# Technical Fact Sheet

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### 1. Is the fuel cycle cost higher for Lightbridge’s seed and blanket fuel?

No. The goal of Lightbridge’s seed and blanket technology is to provide increased proliferation resistance and at the same or slightly lower fuel cost.

### 2. Does Lightbridge’s seed and blanket fuel technology eliminate the need for uranium? Would we run out of thorium?

1. Lightbridge’s seed and blanket fuel does not eliminate the need for uranium. Uranium enriched to less than 20 % is used in both the seed and blanket fuel rods[1].
    a. Uranium ore (yellowcake) requirements are reduced by about 10% compared to conventional uranium fueling.
2. Thorium is at least three times more plentiful than uranium and the quantity of thorium used in out fuel designs is only about a fifth as much as uranium requirements, so we would not run out of thorium.

### 3. Lightbridge calls its fuel design a “Seed and Blanket” fuel assembly. What is a “seed and blanket” fuel assembly and what are its advantages?

1. Uranium fuel assemblies commonly used in reactors today employ an array of fuel rods that are all replaced as a group and each fuel rod is virtually identical to all the other fuel rods in the reactor. In contrast, Lightbridge’s fuel assembly is comprised of two different kinds of fuel rods that are each clustered into a separate subassembly within each fuel assembly: an outer subassembly called the blanket and a central subassembly called the seed that is inserted into the blanket subassembly.
    i. The blanket subassembly employs thorium-uranium oxide fuel rods
    ii. The seed subassembly employs uranium-zirconium metal fuel rods.
2. Excess neutrons from the seed subassembly interact with the surrounding thorium blanket rods, producing the fissile isotope U-233. U-233 is subsequently burned inside the fuel rods to produce power in the blanket rods.
3. The Seed and Blanket design has a number of significant advantages:
    i. Thorium lasts longer in a reactor than uranium. Because the seed and blanket subassemblies are separate, the seed subassembly can be replaced as needed for continued reactor operation, while the blanket subassembly can be put back into the reactor for additional cycles of operation to maximize the production and power

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[1] Uranium is mined mostly for its fissile (U-235) content, which is present in low concentration (the U-235 content is ~0.71%, and the rest is the fertile isotope U-238). Thorium is a metal that contains no fissile isotopes. In Thorium Power’s fuel designs, the uranium is enriched to less than <20%, meaning that it contains less than 20% U-235 isotope. The significance of the 20% figure is that authorities, including the International Atomic Energy Agency and US government consider uranium enriched to over 20% to be highly enriched uranium, which can potentially be used in weapons. At no point in the manufacture or use of fuel with Thorium Power’s designs is the enrichment level of uranium above 20%.

generation from the U-233 produced from the thorium blanket rods (in other words, the purpose is to extract as much energy out of the thorium in the blanket as practical):

        1. Typically, the seed operates for either three or four and a half years (12- or 18-month operating cycle, respectively) before being discharged.
        2. The blanket operates for nine years before being discharged.

    ii. The blanket and seed subassemblies can be separately optimized to improve fuel cycle economics and operating margins[2,3].

### 4. The seed is made of uranium-zirconium metal. Has metallic fuel used in the nuclear industry? Why do you use metallic fuel in the seed?

1. Similar uranium-zirconium fuel has been extensively used in reactors that power Russian icebreakers. Lightbridge has a comprehensive database on the performance of this fuel.
2. Lightbridge's metallic fuel has increased thermal margins[4] that are necessary to accommodate the higher power in the seed region.
3. Thoria (thorium-uranium dioxide or $(Th,U)O_2$) fuel is used in the blankets. This type of fuel has been successfully irradiated in a number of pressurized water reactors (PWRs), including the Shippingport reactor in the US.

### 5. What modifications are required to the reactor to use Lightbridge's seed and blanket fuel?

1. No modifications are required to the reactor itself.
    i. Lightbridge's seed and blanket fuel is designed to be a direct replacement for the conventional uranium fuel that is commonly used in reactors today.
    ii. Core operating parameters, margins, and the results of safety and accident analyses are within the bounds of conventional uranium cores.
2. Refueling equipment and spent and fresh fuel storage racks must be modified to accommodate the seed and blanket fuel.

### 6. How has Lightbridge's fuel been designed to make it infeasible to make a bomb from the used fuel?

1. Lightbridge's seed and blanket fuel technology uses a "once through" fuel cycle (no reprocessing)[5].

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[2] Compared to a conventional uranium fuel assembly, thorium rods in the blanket subassembly may be more closely spaced, enhancing the conversion of a fertile thorium isotope Th-232 to a fissile uranium isotope U-233. Compared to a conventional uranium fuel assembly, the seed subassembly contains a larger percentage of coolant. This helps to more completely consume the U-235 in the seed rods, and helps to accommodate the higher power production in the seed subassembly.

[3] Thermal margin is the difference between fuel temperatures during operation and licensing limits. Thermal margin is necessary to accommodate various unusual and accident conditions without damaging fuel and/or to meet various licensing criteria.

[4] Conventional uranium fuel is in the form of uranium dioxide ($UO_2$), which is a ceramic. Characteristic of ceramic materials, uranium fuel is a comparatively poor conductor of heat (has a low thermal conductivity), resulting in comparatively high fuel operating temperatures. Metallic fuel is a good conductor of heat (high thermal conductivity), and this results in lower seed temperatures. The transfer of energy from the seed fuel rods to the coolant also is enhanced by the increased heat transfer area of the multi-lobed seed rods, higher coolant flow in the seed region, and improved coolant mixing.

2. Lightbridge's fuel uses low enriched uranium (LEU, uranium enriched to less than 20%). This level of uranium enrichment is accepted by the international community as being below that necessary for nuclear weapons[6].

3. The inherent proliferation resistance of the thorium seed and blanket fuel cycle is, in part, provided by:

   a. A reduction in the amount of plutonium present in the used fuel.[7]

   b. Poorer isotopic composition of the plutonium[8], with respect to weapon fabrication and detonation due to the presence of higher levels of Pu-238[9], Pu-240 and Pu-242 and lower levels of Pu-239 and Pu-241[10] compared to plutonium from conventional uranium fuel.

4. The U-233 produced in the blanket is denatured[11] with low enriched uranium (LEU), which is added to the blanket fuel during fabrication. Chemical reprocessing would be required to recover the uranium in the blanket, and isotopic separation (enrichment) would be needed to increase U-233 concentration for use in weapons.

   a. The blanket fuel must be reprocessed to extract the uranium content. The process for reprocessing thorium is less developed and more difficult than that for reprocessing uranium fuel.

   b. Significant concentrations of U-232 are produced in the blanket. The decay products of U-232 produce highly energetic gamma radiation that makes handling of recovered uranium difficult.

   c. The U-232 would also contaminate enrichment facilities, making enrichment unattractive.

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[5] Typically, fissile material recovered by reprocessing from commercial uranium fuel is not suited for use in nuclear weapons. However, reprocessing is a dual use technology that could be used to extract weapons usable plutonium from used fuel.

[6] LEU must be enriched (using diffusion or centrifugal plant technologies) to produce weapons useable material. Although using almost 20% enriched uranium as feed material would allow weapons material to be produced with less increase in enrichment, the same enrichment technology could be used to produce weapons material from the 4-5% uranium enrichment typically used in pressurized water reactors (PWRs) or from natural uranium. Use of natural uranium is probably the most attractive from a weapons standpoint because of availability and reduced chance of detection, and natural (unenriched) uranium is not used in standard nuclear fuel for PWRs or in Thorium Power's fuel designs.

[7] Plutonium is produced from irradiation of U-238 that is converted into plutonium isotope Pu-239 under irradiation in the reactor core. Although low enriched uranium is used in Thorium Power's seed and blanket fuel, the quantity of uranium present is much lower since thorium replaces most of the U-238 in conventional uranium fuel.

[8] Weapons grade plutonium typically contains > 90% Pu-239; the Pu-239 content of Thorium Power's seed and blanket fuel is < 50%.

[9] Difficulty removing the heat produced by the comparatively high concentrations of heat producing isotopes, specifically Pu-238, increases the difficulty of fabricating a weapon as it becomes difficult to prevent melting.

[10] The high concentration of other plutonium isotopes results in a high spontaneous fission rate, increasing the quantity of fissile material needed and reducing the yield and reliability of weapons.

[11] The U-233 is said to be denatured (not suitable for use in weapons) because if becomes mixed with other isotopes of uranium as the U-233 is produced. The U-233 cannot be chemically separated from the other isotopes of uranium.

## 7. How does Lightbridge's seed and blanket fuel technology affect the amount and radio-toxicity of spent fuel?

1. Lightbridge's seed and blanket fuel technology reduces the amount and long-term radio-toxicity of used (spent) fuel.
    i. Reduces volume of used fuel by almost 50% and the weight of used fuel by about 70% compared to standard uranium fuel[12].
2. Lightbridge's seed and blanket fuel technology reduces the long-term radio-toxicity (after the first 200-300 years) of used fuel by about 90% compared to standard uranium fuel[13].

## 8. How do the material properties of thorium compare with those of uranium?

1. Thorium and conventional uranium fuel are used in a ceramic form (thorium dioxide, $ThO_2$ , and uranium dioxide, $UO_2$)

2. The material properties of $ThO_2$ are better than those of $UO_2$:

    a. The melting temperature of $ThO_2$ is about 500 °C higher

    b. The thermal conductivity[14] of $ThO_2$ is higher

    c. The coefficient of thermal expansion is lower[15]

    d. $ThO_2$ is better able to retain gaseous fissions products[16]

    e. $ThO_2$ is relatively inert, has low solubility, and does not oxidize, unlike $UO_2$ that oxidizes easily to $U_3O_8$, which makes $ThO_2$ more attractive for long-term storage of used fuel and more suitable for direct geological disposal[17]

## 9. U-232 is highly radioactive. Does this require remote handling of any used (spent) fuel material or separated uranium from spent fuel?

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[12] The reductions in weight and volume result directly from the higher burnup and reduced weight of the metallic seed fuel used in the Thorium Power fuel design. The exact volume and weight reduction depends on the whether 12- or 18-month cycles are employed with Thorium Power fuel and on the burnup achieved in the comparison $UO_2$ cycle; the values quoted above are typical.

[13] During the first few hundred years after used fuel is discharged radio-toxicity is dominated by fissions product activity, which is essentially the same for uranium and thorium based fuels. After a few hundred years, most fission products decay away and radio-toxicity is dominated by the long half-life transuranic elements. Lesser amounts of the transuranic elements are produced from thorium fuel resulting in lower long-term radio-toxicity.

[14] The capability of the material to conduct heat. A higher thermal conductivity results in lower fuel temperatures.

[15] So thorium is less susceptible to dimensional changes during accidents that change fuel temperature.

[16] Some of the fission products produced during power production are gaseous. Some of these gaseous fission products are retained within the ceramic fuel, while some are released into the free volume between the fuel pellets and cladding, increasing the internal pressure in this region. Since the internal pressure must be limited to licensed values, fission gas release potentially limits how long the fuel can operate. Fission gas release is an order of magnitude (factor of 10) lower than from $UO_2$ fuel. This facilitates designing fuel for very long periods of operation.

[17] Although $UO_2$, like $ThO_2$, is relatively insoluble, UO2 can oxidize to relatively soluble $U_3O_8$. $ThO_2$ does not oxidize. $ThO_2$ is more attractive for long-term geological disposal were there may be eventual water ingress since $ThO_2$ retains its low solubility.

1. No.  The radioactivity of the used fuel is dominated by fission products, and so the radioactivity of the U-232 has no significant impact and no special handling of spent fuel is required due to the presence of U-232[18].
2. Lightbridge's blanket rods are not reprocessed to recover contained uranium.
3. If the blanket fuel were to be reprocessed, radioactivity from the decay products of U-232 would have a significant impact[19] on material handling.  Remote handling of the reprocessed uranium would be required.  Enrichment facilities, needed to increase the concentration of fissile uranium for use in weapons, would become contaminated.  Weapons made from recovered and enriched material would require heavy shielding and would be comparatively easily detected.  U-232 is a significant barrier to the construction of weapons with uranium recovered from Lightbridge's blanket rods.

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[18] All spent fuel is handled remotely. The U-232 will have no material impact on spent fuel handling or storage.  Dose rates from spent fuel are dominated by fission products and the transuranic elements.  The dose rate one meter from a spent fuel assembly, even after cooling for 10 years, is on the order of 10,000 rem/hr, so the dose from U-232 is a minor contributor.

[19] Reprocessed U-233 from thorium bearing fuels is hard to handle because of the radiation from U-232.  U-232, which is produced from U-233 by the (n,2n) reaction, decays by a series of alpha emissions to Tl-208, which emits a 2.6 MeV gamma that is the primary contributor to the radiation hazard.  Typically, U-233 reprocessed from blanket rods would contain about 4000 ppm U-232. The dose rate from a 5 kg sphere of fully enriched U-233 (about half the minimum critical mass) would be about 50 rem/hr at 0.5 meters. Because of this high level of U-232 and the corresponding radiation, recovered U-233 would require remote handling.