America and the world face enormous challenges relating to the procurement of energy, and to the corresponding security ramifications this represents. There exists today a virtually-unknown alternative to the standard uranium fuel cycle for nuclear power reactors, which offers a variety of significant strategic and economic advantages. This alternative is thorium.

Thorium is not new technology, but rather, it is as old as the nuclear age itself, with research ongoing since its inception. The first nuclear reactors in America and Russia were fuelled by thorium. It was then dismissed by policy-makers – the key reason being that the thorium fuel cycle provides no opportunity for obtaining bomb materials. The 21st Century is a different era than the Cold War era. The Obama Administration has recently announced its goal to rid the entire world of nuclear weapons while it must confront both energy and environmental crises. Fossil fuels are expensive and experience wildly volatile price fluctuations. Uranium is in dangerously short supply. The world was not ready for thorium in the 1950s. Thorium could not be more appropriate now.

The Basics

Thorium is a naturally-occurring fertile material – the only other one on earth besides natural uranium. Like uranium, 232-thorium can accept a slow neutron and transmute into a nuclear fuel, which then undergoes nuclear reactions, releasing enormous amounts of energy. The fissile material created is 233-uranium isotope. This thorium fuel cycle carries with it a number of important natural properties some of which contrast sharply with the uranium fuel cycle:

-At no point in the thorium cycle – from mining to waste – can fuel or waste products be used as bomb material in any way;
-The thorium fuel cycle is inherently incapable of causing a meltdown according to the laws of physics; in nuclear reactor parlance, the fuel is said to contain passive safety features;
-Thorium-based fuels do not require conversion or enrichment – two essential phases of the uranium fuel cycle that are exceedingly expensive, and create proliferation risk;
-Thorium fuel cycle waste material consists mostly of 233-uranium, which can be recycled as fuel (with minor actinide content decreased 90-100%, and with plutonium content eliminated entirely);
-Thorium-based fuels are significantly energy efficient;
-Thorium fuel cycle waste material is radiotoxic for tens of years, as opposed to the thousands of years with today's standard radioactive waste;
-Thorium fuel designs exist today that can be used in all existing nuclear reactors;
-Thorium exists in greater abundance and higher concentrations than uranium making it much less expensive and environmentally-unobtrusive to mine;

These facts have many serious implications for the efficiency and security of energy delivery in the United States, and the world.

Proliferation resistance

Proliferation resistance is important in a nuclear fuel solution for many reasons. Thorium delivers added security to every nuclear installation using thorium fuels, as well as to every other phase of the fuel cycle, including mining, processing, fuel fabrication, waste, and all the transport in between each phase. Each of these phases and the corresponding transport require heavy security in order to protect against theft or sabotage of radioactive materials. By using thorium, processing is not even required and all security can be dramatically reduced because the threat simply does not exist.

Abroad, the benefit to having proliferation-resistant nuclear energy in foreign locales is obvious. Never again will the world worry that a foreign state developing its own nuclear program is not genuine about its motives. With a thorium fuel cycle in place, the foreign state in question reduces their costs significantly, increases their energy efficiency, increases their access to fuel, and eliminates any international doubt of their probity.

Passive safety

Serious doubt was cast on nuclear energy as a viable power source by the significant accidents at Three Mile Island in the US state of Pennsylvania and in Chernobyl, Ukraine. Generation III reactors are now built with passive safety features where the laws of nature -- such as gravity or the laws of thermodynamics -- take over to stop any possible runaway reactions, leakage or any other kinds of accidents. The laws of nature cause the reactors to shut down, and remove disaster control measures from requiring human intervention. Thorium fuel continues this tradition, and marginally improves on this natural safety feature. Thorium fuel does not burn as hotly as uranium fuel. This also explains why it burns longer, and more thoroughly. The meltdown scenario is not at all possible with thorium fuel.

The benefits of the total passive safety of reactors to international security are obvious. An extension of this feature of thorium is that it makes nuclear reactor stations impervious to terrorist attacks. Furthermore, by obviating this possibility, security costs at these power stations can be dramatically reduced. A cheaper energy supply provides security the world over.

Elimination of enrichment phases

The standard fuel cycle practiced in the nuclear sector today requires that natural uranium, once mined, undergo an expensive, complex chemical process to increase its content of the 235-uranium isotope. This is the isotope that is fissile, and occurs naturally in mined uranium to the extent of 0.711% of the total mass. This fissile material must be concentrated to between 3% and 5% of the total uranium mass in order to be sufficient to create nuclear reactions within the reactor. This is the same material that, if concentrated to 85%+ of the total mass of uranium, in sufficient quantities – approximately 10 kilograms or more – can be used to make nuclear weapons.

Enrichment is a two-step process. Firstly, the natural uranium is mined, and then transported under security, to a conversion facility, where the uranium, in the naturally-occurring form triuranium octaoxide (U3O8), known as yellowcake, is converted into gaseous uranium hexafluoride (UF6). This gas is then transported under security to the enrichment facility, where the UF6 is enriched to 3%-5% 235UF6. This enriched material is then transported under heavy security to the fuel fabrication facility, where it is solidified once again, and then crafted into pellets, rods and finally highly complex bundles. From there, the fuel bundles are transported under heavy security to the reactor. For countries that have nuclear power stations, but do not have their own enrichment facilities (most don't), these shipments must cross international boundaries. The waste product of this process is depleted uranium, which is stored at the enrichment site.

At present, the Republic of Iran has raised international concern by engineering their own enrichment technology, without the approval of the United Nations. Iran claims that they wish to enrich uranium in order to utilize it as fuel for nuclear power stations in their country. However, with the enrichment technology in hand, they also have the ready capability, if they choose, to develop bomb-grade material.

Thorium does not require any conversion or enrichment. Thorium naturally occurs in the form thorium dioxide (ThO2), with no isotopic content. Thorium oxide, which is not fissile and cannot be weaponized in any way, can be transported directly to the fuel fabrication facility for manufacture into pellets, rods and bundles, and then transported to the reactor. In this scenario, there are only two transports required – compared to four for uranium – and only one transport that requires heavy security.

With thorium, an enormous infrastructure of expensive and risky transport, as well as the associated security, is entirely eliminated. Once again, besides the cost benefits, the benefits to national and global security are clear.

Improved waste profile

The waste profile of today's standard nuclear fuel cycle is problematic. It contains lethal radioactive material, including approximately 1% fissile plutonium, as well as significant quantities of so-called minor actinides: curium, americium, and neptunium. Any of these materials can be concentrated to produce nuclear weapons materials. At present, the United States has no stated policy for the processing of nuclear waste. The material is stored at 100 nuclear reactor sites, where they are subject to theft or attack. Internationally, some countries have their waste material reprocessed, but there is only one facility in the world at present that can reprocess the material – located in France.

The waste profile of the thorium fuel cycle is a vast improvement. The vast majority of the waste is the 233-uranium isotope. 233U can be reprocessed to be used as fuel in a closed thorium fuel cycle, however the technology for this is not yet available. In the meantime, 233U cannot be used to make bomb material because of its natural properties. Specifically, it is because 233U contains 232uranium isotopic content, whose decay products give off significant gamma rays, that would fry the electronics in any conceivable bomb mechanism not to mention being fatal for any human being within several meters, making transport of weapons impossible. Moreover, these gamma rays would be immediately detectable by the most basic satellite surveillance. Bomb fabrication from 233U, though technically possible, is so impractical that it is considered impossible. Minor actinide waste in the thorium fuel cycle is reduced by as much as 99.99% in some models.

Increased energy efficiency

Due to the chemical properties of thorium, when it is used as fuel in a nuclear reactor, it has the ability to give off more neutrons than it absorbs. This means that the neutron economy of any contemplated thorium fuel cycle is superior to the uranium fuel cycle. The fuel burns longer and uses all of the fissile material required to ignite a reaction.

As explained above in today's standard fuel natural uranium is enriched to increase its concentration of 235U fissile content. Approximately two-thirds of this fissile material is burned, with the remainder in the waste product. Natural uranium in the fuel absorbs a neutron to eventually become 239-plutonium. Approximately 0.9% of the final waste consists of this 239-plutonium isotopic material. When concentrated, this is the best material for bomb production. It is due to an inherently inefficient fuel cycle that there is so much residual material.

In the thorium fuel cycle, 232-thorium absorbs a neutron to breed 233-thorium, which decays naturally in 22 minutes into 233-protracinium, which decays naturally after 27 days to become 233-uranium. One hundred per cent of this 233-uranium burns in the reaction (as opposed to only two-thirds of the 238U-bred fuel.) However, approximately one out of every ten 233-Pa molecules are lost in the decay process and become a 234-uranium isotope. In sum, thorium-bred fuel burns with 90% efficiency, whereas uranium-bred fuel burns with only 66% efficiency. The waste products are, respectively, 233U, which cannot be used for bomb production, and 239Pu, which is the best possible bomb material.

The energy differential from this efficiency has been demonstrated to be anywhere from 60% to 200% greater. It should also be noted that because thorium fuel does not require enrichment, whereas uranium fuel does, much less raw material is required. In order to produce one year's worth of fuel for an average reactor (the US average reactor capacity is 1,000 Megawatts of electricity (MW), approximately 550,000 pounds of natural uranium is required. Seven-eighths of this material has the 235-uranium extracted out of it, leaving unusable depleted uranium waste behind. Because thorium does not require enrichment, only one-eighth, or 69,000 pounds of raw material is required for the same energy output. However, there is not even an equivalent energy output because of thorium's enhanced neutron economy and enhanced fissionability characteristics. Therefore, this 69,000 pounds, a full one-eighth of the material required for standard fuel will generate 60% to 200% more energy output.

Thorium creates enormous efficiencies from the micro- to the macroscopic level of fuel, and at virtually every stage in the cycle. Enhanced efficiency translates directly into decreased costs. At the risk of sounding repetitive, cheaper energy provides security benefits the world over.

Short-lived radiotoxicity of waste

Spent nuclear fuel in the current paradigm must be stored in a water medium for cooling, before being stored in a special containment chamber. Currently, these containment chambers exist at nuclear reactor sites. For nearly 20 years, the US government has labored to develop a national storage facility for this waste at Yucca Mountain in Nevada, against broad opposition. Billions of dollars in research has been spent, with billions more being allocated to a sinking fund for the construction of such a facility by utility companies who own and operate reactors. Very recently, the Obama Administration decreed that work on Yucca Mountain was to cease immediately. The sinking fund remains.

Thorium-based waste, also highly radioactive, has the distinction of being radiotoxic for a far shorter time period. The half-lives of 233U's decay products are far shorter than the half-lives of the transuranic wastes mentioned above. These dangerous periods can be measured in tens of years rather than thousands. Certainly, to decrease the period during which these waste products are lethal also provides security benefits.

Thorium fuel utilizable in existing reactor designs

There are no significant infrastructural impediments whatsoever to using thorium fuels in all existing reactor designs in the immediate present. This is also a s security benefit. Typically, any new energy technology, particularly a nuclear energy technology, must pass through a series of daunting obstacles related to legislation, technology development, regulation, user education and finally market penetration before being implemented. For thorium, the reactors themselves require virtually no modifications, and no regulatory paradigm changes in order to accommodate thorium fuel. So this technology development continuum only applies to the fuel development itself, which is a much easier, faster, safer and cheaper exercise.

Security of supply

Perhaps the most significant benefit to security is the abundant supply of easily available thorium. Approximately 190 million pounds of uranium is required in 2009 to fuel the 437 reactors in operation globally. However, less than 110 million pounds of uranium will be produced from mining in 2009. The balance must be provided by blended-down weapons material, and from inventories. At the end of 2012, the Russian contract to provide the United States and others with material from their weapons expires, and the Russians have announced that they will not renew the contract. They require the material for their own civil energy program. The uranium shortfall in 2009 that must be filled from inventory is approximately 26 million pounds. By 2016, this shortfall is estimated to be 106 million pounds, and will continue to increase. By 2020, approximately 150 million pounds of uranium will be required from an inventory stockpile every year in order to keep reactors from operating below capacity. These figures take into account new reactors, and new uranium mines. By 2020, the international stockpile will be dangerously depleted, and the material that reactors depend on will either become unavailable, or will skyrocket in price. This partially explains why the price of uranium increased from $7 per pound in 2001 to $135 per pound in 2006. With the retrenchment of oil prices and the global economy in general, the price of uranium has also retrenched to the $40-45 price range. Nevertheless, the problem remains, and it is far more critical than the attention paid to it.

The United States is probably the most vulnerable to this developing uranium supply crisis. At present, the US is forced to import over 90% of its uranium required for reactor fuel. There are new uranium mines being planned, but there are also 19 new reactor builds permitted as of this writing. Each average reactor requires, on average, 550,000 pounds of uranium feedstock. In 2008, the US produced 3.9 million pounds. The supply required for the new facilities alone will be at least 10.5 million pounds, not to mention the 57.2 million or so pounds required for the existing US reactor fleet. There is no question that the United States is facing a serious problem.

Uranium must be mined from underground, typically requiring costly infrastructure. The mining methods are: the In-Situ Leach (or ISL), or the even costlier, more environmentally-obtrusive open pit mining. Because of the technical complexity and because of the extreme environmental impact involved, an extraordinary level of regulation is required to ensure the safety of uranium mining practices. This further increases costs, and slows down new production. A very typical life cycle for a uranium mine will be 10-15 years from discovery to the first year of production. And then the mine’s lifespan may only be 5-10 years (as is common).

Uranium typically occurs at very low grade in nature – 1% of weight or less. This makes mining operations themselves expensive, even after the large capital expenditure for infrastructure. Mine operating costs, including the processing, can amount to $25-50 per pound. Once again, this is over and above the typical $50-100 million capital cost sunk into mine construction and development.

Thorium mining is an entirely different proposition. Large supplies of thorium exist in surface mineral sands in nearly every corner of the world. These sands can be mined by dredge mining, which is well-known as being an environmentally unobtrusive mining technique. Without having to go underground, the infrastructure and operating costs are a small fraction of any uranium mining operation. These mineral sands are also highly concentrated with thorium, and can contain tens or hundreds of millions of pounds of thorium per deposit. In short, thorium is readily, cheaply and easily available in large quantities. The US itself has enough easily-extractable thorium to power its reactors for thousands of years.

Thorium can also act as a useful supplement to uranium if necessary. With a secure supply of thorium, a nuclear fuel supply crisis can be averted, meaning that energy supply need not be interrupted.

At present, thorium is not purposely mined anywhere in the world.

The Future of Thorium

Leading thorium fuel cycle research is taking place in India, Norway, Russia, Canada and elsewhere. This research is very advanced in nature. The US faces a security issue by becoming an also-ran in this technology race. The US Congress has latently realized this. That is why on March 24, 2009, only eight days after the Bill's introduction, the Congress directed the US Navy to investigate the use of thorium-based nuclear reactors for naval use. Elsewhere in the United States legislative environment is the "Thorium Energy Independence and Security Act" – a bill drafted by Nevada and Utah state senators, Harry Reid and Orrin Hatch. The objective of this bill is to appropriate funds for thorium research and education both in the US and abroad.

The benefits of the US exporting safe, clean, proliferation-resistant nuclear technology and fuel to other nations are clear. World nations can safely take advantage of emission-free energy without any threat of nefarious use.

With all the serious concerns of nuclear energy addressed, the world can have more confidence that nuclear is a safe technology, and that nuclear accidents or attacks will not have any possible apocalyptic side effects. With an increased adoption of nuclear energy, the entire world's dependence on fossil fuels can decrease dramatically. At present, there are 437 nuclear reactors in the world, providing approximately 18% of the entire world's power. Nuclear energy is the only long-run, sustainable and viable alternative energy available to the world today. If the adoption of nuclear could be increased to 50% from less than 20%, carbon emissions would experience enormous declines, thereby alleviating the problem of climate change. And this represents yet another matter of security.

With a true nuclear renaissance, brought about with the help of the thorium fuel cycle, the world will become more secure.

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