being billed as the great green hope of clean energy production, producing less waste and more energy than uranium. Thorium is meltdown-proof, has no weapons-grade by-products, and can even consume legacy plutonium stockpiles. A potential breakthrough.Â Further, thorium has a lower operating temperature and a higher melting point than natural uranium, making it inherently safer and more resistant to core meltdowns. Thorium's renewable energy properties are also quite impressive.