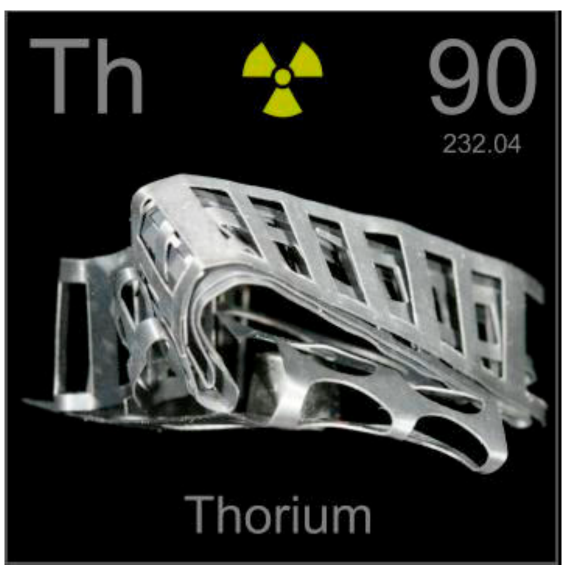
The Superior Design Advantages over all other Nuclear Reactor Designs of the Molten Salt Liquid Fluoride Thorium Reactor Power Generator (LFTR)

✦

with an Emphasis on its Safety Features



White Paper Prepared for The LFTR Energy Group

By GBCN

GBCN.net

Global Buyers' Cooperative Networks

The molten salt reactor was not commercially exploited after its discovery and extensive development at Oak Ridge National Laboratory from 1946 through 1974.

The reasons for this are because in its design and operations it was very different from other nuclear reactors —

- *The MSR could employ ^{232}Th, thorium, or ^{235}U, fissile uranium, or ^{239}Pu, plutonium, as its fuel, burning at higher, more 'energy-to-work' efficient temperatures than other reactor designs burning ^{235}U.*
- *The MSR's operators dissolved the solid state fuel in a 700˚ C. molten salt coolant, (*two to three times hotter than the 285˚ to 325˚ C. operating temperatures of other stainless steel reactors*) that is pumped through the molten salt loop once per minute. The fuel was mixed thoroughly through the molten salt, unlike ALL other reactor designs where the solid fissile fuel is trapped in fixed assemblies of fuel rods – out of reach of coolants – where the heat (*up to 2000˚ C. of trapped heat*) and radiation build-up destroys the fuel's fissioning functionality, before no more than -3%-5% of the fissile material is consumed.*
- *The MSR's architecture prevented easy proliferation of weapons-grade fissile fuel*

The molten-salt LFTR's architectural advantages make it the safest form of the safest source of industrial-level electrical energy today. Here's how and why this is true, revealed by extensive nuclear research analysis.

<u>The Molten Salt LFTR's Safety Advantages</u>

- Operating at 1 atmosphere of pressure, it requires no pressure vessels to control high intensity steam, no reinforced pipes to withstand the constant high forces – there are none.
- There are no chemical driving forces (no steam build up or explosions, no hydrogen production etc., in the molten salt LFTR), nothing can explode, nothing can melt down, the MSR had to melt in order to start up.
- No volatile fission products are in the molten salt (gases are continuously removed, while actinides plate out at designated sites)
- No excess reactivity is needed to manage ^{135}Xenon and other neutron 'poisoners' that can kill the reactor
- Operating only at maximum reactivity, if the level of reactivity goes down, the reactor automatically empties out the molten salt and stops – if the temperature from excessive reactivity begins to rise, the reactivity stops as the fuel becomes too diffuse to fission in the expanding molten salt.
- Very stable with instantly acting negative temperature reactivity coefficients
- Fluoride salts only melt at 450˚ C., and they are operating in the MSR at 705˚ C. A freeze valve, melting a frozen salt plug from too much heat, or melting a frozen salt plug from loss of cooling power, it drains the molten salt into anti-fission-geometry tanks that will passively

pass off decay heat by conventional current powered air flow (outside the radioactive shield)

- No need for elaborate "defence in depth" or massive internal structures for steam containment and or the pumping and management of vast water reserves

LeBlanc, D. (2009, March 29)

> *The LFTR design in its present state of research appears to possess an extremely high degree of inherent safety. The single most volatile aspect of current nuclear reactors is the pressurized water.*
>
> *In boiling light-water, pressurized light-water, and heavy water reactors (accounting for nearly all of the 441 reactors worldwide), water serves as the coolant and neutron moderator. The water is maintained at high pressure to raise its boiling temperature.*
>
> *The explosive pressures involved are contained by a system of highly engineered, highly expensive piping and pressure vessels (called the "pressure boundary"), and the ultimate line of defense is the massive, expensive containment building surrounding the reactor, designed to withstand any explosive calamity and prevent the release of radioactive materials propelled by pressurized steam.*
>
> *In the LFTR design, the coolant—liquid fluoride salt—is not under pressure.*
>
> (Moir & Hargraves, 2010)

…

> *Why didn't the molten-salt system, so elegant and so well thought-out, prevail? I've already given the political reason: that the fast breeder arrived first and was therefore able to consolidate its political position within the AEC. However, there was another, more technical reason.*
>
> *The molten-salt technology is entirely different from the technology of any other reactor. To the inexperienced, molten-salt technology is daunting.*
>
> *It was a successful technology that was dropped because it was too different from the main lines of reactor development. But once the weaknesses in other systems are eventually revealed, I hope that in a second nuclear era, the molten-salt technology will be resurrected.*
>
> (Weinberg, A.M., 1994)

There is a fundamental fork in the road at the basic differences between abundant thorium and abundant uranium, and how to use them. Eugene Wigner and Enrico Fermi recognized this at the dawn of the nuclear age.

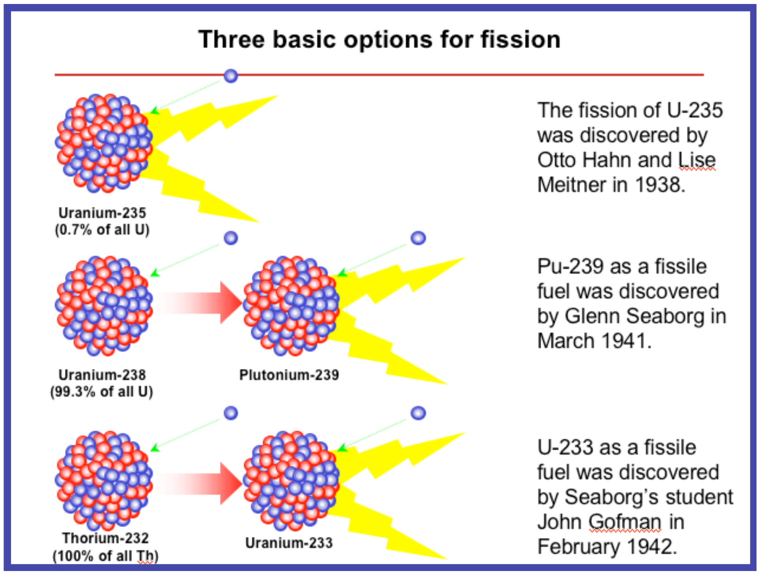


Diagram 1. – The Fork In The Road: Starting with Uranium or Starting with Thorium (Sorensen, K., 2009)

Abundant uranium, in nature as mostly uranium-238 [^{238}U], requires a radioactive 'starter' with which it can burn indefinitely in a fast spectrum reactor. This fast spectrum reactor design focuses on keeping neutrons at high energies, prevents them from slowing down from their 1/10th –the-speed-of -light at which they initially escape their nuclei. The design is constrained by very specific material choices – low atomic-weight materials like hydrogen must be kept out of the reactor. The fast spectrum reactor optimizes neutron speed and therefore must avoid more reactive configurations at all costs.

This is a very dangerous feature for a nuclear reactor design, as sudden changes in geometry, material, or temperature can force the fast spectrum reactor to speed up its reactivity, running out of control. By the same token, abundant thorium, found in nature as ^{232}Th, also requires a radioactive 'starter' – but it only will burn indefinitely in a thermal spectrum reactor. The thermal spectrum reactor moderates neutron speeds to a few kilometers per second, generating a lot of heat in the process. This thermal spectrum reactor's architecture must be designed to optimize the most reactive configuration possible. Thus, any change to the thermal spectrum reactor's geometry or shape, or the make up of its materials or its temperature causes it to shut down by becoming *less* reactive. This is a vital safety feature for a nuclear reactor design. (Sorensen, 2010)

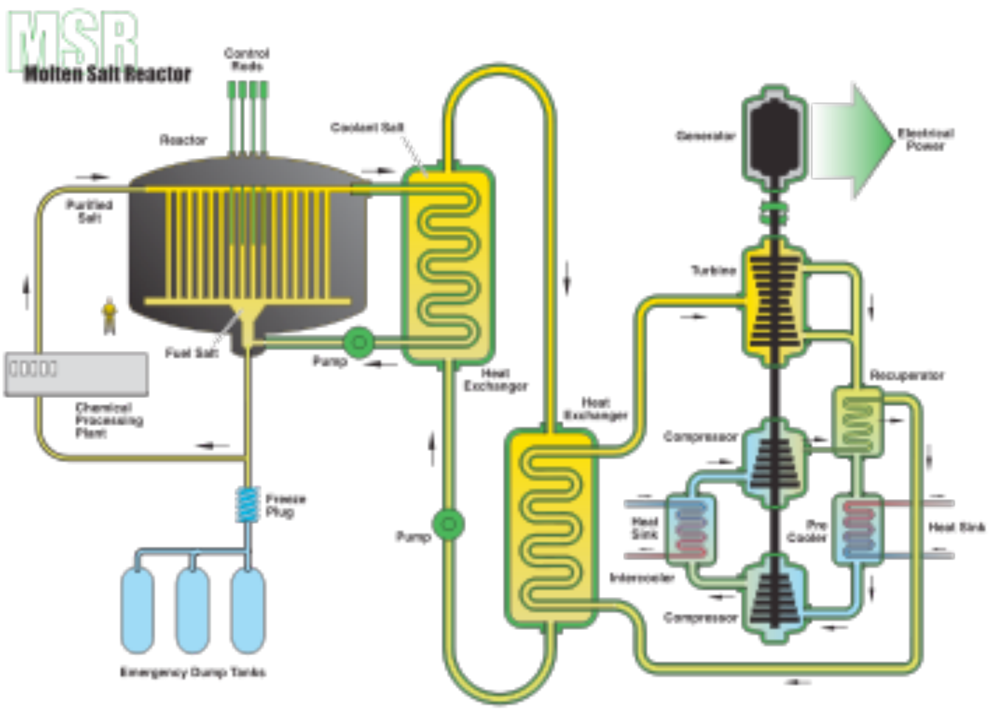
The thermal spectrum reactor (the LFTR's design category) can convert thorium into ^{233}U, and then burns ^{233}U to generate neutrons that make more ^{233}U out of ^{232}Th, which burns, generating heat and neutrons that make more ^{233}U out of ^{232}Th, and so on.

The fast spectrum reactor burns ^{238}U to convert it to ^{239}Pu, and then burns the ^{239}Pu to make neutrons that make more ^{239}Pu out of ^{238}U, and so on.

The thermal spectrum reactor makes ^{233}U generate enough neutrons to keep the fire burning. ^{239}Pu cannot make enough neutrons in the thermal spectrum reactor to keep the fire burning.

"Electricity production and waste burn down are envisioned as the primary missions for the MSR. Fissile, fertile, and fission isotopes are dissolved in a high-temperature molten fluoride salt with a very high boiling point (1,400 C) that is both the reactor fuel and the coolant. The near-atmospheric-pressure molten fuel salt flows through the reactor core. The traditional MSR designs have a graphite core that results in a thermal to epithermal neutron spectrum.

*"In the core, fission occurs within the flowing fuel salt that is heated to ~700 ˚C., which then flows into a primary heat exchanger where the heat is transferred to a secondary molten salt coolant. The fuel salt then flows back to the reactor core. The clean salt in the secondary heat transport system transfers the heat from the primary heat exchanger to a high-temperature Brayton cycle that converts the heat to electricity." (**http://nuclear.inl.gov/gen4/msr.shtml**)*



In the fast spectrum reactor, ^{239}Pu and ^{235}U or ^{238}U make enough neutrons to keep the fire burning -- and the faster the spectrum the more neutrons ^{239}Pu will produce, i.e., up to bomb levels of reactivity. This was the incentive for building fast spectrum reactors -- creating lots of extra plutonium for other purposes, such as nuclear weapons. (Sorensen, 2010)

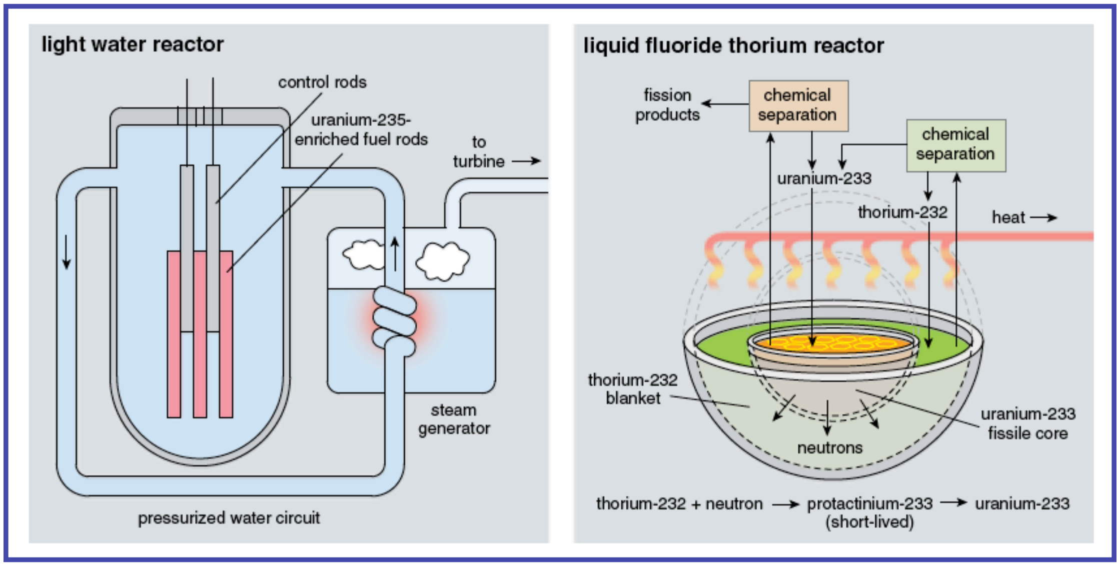


Diagram 2. The Fast Spectrum (Light Water Reactor) versus the Thermal Spectrum (Liquid Fluoride Thorium Reactor) *– At its most schematic, the uranium-fueled light water reactor (all of the U.S. reactor fleet) consists of fuel rods, control rods, and water moderator and coolant.*

The liquid fluoride thorium reactor (LFTR), a two-fluid design earmarked for a pure thorium fuel cycle, consists of a critical core (orange) containing fissile ^{233}U in a molten fluoride salt, surrounded by a molten fluoride salt blanket (green) containing ^{232}Th. Excess neutrons produced by fission in the core are absorbed by ^{232}Th in the blanket, transforming the thorium into ^{233}U.

The ^{233}U and other fission products are recovered by straightforward chemical separation, and then the ^{233}U is placed into the core fuel salts, where it supports the continued chain reaction. (Moir, Hargraves, 2010)

> *Perhaps the most important choice for U.S. nuclear power's trajectory came from Admiral Hyman Rickover, Director of Naval Reactors. He decided that the USS Nautilus (the 1st nuclear sub) would be powered by solid uranium oxide enriched in ^{235}U, using water as coolant and moderator. The Nautilus was commissioned in 1955. Adm. Rickover judged it to be the most suitable design for his subs: It was the likeliest design to be ready the soonest. And this uranium fuel cycle offered ^{239}Pu as a byproduct – which could be used for the development of thermonuclear ordnance.*

> *A reactor of similar design was installed at the Shippingport Station in Pennsylvania and became the first commercial nuclear power plant going on line for the first time in 1957.* (Moir & Hargraves, 2010)

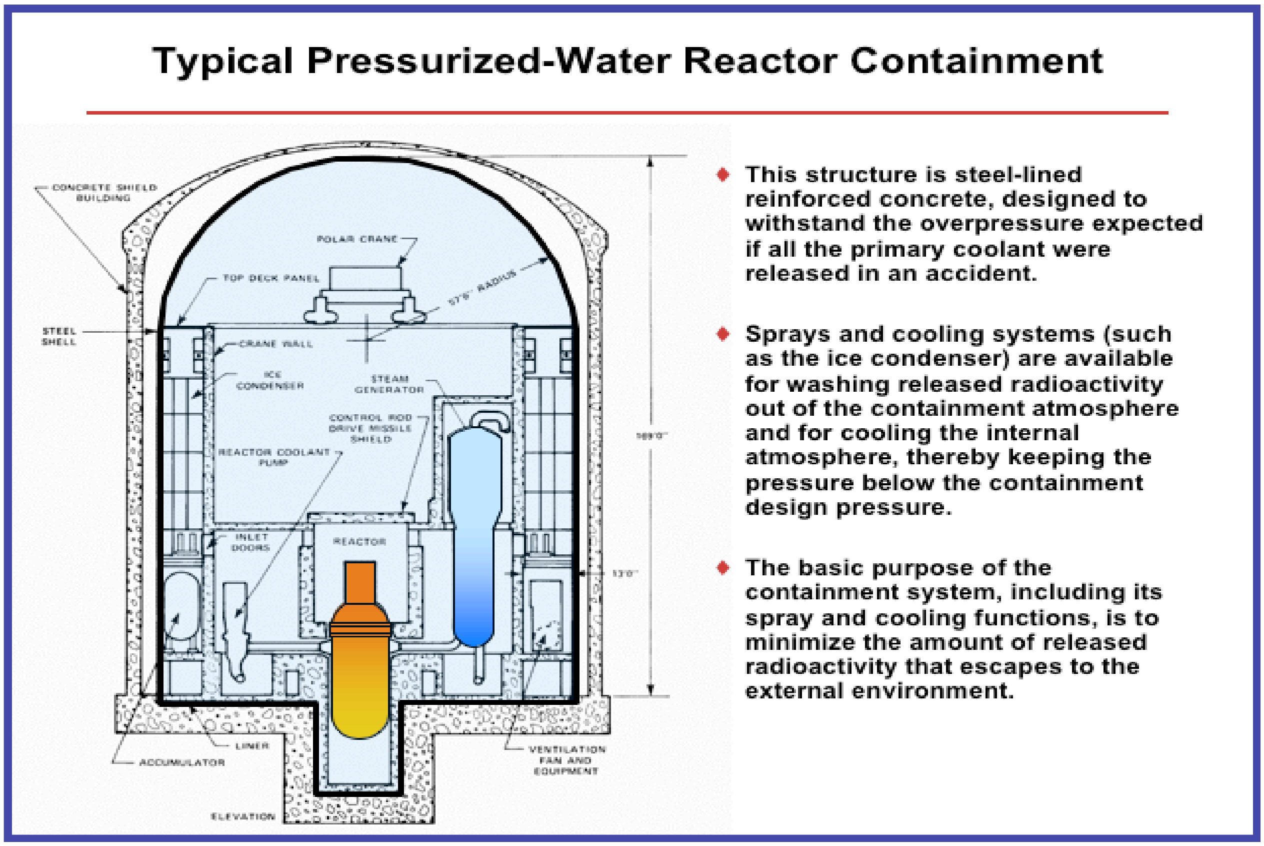


Diagram 3. – Illustration of a Typical Nuclear Reactor In Use Today *(Sorensen, 2009)*

It's estimated that the majority of the cost to build a modern nuclear power plant is invested in containment, anti-meltdown and other safety measures -- as much as $1.5 billion per plant.

No nuclear power plants in the U.S. ordered since 1974 have been completed, and many dozens of partially constructed plants were abandoned. Several large nuclear plants were completed in the U.S. in the early 1970s at a typical cost of $170 million, whereas plants of the same size completed in 1983 cost an average of $1.7 billion – a ten-fold increase.

By the late 1980s some completed plants had cost $5 billion – 30 times what they cost to build 15 years earlier. This was far more than just inflation -- the U.S. consumer price index only increase by a factor of just 2.2 between '73 and '83. (Cohen, 1990)

There were growing environmentalist opponents to nuclear power in the U.S.

Question them about this 30 TIMES cost increase in less than 15 years and they chant about a succession of horror stories – mistakes, inefficiency, sloppiness, and ineptitude. For legions of new nuclear power opponents, the builders of nuclear plants who were so efficient in the late '60s and early '70s had become bungling incompetents by the late 80s. (Cohen, 1990)

To be anti-nuclear in the early 1960s did not mean being against nuclear power but instead, it meant you were opposed to nuclear weapons.

Both the Russians and the U.S. had tested hydrogen bombs for over a decade. A few months after Khrushchev exploded a 100-megaton bomb test in Siberia, Kennedy and Khrushchev faced off in the Cuban Missile Crisis.

Then, eight months after this heart-stopping confrontation, Kennedy gave a surprisingly conciliatory speech inviting Russia to joint a nuclear test ban treaty. 35 days after this speech, British, American and Soviet delegates spent ten days and hammered out a ban on above ground testing – none of them has exploded a nuclear device in the atmosphere since July 1963.

Once testing was banned, however, many anti-nuclear organizations began concentrating on nuclear power – without acknowledging there was any difference.

Environmental bigotry burst into popular media with the fervid "Silent Spring" (with its stark condemnation of the use of DDT). Greenpeace was inaugurated in opposition to DDT. Paul Ehrlich authored "The Population Bomb", a false alarm about global starvation fears abruptly thwarted by Norman Borlaug's genetically altered 'semidwarf' wheat and rice that raised global food yields six fold. Undaunted by this mistake, Mr. Ehrlich argued, "Nuclear Power represents the single greatest threat to the health and safety of humanity!"

At 4am on Wednesday, 28 March 1979, as "The China Syndrome" (a Hollywood movie produced by and starring Jane Fonda) was in its second week of its U.S. theatrical release – operators at the six month-old Unit 2 of the Three Mile Island Nuclear Station near Harrisburg, Pennsylvania experienced a "scram."

In a pressurized water reactor like the one at Three Mile Island, water in the primary cooling loop draws away heat from the core and while it is prevented from evaporating by high pressurization. A pilot-operated relief valve keeps the pressure under control. When Unit 2 shut down, the relief valve opened as it was supposed to do. But after ten seconds it was supposed to close automatically. It did not.

The reactor's computer program took over – responding to coolant loss, pumps injected additional water into the core to cool everything down. The relief valve became stuck in the open position. The operators, unaware of this, sent an instruction for it to close.

A light on the control panel indicated the instruction was sent, but nothing on the room-sized array of gauges and indicators told the operators if the valve had actually closed, or not.

Thinking they were relieving excess pressure, the operators overrode the automatic system, turning off the pumps. The fuel rods were exposed; their decay heat raised the core temperature to 1000 degrees C.

Water remaining in the cooling system evaporated, leaking through the open relief valve into the containment building. The crew realized its serious mistake when radiation monitors started going off in the control room. A seal on one of the waste tanks leaked, and a small amount of radioactive steam escaped into the atmosphere.

The rooftop reading was 1200 millirems – <u>about four times</u> the annual background radiation in most parts of the U.S. The radiation quickly dissipated and readings in adjoining neighborhoods remained normal, as they have to this day.

However, the press – along with the usual environmentalists got word within hours and soon hundreds of reporters were converging on the scene.

A hydrogen bubble now formed in the primary cooling loop, as the white-hot core began splitting water molecules. Oxygen combined with the fuel rods' cladding, leaving some hydrogen free. Twelve hours into the incident, a "small hydrogen explosion" occurred.

Now a 1000-cubic-foot bubble lurked at the top of the containment vessel, hindering cooling. Another explosion potentially could have breached the containment vessel's roof and released radioactivity across the countryside.

General Public Utilities now set about alienating the press with real aplomb, in the manner of BP in the April-August '10 Gulf oil spill.

For three days the U.S. public's attention was riveted on central Pennsylvania. Governor Thornburg asked that pregnant women and children should leave the area within a five-mile radius of Three Mile Island.

Across the rest of the U.S., Three Mile Island produced one outrageous report after another: A Los Angeles Times cartoonist drew a picture of a mushroom cloud emerging from a cooling tower. A New York Post headline screamed one word, "Radiation!" A national correspondent, observing some water running down the side of the cooling tower, swore he saw radiation roiling out of the plant.

At first, President Carter calmed the situation down by taking a tour of the TMI control room with his wife, Rosalynn.

But he then made a mistake, and appointed a special commission that avoided all nuclear industry and anti-nuclear representatives – choosing only 'neutral experts'. Known as the "Kemeny Commission" after its chairman, an IT subject matter expert and president of Dartmouth College, its membership was long on lawyers, public relations specialists and NASA engineers but extremely short on people who understood anything about nuclear power. (Tucker, W., Pp. 40-55, 2009)

When the pressurized water reactors began to be built – they were bid out for tender by the utilities that would own them and run them. It was simply assumed that the people who designed reactors were geniuses while the people who operated them understood nothing, and indeed it was true that many early workers in nuclear plant operations were just high-school graduates.

The reactors' design was therefore intended to make the reactors 'idiot-proof', automated to run themselves with little or no 'interference' from the operations crew.

At TMI, only one training hour per year was devoted to review operations procedures that were used at other reactors,

Pride of authorship by Utility executives and engineers eager to make their own mark built a 'hodge-podge' of unique reactors each an island unto itself. There resulted in the U.S. a checkerboard of utilities isolated from one another trying to operate reactors they had no hope of understanding.

Criticized from all sides, the U.S. Nuclear Regulatory Commission stepped up its oversight. Under heavy criticism, the NRC raised fines from $1,000 to $100,000 per day.

Plants were shut down for weeks for the smallest infractions. Construction of new reactors slowed.

> *Anti-nuclear environmentalist groups demanded and got more and more regulatory oversight of nuclear power. By 1990, the passage from a reactor's construction license to an operating license was averaging 14 years and a number of projects actually required more than 20 years to move into operation from the first shovels in the ground.*
>
> *Somehow, the surviving nuclear power plants continue in operation. They generate 20% of the electricity purchased today by U.S. end-users.*
>
> *"There had been a mentality that nuclear was just an extension of coal, "says J.V. Rees, professor of public administration at Virginia Polytechnic Institute.*
>
> *Another unnamed utility executive made the admission that …In the fossil fuel business the general philosophy is run it till it breaks. Then you shut it down, fix it, and run it again. Every minute you don't use that capital for production purposes you are running costs. That's no good for a nuclear plant. The potential consequences of a breakdown are too great. If something breaks, you can't just walk in and fix it*. (Tucker, W., Pp. 40-55, 2009)

Times change and bring additional information: In the late 1980s, the American public learned from environmentalists that the radioactive gas, *radon*, was invading their homes, exposing them to many hundreds of times more radiation than they could ever expect to get from nuclear power.

In fact, in some homes it was thousands or even tens of thousands of times more. But still only about 2% of the American public bothered even to test for it (at a cost of about $12), although their exposure can easily be drastically reduced.

The public has largely forgotten about being frightened about radiation. They may have caught on to the fact that after all the scare stories, there have been no dead bodies, and not even any injuries to the public. There must be a limit to how often the cry "wolf" will be heeded. (Cohen, B.L., 1990).

An analysis of the 70s to 80s (30 X) cost explosion to build pressurized water reactors shows that it resulted from three factors:

(1) The lack of standardization on a single reactor design and a single set of operations rules and procedures for all reactors produced and run

(2) The rabid, continuous environmentalist bigotry attacked all forms of nuclear technology with their usual weapons – Ignorance, and fear of the resultant unknown

(3) The increased focus on safety problems inherent in the pressurized water reactor design

Lack Of Standardization On A Single Reactor Design And A Single Set Of Operations Rules And Procedures For All Reactors Produced And Run

France is The Model

- *The French government decided in 1974, just after the first oil shock, to expand rapidly the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous fossil fuel energy resources. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense in minimising imports and achieving greater energy security.*
- *As a result of the 1974 decision, France now claims a substantial level of energy independence and the lowest electricity cost in Europe.*

- *The first eight power reactors were gas-cooled, as championed by the Atomic Energy Authority (CEA), but EdF then chose pressurised water reactor (PWR) types, supported by new enrichment capacity. All French units are now PWRs of three standard types designed by Framatome - now Areva NP (the first two derived from US Westinghouse types): 900 MWe (34), 1300 MWe (20) and 1450 MWe N4 type (4). This is a higher degree of standardisation than anywhere else in the world*
- *France derives over 75% of its electricity from nuclear energy. This is due to a long-standing policy based on energy security. In 2007 French electricity generation was 570 billion kWh gross, and consumption was about 447 billion kWh - 6800 kWh per person. Over the last decade France has exported 60-80 billion kWh net each year and EdF expects exports to continue at 65-70 TWh/yr, to Belgium, Germany, Italy, Spain, Switzerland and UK.*
- *From being a net electricity importer through most of the 1970s, France now has steadily growing net exports of electricity, with electricity being France's fourth largest export. (Next door is Italy, with no nuclear power plants. Italy is Europe's largest importer of electricity, most coming from France's nuclear power plants.) The UK has also become a major customer for French nuclear power plant electricity.*
- *France is the world's largest net exporter of electricity, and gains over EURO 3 billion per year from these energy exports. France has been very active in developing nuclear technology. Reactors and fuel products and services are a major French export.*
- *France has 59 nuclear reactors operated by Electricite de France (EdF), with total capacity of over 63 GWe, supplying over 430 billion kWh per year of electricity (net), 78% of the total generated there. Total generating capacity is 116 GWe, including 25 GWe hydro and 26 GWe fossil fuel.*
- *The cost of nuclear-generated electricity fell by 7% from 1998 to 2001 to about EUR 3 cents/kWh, which is very competitive in Europe. The back-end costs (reprocessing, wastes disposal, etc) are fairly small when compared to the total kWh cost, typically about 5%.*
- *Early in 2009, EdF estimated that its reactors provide power at EUR 4.6 cents/kWh and the energy regulator CRE puts the figure at 4.1 c/kWh. The weighted average of regulated tariffs is EUR 4.3 c/kWh. Power from the new EPR units is expected to cost about EUR 5.5 to 6.0 c/kWh.*
- *France's nuclear reactors comprise 90% of EdF's capacity and hence are used in load-following mode and are even sometimes closed over weekends, so their capacity factor is low by world standards, at 77.3%. However, availability is almost 84% and increasing.*

"Nuclear Power In France," http://www.world-nuclear.org/info/inf40.html, World Nuclear Association, Updated June 2010

Standardization Strategy for the LFTR

The molten salt LFTR Energy project will develop *a* 'prudent' design prototype focused on already-demonstrated specifications of a single fluid denatured low-enriched (<5% ^{235}U) fuel without in-line processing and a graphite core, (following ORNL/TM-7207). This is expected to require a 200 MW(e) output with conventional open cycle turbine power trains.

Generations of standardized, mass-produced molten salt power generators will be built on an assembly line in Germany. The German-manufactured MS-LFTR 'kits' will be shipped to India where the India-based Calcutta LFTR Export system integrator will assemble, fuel and license for export each MS LFTR power generation system.

The Indian integrated MS-LFTR power generators will be licensed and exported to one global owner / operator – SA LFTR Energy LLC.

SA LFTR Energy will take delivery of each MS-LFTR and deploy it underground. MS-LFTRs will be deployed in a reinforced watertight concrete shell extending down 60 meters below the surface with some 15 meters of concrete crown and earthworks above the power generator, in co-location with its municipal power grid customer.

Each MS-LFTR will be integrated with a matching hybrid desalination system that will use the power generator's waste heat to purify seawater for sales to the municipalities in SA.

All MS-LFTRs will be started up with low-enriched uranium and/or spent nuclear fuel acquired from other nuclear power producers. All MS-LFTRs will also be fueled from thorium purchased from India initially, and later augmented by thorium purchased from SA mining interests. Each generation of MS-LFTRs will use identical inventories of spare parts, tools, and sub-systems.

All MS-LFTRs will be managed, operated, and maintained by means of identical operations rules and procedures developed by the LFTR Energy group in consultation with the AERB (India) and the IAEA (UN). All operations of each installation are conducted by the LFTR Guild -- a paramilitary organization of career professionals that are continuously trained and under scrutiny at all times. The standardized, qualitative practices and skill-sets of these professionals maintain the highest reliability and accountability of any nuclear facility save that of the U.S. nuclear navy after which the LFTR Guild.

MS-LFTR technicians are responsible for the 'care and feeding' of a highly specialized new family of energy technologies only just commencing their harnessed evolution. The rules and procedures that dictate MS-LFTR success radically differ from those of all other nuclear energy endeavors. MS-LFTR requires the cultivation of a unique scientific and operational culture – equally as unforgiving and demanding as the pioneering U.S. nuclear submarine propulsion efforts that have delivered more than 5,400 ship years of consistent and safe operation without a nuclear incident or accident.

As the MS-LFTR power generator is evolved by its designers, manufacturers, and integrators, periodic upgrades for all currently operating and on-order LFTR power generators will be developed and implemented. All SA IPP power-engineering personnel must be qualified and certified on each upgrade before it is implemented and put in service in their area of operations.

Environmentalists Attack Against All Forms Of Nuclear Technology With Their Usual Weapons -- Ignorance And Fear Of The Resultant Unknown

DDT Ban An Indictment of Environmental Superstition

Rachel Carson admitted frankly that she wrote "The Silent Spring" as if it were a novel. This sensational exposé swung public opinion against DDT in the U.S. and most other parts of the world. (Kemm, K., 2010)

Spraying DDT was summarily greeted by hysteria from environmentalists, who described killing mosquitoes as "disrupting the food chain." As New York's Green Party literature declared after Rachel Carson published, "These mosquito-borne diseases only kill the old and people whose health is already poor."

Dr. William J. Darby, who reviewed "The Silent Spring" for Chemical & Engineering News, on 1 Oct 1962 upon its publication, summed up his reaction to the book:

> "*The responsible scientist should read this book to understand the ignorance of those writing on the subject and the educational task that lies ahead…*"

It turns out that few people listened to Dr. Darby.

William Ruckelshaus, administrator of the U.S. Environmental Protection Agency who made the ultimate decision to ban DDT in 1972, was a member of the Environmental Defense Fund. The **40 million excess malaria deaths** that occurred in the next 40 years were the direct result of this scientifically unfounded decision.

DDT is the only effective agent against the anopheline mosquito. DDT kills mosquitoes. Malaria is transmitted to humans via mosquito bites. According to U.N. estimates, malaria kills one child every 30 seconds and more than a million people each year. These facts eventually did prompt some (but not all) health regulators to belatedly reconsider…after a few decades.

The World Health Organization's Dr. Arata Kochi, announcing the official end of the DDT ban on 15 September 2006, said that in this field, politics usually prevailed, but that the "*WHO are now going to take a stand on the science and the data, and are going to recommend DDT once again as the front line of defence against malaria*."

In South Africa, the most developed nation on the continent, the incidence of malaria had been kept very low (below 10,000 cases annually) by the careful use of DDT. But in 1996 environmentalist pressure convinced program directors to cease using DDT. One of the worst epidemics in the country's history ensued, with almost 62,000 cases in the year 2000.

Shortly after this peak, South Africa reintroduced DDT. In one year, malaria cases plummeted by 80 percent. Still, vestigial superstition hangs on – *in the U.S. DDT is still banned to this day*.

Nuclear Radiation Scares

> *There is a general assumption that all nuclear radiation is bad for people. This is not true. A very interesting case came to light 25 years ago in Taiwan when somebody discovered unusual radioactive activity in the wall of a block of flats. Every rumor and claim about the scare was then investigated. It turned out that 17,000 flats with 10,000 residents in more than 180 buildings were exhibiting unusually high levels of nuclear radiation.*

> *Investigations showed that some radioactive steel had been accidentally melted into other steel to manufacture the steer reinforcing bars used to construct these buildings. So for some 20 years, the residents had been living in 'radioactive' flats. The authorities feared the worst and examined all the residents thoroughly.*
>
> *They discovered something astounding – only 3.4% exhibited the cancer that was evident in the general population. Hereditary abnormalities in the children born and living in these flats were found to be at a very low percentage. Overall, the people in the 'radioactive' flats were found to be much healthier than the general population.*
>
> *The total sample size was 200,000 person years – so the data's reliability was considered quite significant. For the inhabitants of these flats, the extra radioactivity that they had been living with impacted them like vitamins. It is not true that small amounts of nuclear radiation are bad for people.* (Klemm, K., 2010, May 21)

These findings were published in the ***Journal of American Physicians and Surgeons*** in 2004. As one researcher phrased it, exposure to high levels of background radiation had apparently bestowed upon residents "an effective immunity from cancer."

> *In order to avoid any possible charge of negligence, regulatory bodies around the world have adopted what is called a "linear-no-threshold" or "no safe dose" standard for radiation safety.*
>
> *This says, quite simply, that because huge doses of radiation—the kind you might get from standing in the same room with a spent fuel rod—can cause illness or cancer, we must assume that even the smallest doses will have the same effect on a smaller scale. It's exactly the same as saying that because jumping off a 10-story building will break every bone in your body, stepping off a one-foot curb will also cause some minor damage.*
>
> *So far there have been zero fatalities or adverse health effects from radiation exposure at Fukushima. All the damage has been from depression, despair and even suicide among the 100,000 people who have been evacuated from their homes within a 12-mile radius*. (Tucker, W., "Fukushima and the Future of Nuclear Power," WSJ 6 Mar 2012.)
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> …
>
> *"...LNT was first accepted in 1958 and 1959 by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP) as a philosophical basis for radiological protection, stating outright that "Linearity has been assumed primarily for purposes of simplicity, and there may or may not be a threshold dose". The Soviet, Czechoslovakian and Egyptian delegations to UNSCEAR strongly advocated the LNT assumption in the 1950's and 60's and used it as a basis for recommendation of an immediate cessation of nuclear test explosions. It was a Cold War issue.*
>
> *...LNT is not established science, it's established policy. You need to go back and read the primary documents, review the actual data, read Hermann Mueller's letters from 1946 and why he chose to ignore certain studies, understand the math of risk analysis, understand the Cold War environment under which LNT was adopted. The job of science is to understand. The job of ideology is to coerce. The people of Japan are not being hysterical, they're being afraid because we told them to be.*
>
> *Risk is relative and only relative. Anyone reading this has a risk of developing cancer by age 70 of about 1 in 5. A risk of developing heart disease of about 1 in 3. A risk of dying in an auto accident of about 1 in 300. A risk of developing cancer from a*

radiation dose of 100 rem (1 Sv) of about 1 in 100. A risk of developing cancer from a radiation dose of 10 rem (0.01 Sv) of about 1 in 1,000,000. A risk of getting food poisoning during forced evacuation of about 1 in 1000. A risk of dying from lost medical care during forced evacuation of about 1 in 600. The risk of dying from depression, suicide or alcoholism in the 20 years following a forced evacuation from a serious disaster of about 1 in 100.

If you have an overall risk of 1 in 100 of dying from several causes, then adding a risk of one in a million does not change that risk at all. You would be insane to focus on that 1 in a 1,000,000 risk, but that's what we are doing in this case. That is all this discussion is about. Not about the real risks that exist from doses above 10 rem/yr (11.5 microSv/hr) that we need to address and to clean-up in those areas around Fukushima, but about the vanishingly-small risks from less than 10 rem/yr (11.5 microSv/hr).

"LNT forced the U.S. to spend about $200 billion since 1970 to save 100 virtual lives as modeled by LNT.

"We don't generally spend $2 billion dollars to save a life, but we do when it comes to radiation, and Japan can't afford this. It will hurt many more people to waste this money and this effort protecting against nothing when so many real dangers to the people of Japan exist from the tsunami devastation itself and the actual hot zones around Fukushima.

"This is not an academic exercise. Just ask the thousands of evacuees recently told by the Belarus government that, oops, we made a mistake, there wasn't really any risk and you can go back to your homes.

"No matter that a generation of their lives were destroyed, that about 10,000 died from suicide, depression and alcoholism because the fear was far more devastating than the event itself, using even the most pessimistic pro-LNT estimates.

"During the first year after the Chernobyl accident, the average dose to inhabitants in Northern Europe was 4.5 mrem (0.045 mSv), i.e., less than 2% of the average global annual natural dose 240 mrem/yr (2.4 mSv/year). This was not worth destroying these people's lives.

"And it is exactly the same as eating a bag of potato chips a day.

"So it's all about LNT, the Linear No-Threshold Dose hypothesis, a supposition that all radiation is deadly and there is no dose below which harmful effects will not occur. Double the dose, double the cancers.

"Of course, this isn't true.

"No matter what you feel about the corporate arrogance and lack of Government oversight that led Tepco to ignore warnings from the U.S. and the IAEA for 20 years, they did properly evacuate to 50 km immediately, told everyone not to eat anything from that region for 3 months while iodine-131 decayed away, and mapped out the dose contours of >10 rem/yr (>0.1 Sv/yr), 5-10 rem/yr (0.05-0.1 Sv/yr), 1-5 rem/yr (0.01-0.05 Sv/yr), and <1 rem/yr (<0.01 Sv/yr). Now they need to clean-up the >10 rem/yr (>0.1 Sv/yr) area as quickly as possible (we can do this, it's going to cost on the order of $50 billion), provide each evacuee with a small alarming dosimeter pin that can be set at 2 or 5 mrem/hr, runs on a watch battery and comes with an easy-to-understand app (this will cost less than $20 million), repatriate anyone that wants to return, show that any foods grown outside the >10 rem/yr (>0.1 Sv/yr) area is safe (there's only a few foods that bioconcentrate Cs or Sr, don't grow those), while rebuilding the infrastructure that

> *was destroyed by the tsunami and quake. And listen to the international community when we tell you you're not prepared for something like this.* (Conca, J., 16 March 2012)

The Increased Focus On Safety Problems Inherent In The Pressurized Water Reactor Design

> *The single most volatile aspect of current nuclear reactors is the pressurized water. In the 441 boiling light-water, pressurized light-water, and heavy-water reactors worldwide, water serves as both the reactor's coolant and neutron moderator. Fission heat causes water to boil, either directly in the core or in a steam generator that drives a turbine. In the core, water is maintained at a high pressure to raise its boiling temperature. The explosive pressures involved (up to 160 atmospheres) are contained by a highly engineered system of expensive piping and containment vessels collectively named the 'pressure boundary.'*
>
> *This 'pressure boundary' is the ultimate line of defense – a massive, expensive containment building surrounding the reactor, designed to withstand any explosive calamity and prevent the out-of-control release of radioactive materials.* (Moir & Hargraves, 2010)
>
> *Water, used as the reactor's coolant and neutron moderator, is pressurized up to 3,000 pounds per square inch, has to be controlled inside a 9-inch thick nuclear-grade steel containment shield.* (Sorensen, K, 2009 July 29)

Lloyd's 360º Insight's "Sustainable energy security" points out that 'Energy production and sources of drinkable water are intimately linked. Their interdependence, coupled with increasing shortages in some parts of the world, poses a major global dilemma.

Energy is essential for obtaining drinkable water while water is a prerequisite for major sources of energy production.

Energy production accounts for approximately 39% of all water withdrawals in the U.S. and 31% in the EU.

Contamination of underground and surface fresh water from energy generation worsens this impact. With energy production forecast to grow by approximately 45% over the next two decades, water consumption for energy production will more than double over the same period.

***Nuclear Power Plants manage waste heat with flowing water or evaporative cooling towers. A typical 1 GW coal or nuclear plant requires 600,000 gallons per minute of river water, or it will evaporate 20,000 gallons per minute of water – all in order to remove dangerous, unwanted waste heat*.**

Diagram 4. - Current Cooling of PWRs – (Hargraves, 2004)

> *The Boogeyman of early light water reactors, the 'China Syndrome' Meltdown, is simply designed out of today's nuclear fuels. If the temperature rises beyond the intended levels, the fuel expands, reducing the effective area for neutron absorption – the temperature coefficient of reactivity is negative, suppressing fission and ultimately dropping the temperature. In the LFTR, thermal expansion of the liquid fuel reduces the core's reactivity. This instant response enables the LFTR to follow the conditions of changing electricity demand (load), without operator intervention, responding automatically with increases or decreases in power production.*
>
> *The LFTR also has a second tier of defense – a freeze plug made of frozen salt that is cooled by a fan to keep it at a lower temperature than the salt's melting point. If the core's temperature rises beyond a critical point, the frozen salt plug melts, and the liquid fuel in the core is immediate evacuated, pouring into a sub-critical geometry in a catch basin. This is only possible because the fuel is a molten salt liquid. The freeze-plug safety feature was used in Alvin Weinberg's 1965 Molten Salt Reactor Experiment (the MSRE).*

Water must be kept under high pressure to stay fluid so that it can remove heat.

Molten fluoride salts in general are excellent coolants, with a 25% higher volumetric heat capacity than pressurized water and nearly 5 times that of liquid sodium. The molten salt coolant in the MS-LFTR melts at 450˚ C., operates at 705˚ C., and it remains at atmospheric pressure unless its temperature finally reaches its boiling point at 1,400˚ C.

Molten salt's neutral pressure drops the cost and the size of the MS-LFTR structure – there are no billion-dollar containment vessel requirements. There is no pressure explosion possible. A leak in a transport line will drop the molten salt into the LFTR's heat loss tanks, where its diffusion stops fissile reactivity, enabling the salt to cool off and freeze into a solid.

PINT-safe features of the LFTR

The MS-LFTR's 700˚ C. molten salts make possible gravity-based safety functions that are **P**assive, **I**nherent, and **N**on-**T**amperable (**PINT-safe**): Freeze valves, for example can be utilized in critical locations – such as in draining the fuel to the heat sink storage tanks. An ordinary section of pipe can be used – by exposing it to a cooling stream of environmental gas so that it creates a frozen plug of salt, blocking the molten salt flow and thus forming a valve.

The freeze valve can be configured so that when the molten salt rises above a certain specified temperature; the heat overrides the freeze plug's cooling, melts the plug and opens the valve. The cooling drive, an electric fan for example, will cease to cool the freeze valve when there is a power failure, releasing the valve to melt and perform its safety function. This safety function is again, PINT-safe. (Gat and Dodds, 1997)

One of the current requirements of the U.S. Nuclear Regulatory Commission (NRC) for certification of a new nuclear plant design is that in the event of a complete electricity outage, the reactor remains at least stable for several days if it is not automatically deactivated.

This formidable NRC 'safety ideal' for the reactor to automatically deactivate is only possible if the reactor fuel is melted in liquid molten salt. (Moir & Hargraves, 2010)

The accidents at Three Mile Island in Pennsylvania and at Chernobyl in the Ukraine inspired the environmentalists to raise many alarms, casting serious doubt on nuclear energy. Generation III reactors are now built with passive safety features where gravity and/or the laws of thermodynamics take over to stop any possible runaway reactions, leakage or any other kinds of accidents.

The "China Syndrome's" meltdown scenario is not possible -- the MS-LFTR's uranium / thorium fuel is already melted into a liquid fluoride fuel salt.

The benefits of the total passive safety of MS-LFTRs to international security are obvious:

- If the MS-LFTR loses electrical power, the freeze plug, no longer cooled, warms up, melts the frozen salt, and drains the fuel to heat loss tanks.
- If the MS-LFTR temperature rises, the freeze plug warms up beyond the system's electric cooling capability, melts the frozen salt, and again drains the fuel salt to heat loss tanks.

The molten salt cools down from its operating temperature of 705˚ C. to its freezing point of 450˚ C. When it is frozen solid and capable of being handled, the frozen fuel salt has chemically and physically imprisoned the fissile fuel in solid fluoride salt, sequestered in heat-loss tanks sixty meters underground with at least 15 meters of concrete and earthworks overhead. These features make it inconvenient, time consuming as well as extremely expensive for terrorists to ever benefit from attacking MS-LFTRs.

Because of the architecture, and the MS-LFTR system underground design, security costs at these power stations will be dramatically reduced from those of LWRs. A cheaper energy supply improves security the world over. (Bryan, 2009)

Making Uranium Fissile Fuel.

In the solid-state uranium fuel cycle, used by light water, heavy water, and pressurized water reactors, natural uranium is mined, and then must undergo an expensive and complex chemical process to increase its content of the fissile ^{235}U. The mined uranium (tri-uranium octa-oxide (U_3O_8), the famous "*yellowcake*") is taken under security to a conversion factory where it is converted into the gas, uranium hexafluoride, or UF_6.

The ^{235}U isotope as it is found in nature only amounts to .711% of the total mass of U_3O_8. ^{235}U must reach 85% concentration in amounts of 10 kg or more before it can be used to create a nuclear weapon.

The radioactive gas must still be enriched up to 3%-5% $^{235}UF_6$, in order to sustain the nuclear reaction necessary to make sufficient heat to generate electricity. The enriched 3%-5% $^{235}UF_6$ must next be transferred to a fuel fabrication facility, where it is solidified again, then crafted into ceramic-coated pellets. The pellets are piled into long zirconium alloy tubes that are then welded shut. These zirconium covered 'fuel rods' are finally bundled into 17 X 17 "fuel rod assemblies" that are then shipped under heavy security to the reactor.

Thorium doesn't require any conversion. It is found in nature as thorium dioxide (ThO_2) with no isotopic content. It can be readily transported to the solid-state fuel fabrication facility to be purified, then made into pellets, rods and bundles, a straightforward albeit expensive process.

When used in the MS-LFTR, ThO_2 can be put directly into the reactor without fuel processing. With the liquid molten salt fuel cycle, an enormous infrastructure of expensive manufacturing and risky transport requiring the associated heavy security, is entirely eliminated. Besides the obvious cost reduction over solid-state fuel-cycle reactors, the benefits to national and global security are clear. (Bryan, 2009)

<u>6 kg of Thorium in LFTR Can Produce the Same Energy as That Produced by 300 kg of Enriched Uranium in a Pressurized Water Reactor -- Why?</u>

One Reason: Uranium fuel rod assemblies must be removed from the reactor after LESS than 5% of their potential energy is consumed.

Why so little? Noble gases such as krypton and xenon build up, along with other fission products from the nuclear reactions. These fission products accumulate and absorb neutrons, "poisoning" the chain reaction, and ultimately stopping it. In addition, the solid uranium fuel pellets do not transfer heat efficiently – the heat generated from a nuclear reaction in the pellet accumulates and create severe temperature differences in the pellet, -- some spots at 200˚, others up to 2000˚ -- which stresses the uranium and distorts it. Radiation damage from the same nuclear fission breaks down the covalent bonds of the uranium dioxide fuel, and fission by-products disrupt their solid lattice structure. Fission heat and radiation so damage the fuel rod assemblies structurally they can no longer sustain new nuclear reactions.

The spent fuel in these 30-foot-long assemblies is hot as well as intensely radioactive – these assemblies must be handled by remotely operated equipment, and must be stored under ten feet of water in cooling pools for at least five years before the spent fuel rods can be extracted, safely cut up and then transferred to dry cask storage.

Replacing fuel rods involves an elaborate, expensive shutdown of the reactor plant once every 18 months. About a third of the fuel rods are removed and placed in local cooling pools, while the rest can be swapped around to other positions in the core. (Moir & Hargraves, 2010)

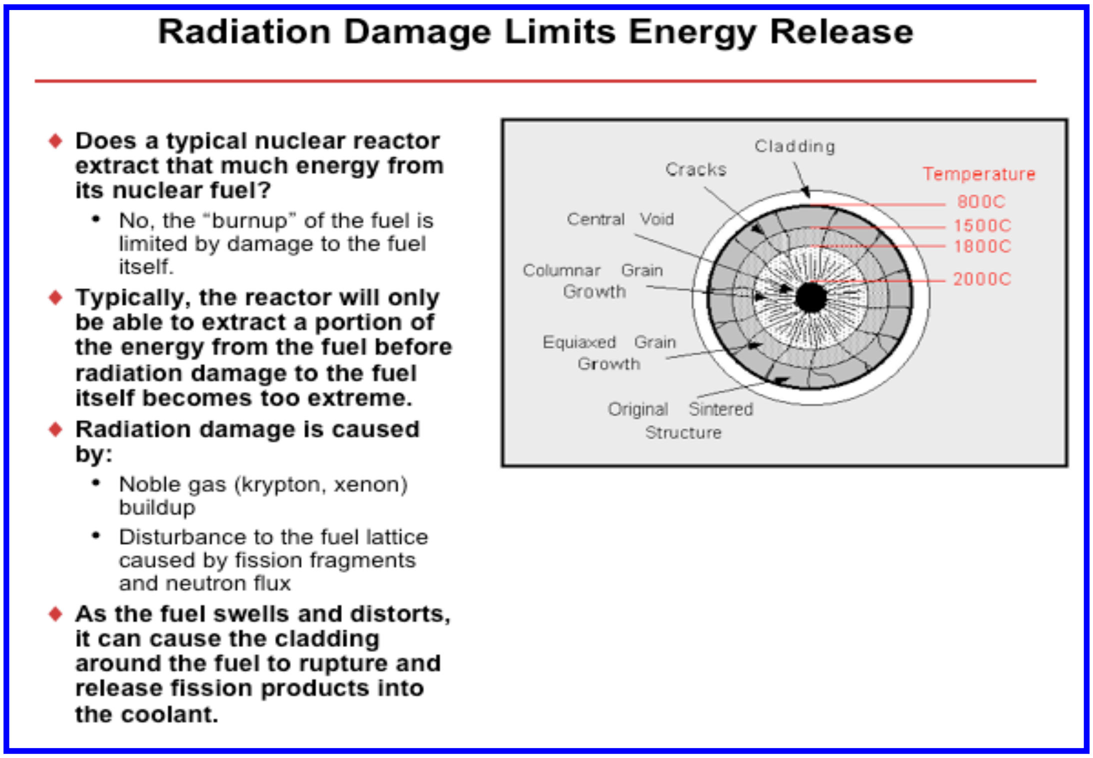


Diagram # 5 - Solid Fuel Limitations in a Nuclear Reactor *(Sorensen, 2009)*

Liquid molten salt reactors differ fundamentally from solid-state uranium fuel reactors. With the MS-LFTR, the fuel can be readily processed on line to remove or add specific components.

This processing differs from solid fuel reprocessing where the entire fuel elements must be removed from the reactor core, treated in a reprocessing facility -- and then remanufactured into fuel elements before being brought back and reinserted into the reactor.

On the other hand, processing the entire MSR fuel complement consists of continuous removal of gases in a small on-line processing of a selected side stream over a period of days in the MS-LFTR plant itself while the MS-LFTR continues to operate.

In the MS-LFTR the fuel salt itself is the coolant, circulating outside the reactor core, to an external heat exchanger, which carries the heat away from all radioactivity with a secondary molten salt loop that powers the electricity generator.

External cooling and on-line processing are additional, unique safety features of the MS-LFTR.

MS-LFTRs have high negative reactivity temperature coefficient, which expands the fluid salts upon heating, expelling fuel from the core, thereby slowing down the fuel's reactivity.

MS-LFTRs can operate with no externally operated controls, constrained by the speed of sound propagation and low excess reactivity. Safety is passive, inherent and tamper-proof.

The MS-LFTR's ultimate shutdown is simply accomplished as gravity drains the fuel from the critical configuration in the core to the guaranteed sub-critical configurations in drain tanks. (Gat & Dodds, 1997)

The molten salts specified for MS-LFTRs are chemically stable – they do not react rapidly with moisture or air. They are chemically inert, precluding accidents from chemical interaction.

With molten salts there is no fire or explosion risk.

Oak Ridge National Laboratory's 1965 Molten Salt Reactor Experiment ("MSRE") showed that high-nickel alloys, combined with adequate oxidation potential balancing of the salt can result in low corrosion over the long term of the reactor's structure.

The MS-LFTR's molten salts remain stable up to high temperatures at low pressures. The inherently efficient operation of the MS-LFTR's molten salt environment makes no extreme safety demands on the structure's materials.

Such a liquid system operating at low pressure eliminates the storage of potential energy as well as any risk of an energetic burst or explosion. (Gat & Dodds, 1997)

> *Liquid fluoride molten salt solutions are familiar chemistry: Millions of metric tons of liquid fluoride salts circulate through hundreds of aluminum chemical plants daily, and all uranium that is used in today's reactors has to pass in and out of a fluoride form in order to be enriched.*
>
> *The LFTR technology is in many ways a straightforward extension of contemporary nuclear chemical engineering*. (Moir & Hargraves, 2010)

Nuclear waste in the form of fuel rods that have had only 3% to 5% of their fuel burned up by PWRs has been accumulating since 1977, when the U.S. President Carter's Administration cancelled all reprocessing of spent nuclear fuel.

Today this build up of spent fuel rods has become more urgent, because in 2009 the Obama administration ruled that Yucca Mountain Repository is no longer considered an option for the site designated to permanently isolate geologically existing U.S. nuclear waste.

One component of a long-range plan that would keep the growing "Nuclear Waste" problem from getting worse would be to mobilize nuclear technology that creates far less waste that is far less toxic.

The MS-LFTR answers that need.

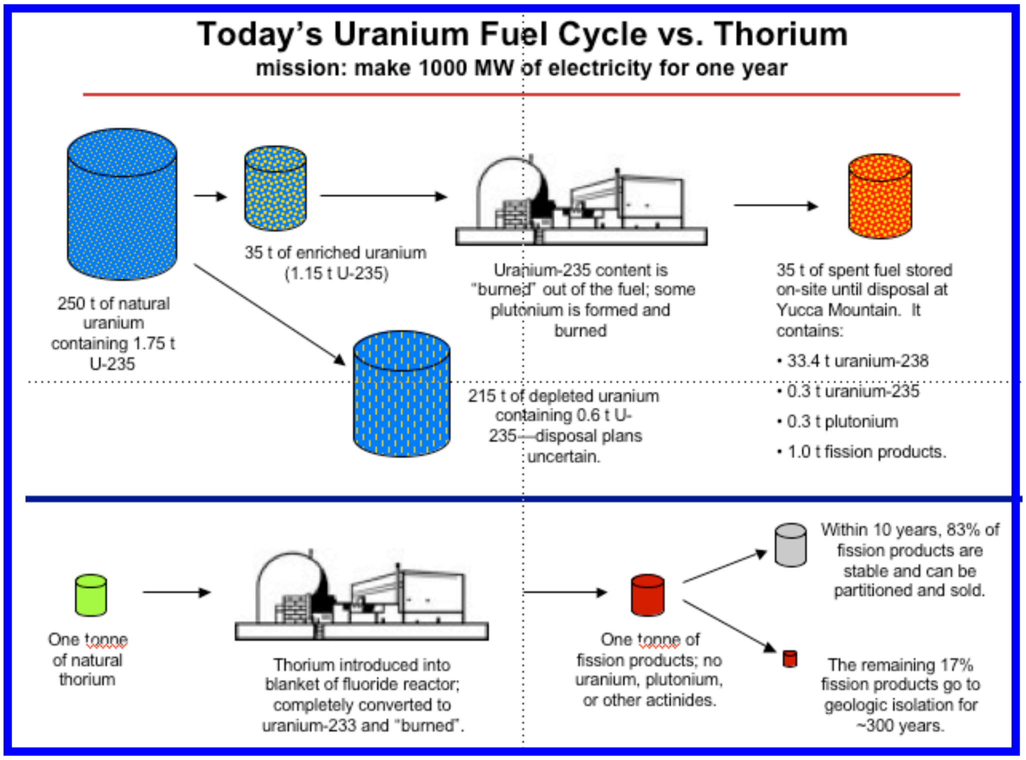


Diagram # 6. Uranium vs Thorium Resources Required to Produce a 1000MW Yr of Electricity (Sorensen, 2009)

Using a molten salt LFTR instead of pressurized or light water or heavy water solid uranium fueled reactors could neutralize the nuclear waste storage issue.

The relatively small amount of waste produced in MS-LFTRs requires a few hundred years of isolated storage versus the few hundred thousand years for the waste generated by the uranium / plutonium fuel cycle.

Thorium- and uranium-fueled reactors produce essentially the same fission products, whose radiotoxicity is displayed in blue in the following diagram below depicting radiation dosage versus time.

The purple line is actinide waste from a light-water reactor, and the green line is actinide waste from a MS-LFTR.

After 300 years the radiotoxicity of the thorium fuel cycle is 10,000 times less than that of the uranium/plutonium fuel cycle waste.

This is because the mass number of Thorium-232 is six (6) units less than that of Uranium-238, thus requiring MANY more neutron captures to transmute Thorium up to the first Transuranic.

The LFTR can also be utilized to consume fissile material extracted from light-water reactor waste as the fissile startup "trigger" to initiate the thorium / uranium fuel generation. (Moir and Hargraves, 2010)

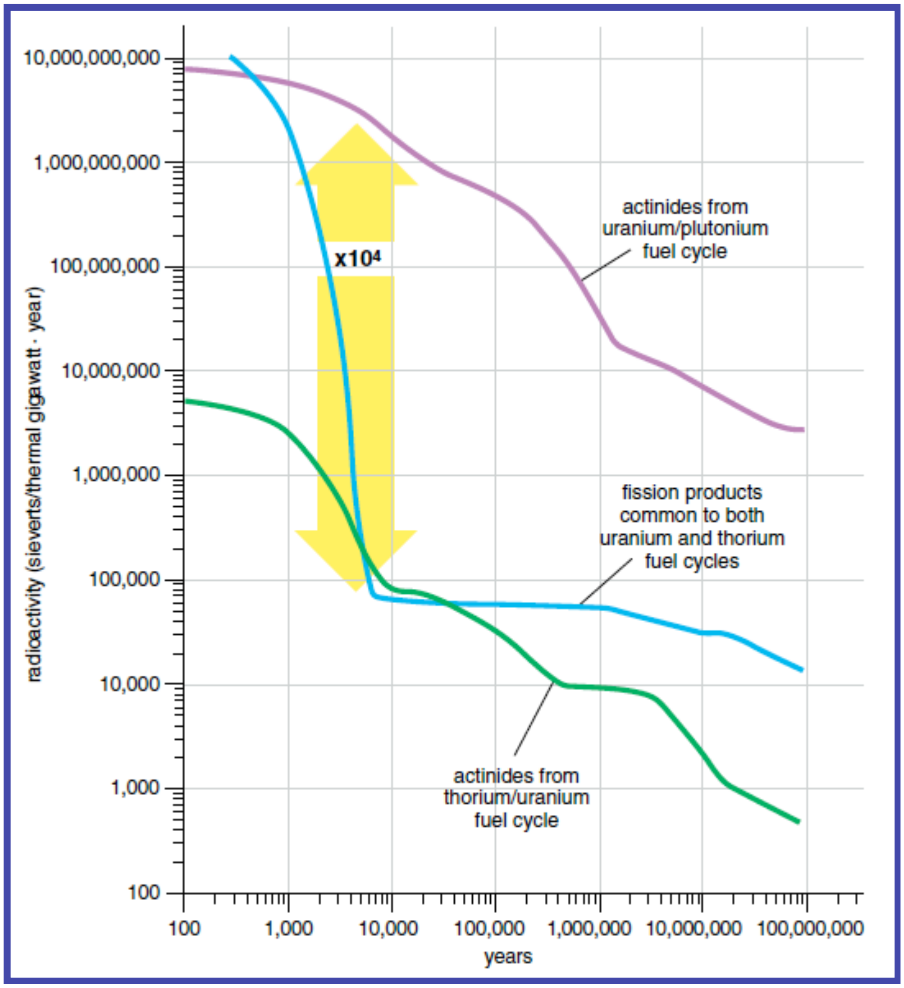


Diagram # 7, Radiation Dose Versus Time. (Moir and Hargraves, 2010)

Tritium Control

A lot of fear and trepidation has been expressed about Tritium contamination in the U.S., where the Vermont Yankee nuclear plant was threatened with revocation of its operating license (after 25 years' safe operation) from claims of traces of tritium leaking into VT's ground water.

Tritium (^3H, also known as hydrogen-3) is a radioactive isotope of hydrogen.. Its nucleus contains one proton and two neutrons, whereas the nucleus of Protium (by far the most abundant hydrogen isotope) contains one proton and no neutrons. When molten salt reactors were initially developed, conversion of heat to electricity was accomplished using the steam (Rankine) cycle. In the MSR, tritium can be generated as a fission product and may be generated by coolant activation. Unlike solid-fuel reactors, tritium is highly mobile in the molten salt and will diffuse through the high temperature heat exchangers into the working fluid of the power cycle. Isotopically separating tritiated water from non-tritiated water in the steam cycle is difficult and expensive.

Helium-cooled high-temperature reactors produce tritium from nuclear reactions with ^{3}He and from leaking fuel; consequently, these reactors are equipped with well-functioning systems to remove the tritium from the helium. Tritium management approaches are discussed in Ch. 16 on Tritium, of the APEX Interim Report, November 1999. (Forsberg, Peterson, Zhao, 2004)

> *Managing tritium, which can diffuse through hot metal walls of heat exchangers, was always a significant part of ORNL's work on these MSR systems. Their choice of intermediate coolant salt (NaF-$NaBF_2$) was made in part to trap tritium and in general, while certainly not a 'show-stopper,' tritium has always been a concern.*
>
> *It should also be mentioned that gas Brayton cycle turbines have been determined to be the best fit for molten salt reactors. These gas Brayton turbines offer still further advantages for tritium management because any tritium making it to the gas is far easier to remove than from steam.* (LeBlanc, D., 2010)

Tritium control in MS-LFTRs can be addressed by using a coolant that can chemically trap tritium for removal -- a mix of sodium fluoride and sodium tetrafluoroborate (NaF / $NaBF_4$) has proven most successful in this regard.

Additionally, however, integrating a closed gas Brayton power cycle with the LFTR, instead of the Rankine steam cycle, largely eliminates tritium control issues. There is no water with which tritium can combine without steam. Tritium is easily removed from the gas Brayton cycle in the cold parts of the cycle.

Moving to Brayton from Rankine is also a high performance, low-cost option based on demonstrated inexpensive methods to remove tritium gas or tritiated water from inert gases. The gas Brayton cycle raises the MS-LFTR's heat-to-electricity conversion efficiency, making more power from the MS-LFTR's operating temperatures.

"Nuclear Waste" – A False Premise

At the MELOX plant in suburban Marcoule, France, the biggest task is recycling spent fuel from La Hague. When depleted fuel rods come out of reactors, they're shipped to La Hague for reprocessing. After cooling down a few years, the uranium and plutonium is removed. The plutonium comes to Marcoule, where it is mixed with scrap left over from uranium enrichment. The ^{235}U content of this scrap is very low, so it is mixed together with the plutonium and the result, "Mixed Oxide Fuel" or MOX for short, is fed to twenty French reactors as their fuel, plus ten German ones and two Swiss reactors – everything is used, *there is no waste*.

It should be noted that the plutonium that comes out of a commercial reactor, embedded in spent fuel rods, cannot be used to make a bomb. There are four (4) plutonium isotopes -- ^{239}Pu, ^{240}Pu, ^{241}PU and ^{242}Pu. Only ^{239}Pu can sustain a chain reaction properly for a bomb. Other forms of Pu are contaminating, while ^{241}Pu is too highly radioactive, fissiling far too fast to control well enough to make a bomb. However, all four isotopes sustain fission quite well in a MOX reactor.

What this means of course is that the Carter Administration ended all nuclear reprocessing in the U.S. in the '70s on the mistaken premise that the plutonium extracted from these reactors could be used by someone to make a bomb. The Carter Administration portrayed itself as saving the world from nuclear proliferation.

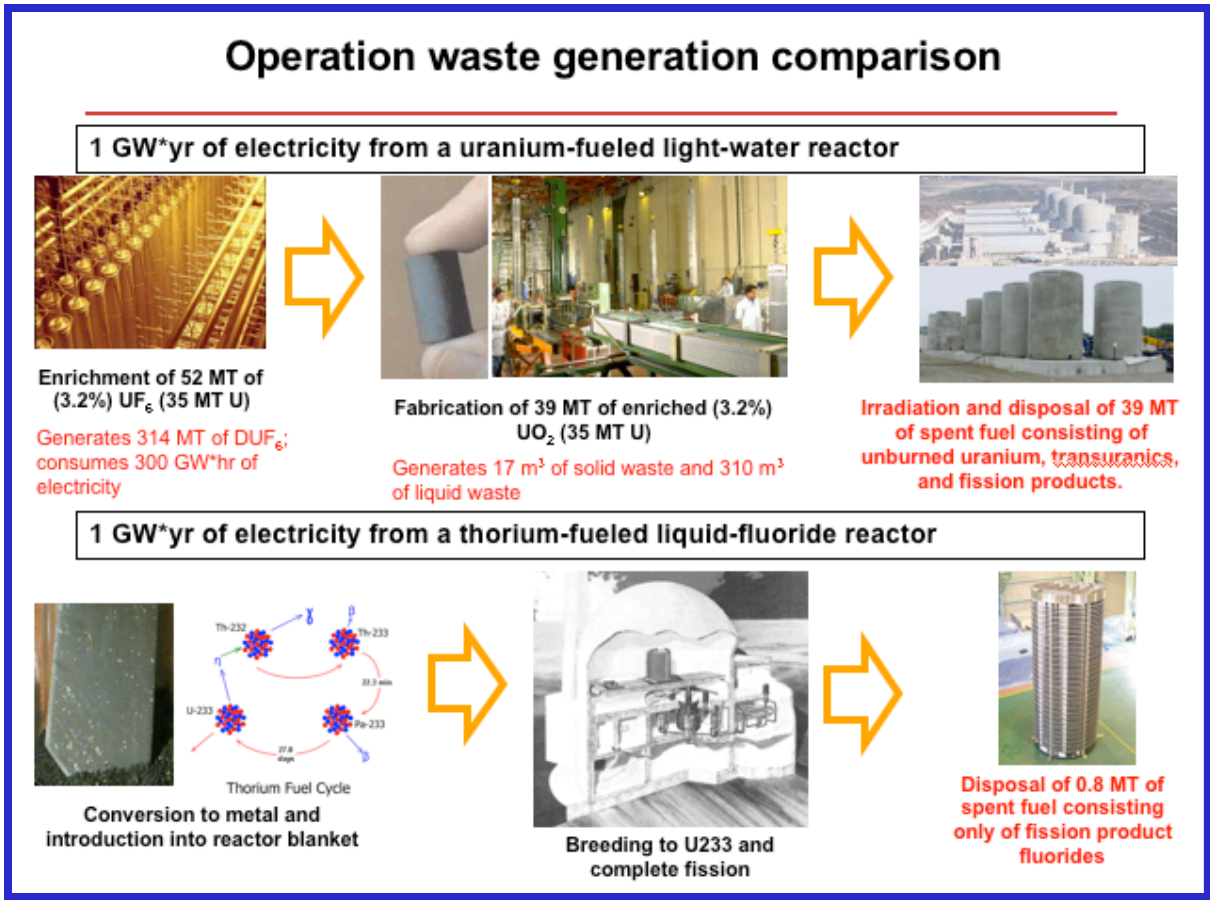
In fact, this premise is *wrong*, because extracted plutonium from these power reactors *cannot* be used to build a bomb.

The North Koreans, at a terrible expense, developed and built a special kind of fast spectrum reactor that breeds only ^{239}Pu in order to get enough appropriately fissile Pu to build their bombs.

The U.S. forced this growing national problem of "nuclear radioactive waste" on itself – mandating the storage of spent 30-foot fuel rods in cooling pools until their heat abates, then transferring the rods into some specially-isolated, highly stable (Yucca Mountain) repository to decay for 10,000 years -- based on a totally *false* premise, serving *no* purpose.

We can contrast this with the French Nuclear Model: The French are able to store all the high-level wastes from 30 years of 59 nuclear reactors that provide 78% of their electricity while generating EUROS 3 billion in annual exports within a *single* room in La Hague the size of a basketball court. There's still a lot of space left in there. (Tucker, W. Pp. 357, 370-371, 2009)

> *Nuclear Waste in Uranium Fuel Cycles vs. LFTR's Fuel Cycle*
>
> *Long-lived waste reduction is also an area in which the LFTR can perform admirably. The long-term radiotoxicity in LWR spent fuel is dominated by transuranic elements.*
>
> *The much lower production rate along with the ability to return any produced TRUs to the core or simply keep them in the salt for the core lifetime can convert a "million year" problem of spent fuel into a "300 year" issue of simply allowing for the majority of fission products to decay.*
>
> *However, the costs involved do lead to a consideration of what level of effort is employed versus the effect on net power costs. That optimization would appear well worth any modest expense to virtually eliminate transuranics going to waste.*
>
> *The lack of transuranics also has the additional benefits of removing any remote concerns over accidental criticality events such as how LWR spent fuel can become critical if stored in too high a density in the presence of water.*
>
> *In terms of long-term radiotoxicity of wastes, these converter designs also perform remarkably well. All transuranics remain in the salt during operation and will not reach high concentrations due to the very large cross sections for fission and/or absorption. At the end of 30 years there is only about 1000 kg present.*
>
> *It is prudent to remove these transuranics in a one-time-only process for recycling into the next core salt. If this is done and a typical processing loss of 0.1% is assumed, this represents a mere 1 kg of TRUs going to waste over 30 years which is about a 10,000 fold improvement over the LWR's once-through fuel cycle.*
>
> *This yields an average of 30 grams per GW(e)-year of TRU waste -- better than most pure Th-^{233}U MSR designs that process smaller TRU amounts much more frequently.*
>
> *Note that removing and reusing TRUs does not involve isolating plutonium.*
>
> *Liquid Bismuth Reductive Extraction can be used for this process, resulting in plutonium (Pu) remaining with Am, Cm, Cf, and zirconium.* (LeBlanc, D., 2010)

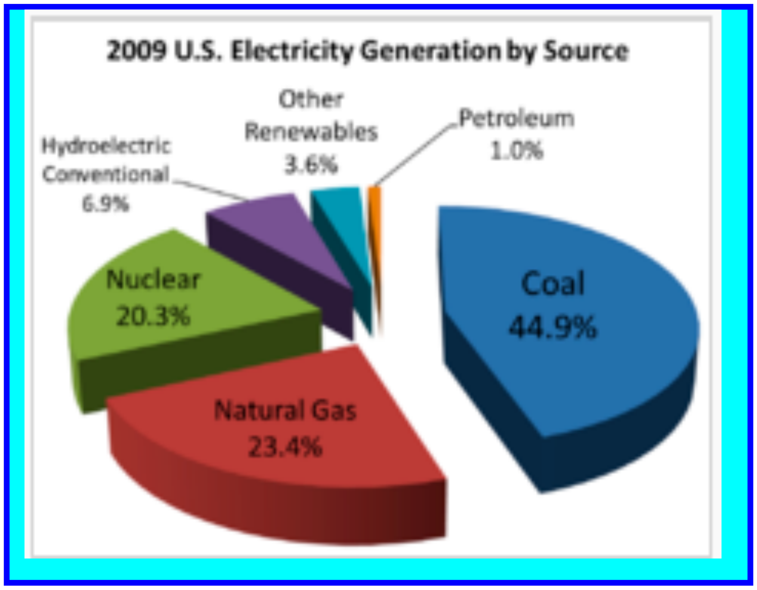


Thorium mining calculation based on data from **ORNL/TM-6474: Environmental Assessment of Alternate FBR Fuels: Thorium**

Diagram # 8. Waste generation from 1000 MW*yr thorium-fueled liquid-fluoride reactor

(Sorensen, 2009)

Relative Safety of Electricity Generation Alternatives



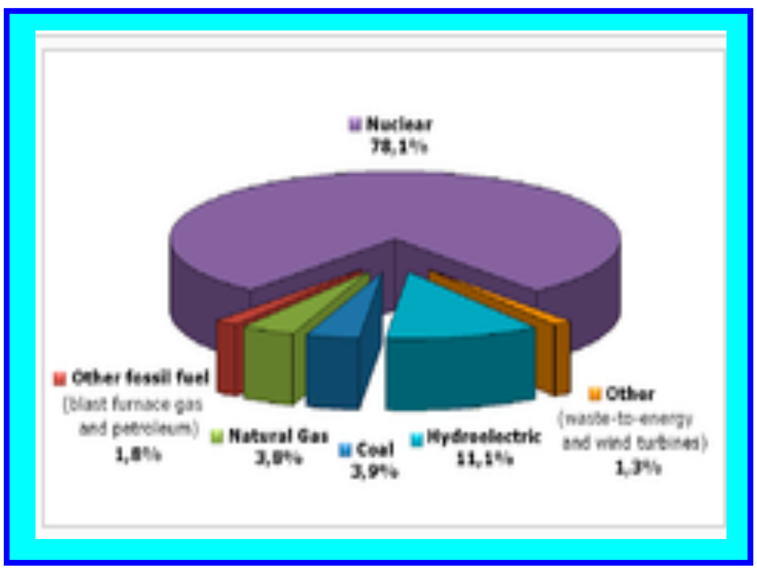


Diagram # 9 - 2009 U.S. and French Electricity Generated by Source (Wikipedia, "Electricity Generation")

7.2.1 Number of severe accidents

In Fig. 7.2.1 the number of severe (≥ 5 fatalities) accidents associated with the various energy sources (coal, oil, natural gas, LPG, hydro power and nuclear) is shown for the two time periods examined. For comparison, the results from [Fritzsche, 1989] are shown.

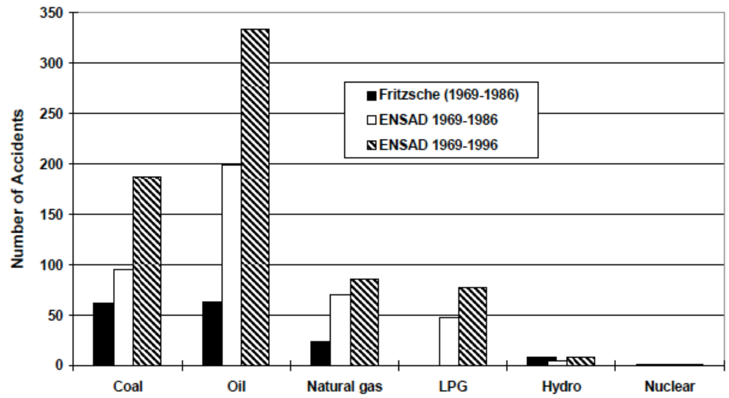


Fig. 7.2.1 Comparison of severe (≥ 5 fatalities) accident records: Total number of events in examined time periods according to ENSAD and [Fritzsche, 1989].

In Fig. 7.2.6 the **immediate** fatality rates per "gigawatt(electric)-year" (denoted as GWe*a in figures)[2] are given for different energy options. The values estimated in [Chadwick, ed., 1991] are provided for comparison.

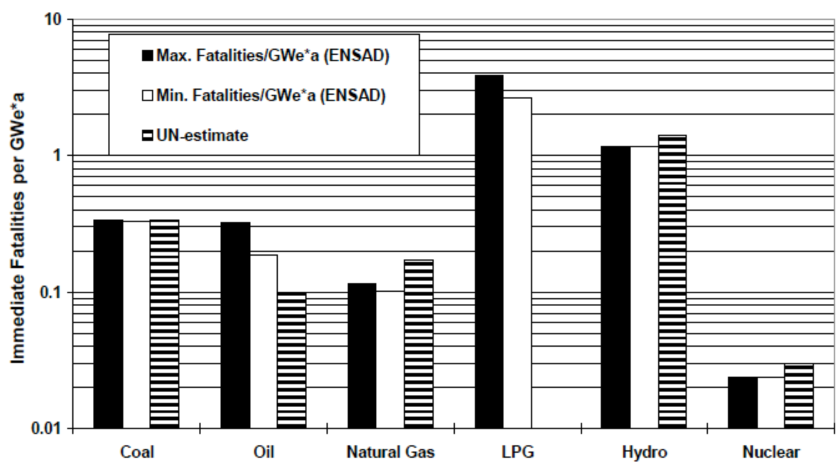


Fig. 7.2.6 Comparison of severe (≥ 5 fatalities) accident records: **Immediate** fatality rates in the period 1969-1986 according to ENSAD and [Chadwick, ed., 1991].

Diagram #10 – "Severe Accidents in the Energy Sector (Hirschberg S., Spiekerman G., and Dones, R. (November 1998)

The World Waking Up To Thorium Power

Energy has become more expensive in the last few decades. More demand has exhausted supply. Governments have heavily taxed existing energy supplies. One of the 'unforeseen consequences' of this new energy scarcity and expense has been the re-emergence of a "second nuclear era" dreamed of by Alvin M. Weinberg, a father of both the Light Water Reactor and the Molten Salt Reactor.

> *Norway*
>
> *Safer, cleaner nuclear power is a step closer to reality after Norway's state-owned energy company, Statkraft, this week announced plans to investigate building a thorium-fuelled nuclear reactor. Statkraft (which translates to "state power") announced an alliance with regional power providers Vattenfall in Sweden, and Fortum in Finland, along with Norwegian energy investment company, Scatec AS, in a bid to produce the thorium-fuelled plant.*
>
> *Thorium (Th-232), has been hailed as a 'greener' alternative to traditional nuclear fuels, such as uranium and plutonium, because thorium is incapable of producing the runaway chain reaction that in a uranium-fuelled reactor can cause a catastrophic meltdown. Thorium reactors also produce only a tiny fraction of the hazardous waste created by uranium-fuelled reactors.*
>
> *Statkraft, which is already Europe's second largest producer of renewable energy - mainly thanks to Norway's abundant hydroelectric resources - has recently made thorium-fuelled nuclear power a point of serious consideration. "It would be a sin of omission not to consider it," said Bård Mikkelsen, CEO of Statkraft.*
>
> *To date, thorium has seen only limited application. However a reactor fuelled entirely by thorium would have significant advantages over conventional uranium or mixed-fuel reactors. Besides their inability to go critical and their low generation of waste, thorium-fuelled reactors don't suffer from the same proliferation risks as uranium reactors. This is because the thorium by-products cannot be re-processed into weapons-grade material. Thorium also doesn't require enrichment before use as a nuclear fuel, and thorium is an abundant natural resource, with vast deposits in Australia, the United States, India and Norway. Another advantage of thorium-powered reactors is they can be used to 'burn' highly radioactive waste by-products from conventional uranium-fuelled power plants.*
>
> *Over the past eight months, there has been a substantial rise in public support for thorium reactors in Norway.*
>
> *In June 2006, polls showed 80 per cent of the population were completely opposed to any form of nuclear technology.*
>
> *Then in February 2007, the same percentage were in favour of investigating thorium reactors as a potential energy source.*
>
> *"It is an absolutely incredible surprise that it has been possible to turn around the population in a country, just by quietly campaigning and explaining the benefits of the technology," said Egil Lillestøl, a nuclear physicist at the University of Bergen.*
>
> *Lillestøl is a keen supporter of the technology used in thorium-fuelled reactors..*
>
> *Statkraft is the third Norwegian company to express interest in thorium reactors this year; Thor Energi and Bergen Energi, have both applied for government licenses to build thorium power generation plants.* (Williams, L., 2007, May 24)

South Korea

South Korea is set to become a major world nuclear energy country, exporting technology.

Nuclear energy is a strategic priority for South Korea and capacity is planned to increase by 56% to 27.3 GWe by 2020, and then to 35 GWe by 2030.

Today 20 reactors provide almost 40% of South Korea's electricity from 17.7 GWe of plant.

Power demand in the Republic of Korea (South Korea) has increased by more than 9% per year since 1990 but slowed to 2.8% per year projected 2006-10 and 2.5% per year to 2020.

Per capita consumption in 2006 was 7700 kWh, up from 850 kWh/yr in 1980.

Over the last three decades, South Korea has enjoyed 8.6% average annual growth in GDP, which has caused corresponding growth in electricity consumption - from 33 billion kWh in 1980 to 371 billion kWh in 2006.

Gross power production in 2007 was 439 billion kWh.

Nuclear power costs are low in Korea: For 2008 KHNP reports 39 won per kWh (3¢/kWh), compared with coal 53.7 won, LNG 143.6 won and hydro 162 won. KHNP average price to KEPCO is 68.3 won (5¢) per kWh. (Nuclear Power In South Korea," http://www.world-nuclear.org/info/default.aspx?id=348&terms=Nuclear%20Power%20in%20South%20Korea, World Nuclear Association, Updated 23 April 2010)

On 28 January 2011, the Chinese Academy of Sciences announced "the future of advanced nuclear fission energy --, thorium-based molten salt reactor system project was officially launched. The scientific goal is to use 20 years to develop a new generation of nuclear energy systems, to fully trial all the technology, then file and control all intellectual property rights. The Chinese Academy of Sciences announcement explicitly states that "*the PRC plans to develop and control intellectual property around thorium for its own benefit.* This will enable China to firmly grasp the lifeline of energy in its own hands," stated the Wen Hui Bao report.

"…In the innovation race, China is thinking long term—and big. Its goal isn't just to tinker with foreign technology. It plans to supplant It…" 2 Feb 11, WSJ

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