On the Practical Use of Lightbridge Thorium-based Fuels for Nuclear Power Generation

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This document has been written to clarify some of the key questions that are often raised about Lightbridge Corporation's thorium-based nuclear fuel designs. For a more technical overview of the Lightbridge thorium-based fuel designs please see the Lightbridge Technical Fact Sheet[1].

BENEFITS OF THORIUM-BASED NUCLEAR FUELS

The primary benefits of utilizing thorium in a nuclear fuel are safe, clean energy production, enhanced proliferation resistance, and potential fuel cycle cost savings.

The Lightbridge thorium-based nuclear fuel utilizes a seed and blanket fuel assembly. In the seed and blanket design, the central region of the fuel assembly (seed) can be separated from the outer (blanket) region wherein the thorium-uranium oxide mixture resides. This differs from conventional fuel assemblies that are comprised of all uranium oxide fuel rods that are not designed to be separated during normal operation.

The seed and blanket design offers several benefits including more efficient utilization of the thorium component and decreased used fuel inventory. The Lightbridge Technical Fact Sheet, available on the Lightbridge corporate website, discusses this design in more detail.

SAFETY OF LIGHTBRIDGE'S THORIUM-BASED FUEL

The Lightbridge thorium-based fuel allows for safe operation of nuclear power plants during normal and off normal operation. The thorium-based fuel has improved thermo-physical properties compared to uranium fuels, which provide more reliable fuel performance during reactor operation. The lower operating temperature and higher thermal conductivity of thorium fuel leads to increased safety margins during off-normal and accident scenarios.

Thorium's improved properties provide a more stable vehicle for storage of used fuel as well. Thorium dioxide will not oxidize in water like uranium dioxide, and therefore retains a larger percentage of the radioactive isotopes even in the breach of a storage container.

THORIUM AS A NUCLEAR FUEL

In a nuclear reactor, "fuel" refers to a composition containing fissile material, which are isotopes that can be fissioned (split) after absorbing a neutron. Thorium itself does not fission in a light water reactor. However, through a series of nuclear reactions (neutron absorption and decay) it can be converted into a type of uranium that does fission (U-233). Naturally occurring thorium is almost entirely composed of the isotope Th-232, the necessary isotope for U-233 production.

So, by itself, thorium is not a nuclear fuel and cannot be used on its own to produce power in a nuclear reactor. Some other source of neutrons must be used to convert the Th-232 into U-233. The most

[1] Available Online [6/2010]: http://ltbridge.com/assets/Lightbridge_Technical_Fact_Sheet.pdf

common fissile isotope used in nuclear reactors today is U-235. Any fissile isotope can be used in a reactor to provide neutrons for thorium conversion. The Lightbridge seed and blanket design is capable of using uranium (enriched in U-235) or Pu-239 (recovered from used fuel or surplus nuclear weapons material) to both provide power generation and the neutrons necessary for conversion of thorium into uranium. This production of fuel *in situ* means that less fissionable material per megawatt-day has to be loaded into fresh fuel (megawatt-day is a measurement of electrical energy). For instance, if 20% of the energy from fission comes from the U-233 created in the Lightbridge fuel, the fresh fuel fissile loading per megawatt-day can be reduced by almost a proportionate amount. Because natural uranium ore contains ~0.7% (by mass) of U-235, extensive effort goes into increasing the percentage of U-235, through a process called enrichment, in order to have enough fissionable material to run a light water reactor. Therefore, a reduction in the U-235 requirements of a fuel lead to a reduction in the amount of natural uranium that has to be mined. Lightbridge's seed and blanket fuel can save up to 10% of natural uranium per reactor-year compared to conventional uranium fuel in a once-through fuel cycle system.

ENHANCED PROLIFERATION RESISTANCE

Nuclear proliferation refers to the spread of special nuclear material (material that can be used to make a nuclear weapon) to nations or organizations that are not recognized as Weapons States under the Treaty on the Non-Proliferation of Nuclear Weapons.

All nuclear fuels and nuclear reactors have an inherent nuclear proliferation risk. In order to have a sustainable nuclear chain reaction (necessary for power production) one must use fissionable material. A nuclear weapon uses these same materials in much higher concentrations to achieve an uncontrolled nuclear chain reaction. To reiterate, there is always some proliferation risk present in any kind of nuclear power production system. There are several methods to enhance the proliferation resistance of a nuclear fuel cycle which are classified as intrinsic and extrinsic barriers. Intrinsic barriers are inherent to the physical properties of the fuel and the technical capabilities required to produce a weapon from the fuel. Extrinsic barriers (also called institutional barriers) include a wide array of nuclear safeguards such as material control and accountability and numerous international agreements[2].

Measurement of the proliferation resistance of a nuclear fuel cycle has a large subjective component. Several analytical methods have been developed which attempt to quantify proliferation resistance; however, there is no agreed value that exists to objectively compare two different nuclear fuel cycles.

Lightbridge's thorium-based nuclear fuel provides enhanced proliferation resistance through several intrinsic barriers (related to the properties of the fuel and the technology required to produce a weapon). A few are listed here:

[2] For further reading about various international safeguards and practices, we recommend reviewing the "Safeguards & Verifications" fact sheets available from the International Atomic Energy Agency. Available Online [6/2010]: http://www.iaea.org/Publications/Factsheets/index.html

Utilization of low-enriched uranium. The international community has determined that uranium enriched to less than 20% by weight of U-235 is insufficient for producing a nuclear weapon. All nuclear fuel used for commercial power production is low-enriched, including the thorium-based fuel being developed by Lightbridge.

Reduced quantity and quality of plutonium in the used fuel. Plutonium is a byproduct of the nuclear fission process. The isotope Pu-239 is a weapons-useable isotope and is the primary concern with regards to making a plutonium weapon. Other isotopes of plutonium actually hinder the ability to make a successful plutonium weapon (e.g. Pu-238 & Pu-240).

Lightbridge's thorium-based fuels generate less overall plutonium with a higher composition of Pu-238 and Pu-240 than conventional uranium fuel. The isotopic mixture of the plutonium in the Lightbridge used fuel is not readily suitable for weapons production, and construction of a weapon with such material by a rogue nation or sub-national group would present additional technological barriers and likely would not be successful.

Once-through fuel cycle does not require reprocessing. There are two main reasons to reprocess (i.e. recycle) used nuclear fuel; recovery of fissionable material for further use and separation of waste material to simplify ultimate disposal. Some thorium fuels have been designed to use reprocessing to recover the U-233 that is created in the fuel to use in subsequent fuel cycles. The Lightbridge thorium-based fuel is different in that it is designed as a "once-through" fuel cycle, for which reprocessing is not required on the used thorium fuel to take advantage of the energy content of the U-233. The unique design of the Lightbridge thorium fuel allows it to utilize a significant amount of the generated U-233 before the fuel leaves the reactor, reducing the residual energy value of the used fuel.

Other intrinsic barriers are employed to further reduce the attractiveness of reprocessing Lightbridge's thorium-based fuel. The thorium-bearing fuel rods are denatured (i.e. diluted) with uranium oxide prior to going into the reactor. The presence of this uranium makes chemical separation of fissile U-233 from the used fuel impossible as reprocessing facilities cannot chemically separate various isotopes of the same element from one another. Further, a high fraction of U-232 in the uranium material contained in used thorium-based fuel rods is another major technological barrier to handling, transporting, and use of separated uranium material. As stated in a fact sheet by the Institute for Energy and Environmental Research and Physicians for Social Responsibility[3]:

> The radiation-dose-related problems associated with separating U-233 from U-238 and then handling the U-233 would be considerable and more complex than enriching natural uranium for the purpose of bomb making. … Therefore fabricating fuel with U-233 is very expensive and difficult.

[3] Available Online [6/2010]: http://www.ieer.org/fctsheet/thorium2009factsheet.pdf

In other words, trying to make a weapon from Lightbridge's used thorium fuel would be more difficult both with regard to technological capability and economic feasibility than making a weapon from material produced in a conventional fuel enrichment facility.

Intrinsic barriers by themselves are not enough to prevent proliferation and must be coupled with the myriad extrinsic barriers that are utilized across the globe. Lightbridge's seed and blanket thorium-based fuel provides enhanced proliferation resistance compared to conventional fuels through increasing the number and magnitude of the inherent proliferation barriers in the fuel cycle.

REDUCTION IN FUEL CYCLE WASTE AND USED FUEL

The design of Lightbridge's thorium-based nuclear fuel allows for drastic reductions in the generation of used nuclear fuel (sometimes referred to as "waste"). Because the blanket rods reside in the reactor core for extended time, the volume of used fuel that has to be disposed of is reduced by up to 40% compared to conventional reactor fuel. The United States is currently undergoing an extensive review process to develop a safe, long-term solution to manage our used nuclear fuel stockpiles[4]. No matter what solution the country decides to pursue, a 40% reduction in the volume of waste generated represents a significant move in the right direction towards reducing the overall stockpile. This reduction in used fuel generation is particularly relevant to emerging nuclear nations which may not have the means to store their own used fuel and have to contract services from other nations to do so.

REDUCED LONG-TERM RADIOACTIVITY IN THE USED FUEL

When nuclear fuel assemblies come out of a reactor, they are "hot" with respect to temperature and radioactivity, and are stored in a pool of water for approximately 6-10 years or longer while the heat generated from this radioactivity decreases. When the used fuel has "cooled" thermally, it is still quite "hot" with regard to radioactivity. The radioactive isotopes in the used fuel can be grouped into two categories based on their half-lives, short-lived (< 300 years) and long-lived (> 500 years) isotopes. The short-lived isotopes constitute the majority of the used fuels radioactivity for the first 300 years until those isotopes decay away and the long-lived isotopes become the major radioactivity contributor. The bulk of the long-lived isotopes are actinide elements such as neptunium, plutonium, and americium among others. These elements have very long half-lives and remain radioactive for thousands of years. The generation of these elements is a consequence of irradiating U-238 (the bulk of uranium fuel) in a reactor. Because the Lightbridge thorium-based fuel replaces a significant portion of uranium with thorium, fewer of these long-lived isotopes are generated in the reactor and have to be disposed of. Some have argued that the radioactivity associated with thorium itself is deadly and contributes a significant portion of the radio-toxicity of used thorium-based fuels. This is incorrect. Thorium, as mentioned, is a naturally occurring isotope and decays much slower than the other long-lived isotopes in used fuel and the

[4] "Secretary Chu Announces Blue Ribbon Commission on America's Nuclear Future". US DOE. Available Online [6/2010]: http://www.energy.gov/news/8584.htm

radiation it gives off (so-called α-particles) travels only a few centimeters in air and can be stopped by human skin or a sheet of paper. This type of radiation is extremely harmful if ingested; however, the likelihood of ingesting α-emitting elements from used thorium fuel is no greater than ingesting uranium from conventional fuel. Thorium-dioxide is more stable than uranium-dioxide with respect to further oxidation in the presence of water. Therefore, it could be argued that the likelihood of ingesting material from thorium-based fuels is lower than conventional fuel because the fuel would not disperse as easily in the event of a storage system failure.

MINING OF THORIUM

The quantity and radio-toxicity of waste produced from mining thorium ore is two orders of magnitude lower than the mining of uranium ores. For more information on mining and milling of thorium please review section 5.1 of the International Atomic Energy Agency's TECDOC-1450[5].

[5] "Thorium Fuel Cycle – Potential Benefits and Challenges". May 2005, International Atomic Energy Agency. Available Online [6/2010]: www-pub.iaea.org/mtcd/publications/pdf/te_1450_web.pdf