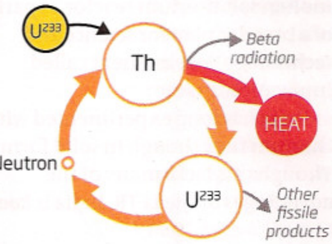
Power from thorium

Nuclear reactors based on thorium - a naturally occuring metal - offer several advantages over their uranium and plutonium-based cousins

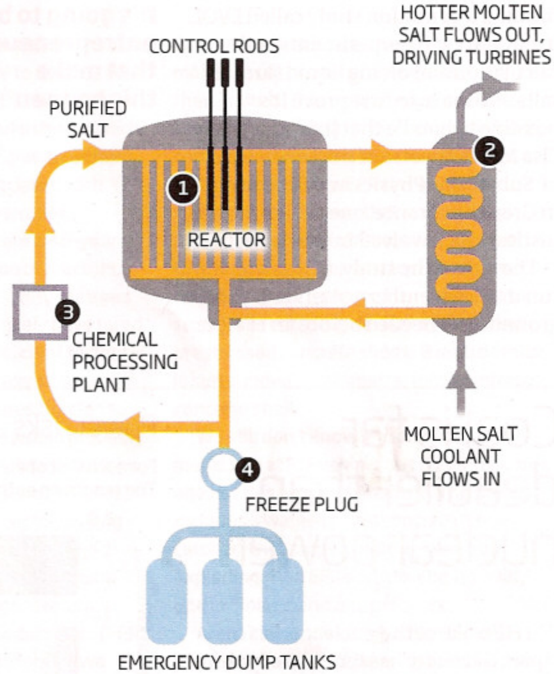
HOW IT WORKS

1. Thorium dissolved in a molten salt (Lithium flouride), plus a small amount of uranium-233 starts the following chain reaction



SAFETY FEATURES

2. Nuclear fuel is cooled by the salt not water, so no steam to generate hydrogen (which has led to explosions at Fukushima)
3. Unlike solid fuel rods, liquid radioactive mixture can be cycled until most fissile material is used up
4. In the event of a power loss, cooling for the freeze plug is lost. Plug melts and allows fuel to drain into the dump tanks and spread out, slowing down the reaction



"IT IS not difficult to conceive of an entire planet powered by thorium," wrote Kirk Sorensen on his blog Energy From Thorium in 2006. Some would contest this bold claim, but given the crisis at the Fukushima Daiichi nuclear power plant in Japan, the energy source Sorensen advocates has been thrust into the spotlight.

Sorenson and others propose building reactors that use a naturally occurring element called thorium as the main starting material, instead of uranium or plutonium. Though the technology is far from fully developed and very different to conventional plants based on solid uranium and plutonium fuel, advocates say it would be immune to the problems that have plagued the Fukushima reactors and should produce less radioactive waste than conventional reactors.

"It has some really compelling safety advantages," says Sorensen, who is now chief nuclear technologist at the firm Teledyne Brown Engineering in Huntsville, Alabama.

He is not alone in his passion for thorium, which is globally much more abundant than uranium-235, the fuel used in conventional uranium reactors.

For some, nuclear energy, in particular thorium, is the best way to fight climate change. "We have got to stop using carbon fuels," says Roger Barlow, a particle physicist at the University of Manchester, UK. "I don't think unfortunately that renewables will provide the energy we need."

Still, thorium is just one of many possible ways of improving the safety of nuclear power plants (see page 11). Thorium reactors also present unique challenges that must be overcome before a working version could become reality. And that's without considering the cost of a switchover.

At the heart of a liquid fluoride thorium reactor (LFTR) is a chamber filled with thorium dissolved in a molten salt such as lithium fluoride at several hundred degrees Celsius. Thorium itself is barely radioactive, so a small amount of uranium-233 is added to kick-start nuclear reactions. Like U-235 , it is radioactive and so fissions, releasing heat as well as neutrons. These hit thorium atoms, transforming them into more U-233 and producing heat in the process. The U-233 in turn fissions to produce more neutrons (see diagram above). "It is a continual process of turning thorium into U-233, burning it up and generating new U-233," says Sorensen.

The fuel cools as it passes through a heat exchanger containing more molten salt, and this heated salt can then be used to drive turbines and generate electricity.

Without water as a coolant, there is a much lower risk of explosions. At Fukushima, these were caused by the build-up of steam and the generation of hydrogen by the breakdown of water.

A liquid fuel also reduces the volume of radioactive waste. In conventional uranium reactors, the solid fuel rods have to be removed from the core long before their radioactive waste products have decayed and the uranium fuel has been used up. That's because too much radiation makes the fuel rods swell and crack, allowing radiation to leak out.

By contrast, the fuel in a liquid reactor is unaffected by radiation and so can continue to be used until virtually all its radioactive components have undergone further reactions, or decayed into non-radioactive waste products.

Another advantage is that, unlike conventional solid fuel rods, fluoride salts are not flammable. If solid rods catch fire they release plumes of radioactive smoke.

The difficulty with fluoride salts, though, is that they are highly corrosive, so special materials are needed to contain them. An experimental molten salt reactor that ran from 1965 to 1969 at Oak Ridge National Laboratory in Tennessee used a corrosion-resistent nickel-molybdenum alloy called Hastelloy N as a container material. But even this had degraded by the end of the project.

Also, athough LFTRs would burn up most of the waste they produce, they would not eliminate every trace. Safe storage for some long-lived radioactive material would still be needed.

Pavel Tsvetkov, a nuclear engineer at Texas A&M University in College Station, points out that many of the claimed safety advantages of LFTRs must still be proved in more detailed ›

"Using molten salt instead of water as a coolant avoids the possibility of hydrogen explosions"

studies. "Safety research is yet to be done," he says.

In December 2010, Europe's atomic energy agency Euratom committed to funding a €1 million study called EVOL. It will start with experiments and calculations involving liquid fluoride salts. "We have to first prove it's possible to handle that [material]," says Elsa Merle-Lucotte of the Laboratory of Subatomic Physics and Cosmology in Grenoble, France, one of the institutions involved in the project.

The aim of the study, which will run until November 2013, is to lay the groundwork needed before an LFTR can be designed. The project's participants then hope to win funding for a prototype. "Our dream is to build a demonstrator," says Merle-Lucotte.

"Thorium technology is totally different. It's going to be entrepreneurs that make this happen"

Other countries are working on thorium energy, too. In January, the Chinese Academy of Sciences announced funding to develop a molten salt thorium reactor as part of a broader plan for science and technology development called Innovation 2020.

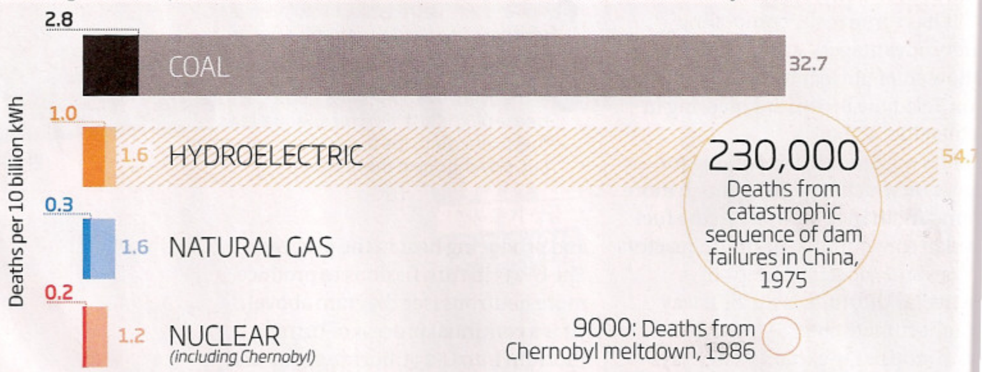
India has long experimented with thorium fuel, though in solid form. Though this lacks many of the advantages of the LFTR, India is keen to find ways to use thorium in conventional nuclear reactors as the country has abundant deposits of the metal and a scarcity of uranium.

Sorensen says he thinks the benefits of LFTRs will spur technology start-ups to invest in developing it, even if the established nuclear companies are reluctant because it is so different from what they know. "When you look at the individual technologies that go into a fluoride reactor they're totally different to what we use today," he says. "I think it's going to be new entrepreneurial companies that make this happen." **David Shiga** ■

Coal is far deadlier than nuclear power

Power risks

For each unit of electricity produced, nuclear power is nowhere near as deadly as coal. The ranges on each power source indicate estimates from different studies, as collated by the IEA



IN THE wake of the nuclear crisis in Japan, Germany has temporarily shut down seven of its reactors and China, which is building more nuclear power plants than the rest of the world combined, has suspended approval for all new facilities. But this reaction may be more motivated by politics than by fear of a catastrophic death toll. It may be little consolation to those living around Fukushima, but nuclear power kills far fewer people than other energy sources, according to a review by the International Energy Agency (IAE).

"There is no question," says Joseph Romm, an energy expert at the Center for American Progress in Washington DC. "Nothing is worse than fossil fuels for killing people."

A 2002 review by the IAE put together existing studies to compare fatalities per unit of power produced for several leading energy sources. The agency examined the life cycle of each fuel from extraction to post-use and included deaths from accidents as well as long-term exposure to emissions or radiation. Nuclear came out best, and coal was the deadliest energy source.

The explanation lies in the large number of deaths caused by pollution. "It's the whole life cycle that leads to a trail of injuries, illness and death," says Paul Epstein, associate director of the Center for Health and the Global Environment at Harvard Medical School. Fine particles from coal power plants kill an estimated 13,200 people each year in the US alone, according to the Boston-based Clean Air Task Force (*The Toll from Coal*, 2010). Additional fatalities come from mining and transporting coal, and other forms of pollution associated with coal. In contrast, the International Atomic Energy Agency and the UN estimate that the death toll from cancer following the 1986 meltdown at Chernobyl will reach around 9000.

"Fine particles from coal power plants kill 13,200 people each year in the US alone"

In fact, the numbers show that catastrophic events are not the leading cause of deaths associated with nuclear power. More than half of all deaths stem from uranium mining, says the IEA. But even when this is included, the overall toll remains significantly lowe than for all other fuel sources.

So why do people fixate on nuclear power? "From coal we have a steady progression of deaths year after year that are invisible to us, things like hea attacks, whereas a large-scale nuclear release is a catastrophic event that we are rightly scared about," says James Hammitt of the Harvard Center for Ri Analysis in Boston.

Yet again, popular perceptions are wrong. When, in 1975, about 30 dams central China failed in short successi due to severe flooding, an estimated 230,000 people died. Include the toll from this single event, and fatalities from hydropower far exceed the number of deaths from all other ener sources. **Phil McKenna** ■

For more on why radiation fears are often exaggerated, read our interview with risk statistician David Spiegelhalter on page 33