Concept Paper – Hybrid Thorium Reactor (HTR)
TransPower – University of Michigan – General Atomics – Boeing

Project Overview

Transportation Power, Inc. ("TransPower") and the University of Michigan ("UM"), supported by Boeing and General Atomics (GA), seek seed funding to perform an initial feasibility study of a novel Hybrid Thorium Reactor (HTR), which UM computations suggest can generate enormous net power density (NPD) – up to 500 MW/cm of reactor length. The hybrid reactor uses a fusion reaction to generate neutrons that drive a fission reaction in which they transmute Thorium-232 into Uranium- 233, whose fission produces substantial energy. The proposed research will focus on developing three essential components of the reactor and power generation system: (1) a containment mechanism for the fusion plasma based upon innovative Gasdynamic Mirror (GDM) technology; (2) a solid or liquid thorium shell engineered to optimize energy production and heat removal, preventing excessive heat buildup; and (3) a heat transfer mechanism for converting the enormous heat energy produced by the fission reaction to usable electric power.

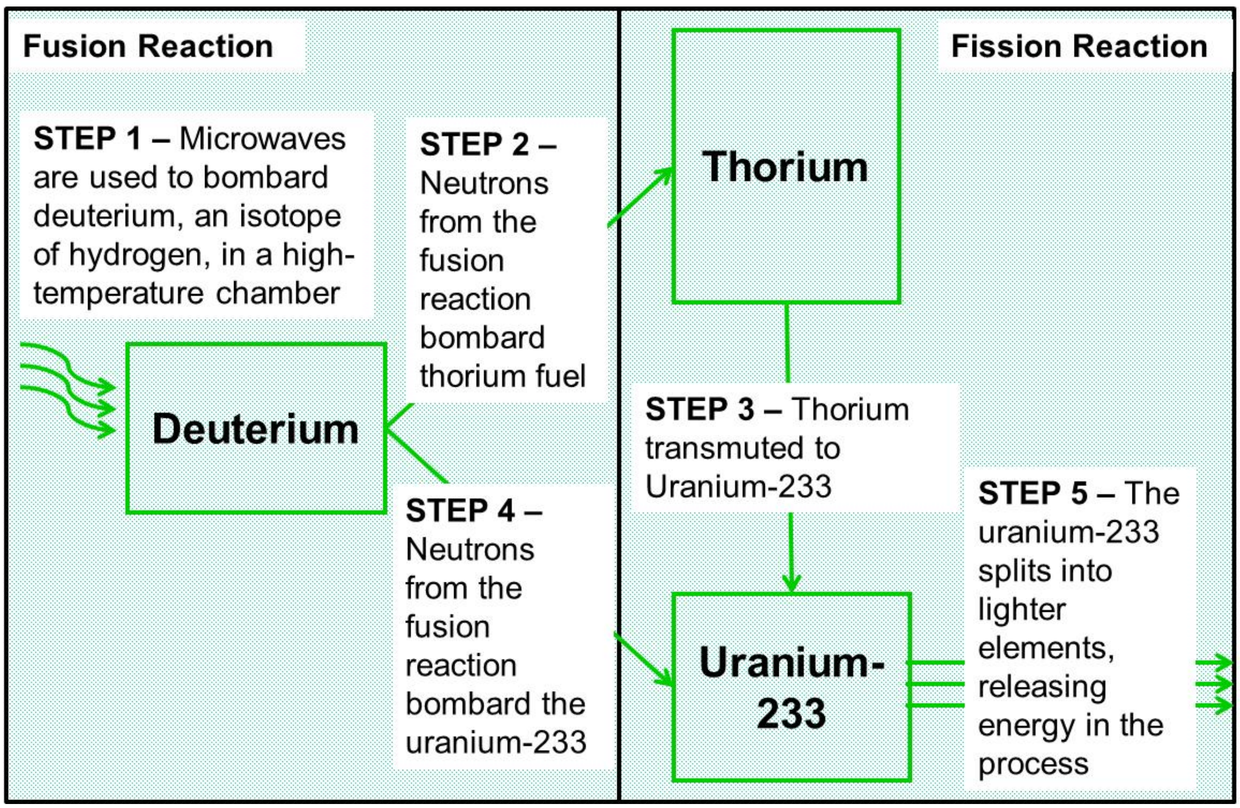

Figure 1. Illustration of Hybrid Thorium Reactor process.

The feasibility of producing energy via the thorium cycle has been established for decades, and working thorium reactors have been built. China, India, and other nations are racing to develop new generations of thorium reactors because such devices, if perfected, will have numerous major advantages over conventional light water reactors that use enriched uranium or plutonium as fuels, which have been the standard since the 1950s. Chief among these are the amazing safety advantages of thorium, based on its atomic stability. Unlike enriched uranium or plutonium, thorium will not "go critical;" the thorium cycle requires an external neutron source and it shuts down if the supply of neutrons is interrupted. This results in the following advantages:

- Thorium reactors cannot produce meltdowns, a present danger with every light water reactor in operation around the world.
- Thorium produces less than 1% of the hazardous nuclear wastes produced by today's light water reactors; in fact thorium reactors can be used to destroy much of the light water reactor nuclear wastes currently stockpiled.
- Thorium cannot be used to produce nuclear weapons, so the risk of nuclear weapons proliferation that presently haunts the nuclear industry can be eliminated if thorium is adopted as the new standard nuclear fuel.
- Since the thorium reaction is inherently stable, thorium reactors will not require many of the expensive safety features or the level of monitoring required by conventional light-water reactors, making them far less expensive to build and operate.

In addition to these advantages, thorium is a naturally-occurring element, unlike plutonium, and is more plentiful than uranium. Proven thorium reserves could meet global energy needs for at least the next 10,000 years. For these reasons, there has recently been a surge of public interest in thorium, particular on the internet. Brooklyn-based Motherboard TV recently produced an extremely favorable documentary on thorium, *The Thorium Dream*, which can be viewed at http://www.motherboard.tv/2011/11/9/motherboard-tv-the-thorium-dream.

The proposed HTR energy system is a critical innovation because it *provides a practical, cost-effective means of generating the neutrons required to sustain the thorium fission cycle.* This neutron production is achieved with nuclear fusion, but with a type of fusion far easier to achieve than using fusion alone to produce usable energy. Use of fusion alone for cost-effective power generation remains an elusive goal because fusion must achieve ten times energy breakeven to be economical on its own. By contrast, when used solely to produce sufficient neutron flux to sustain thorium fission, the fusion reaction needs to achieve only *one-tenth* or less of energy breakeven. This is much closer to present-day capabilities. A prototype GDM (Figure 2) successfully generated plasma at NASA's Marshall Space Flight Center in the late 1990s, and Russian physicists have successfully operated a GDM as a neutron source. Although further research is needed, confidence is high that the GDM can produce the neutrons required to sustain effective thorium fission reactions.

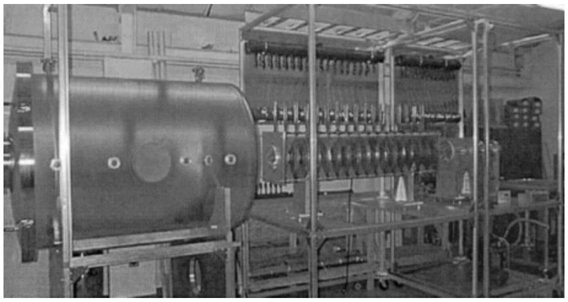

Fig 2. Prototype GDM.

Combining an efficient neutron-generating source such as GDM-fusion with the thorium fission cycle could literally change the world with the energy production and applications that would be enabled. HTR reactors could provide an inexpensive source of clean energy without dependence on fossil fuels or emissions of carbon or criteria pollutants. If the theoretical power density level of 500 MW/cm could be realized, a single reactor the size of a football stadium could meet all of U.S. electricity needs. Achieving even just a fraction of this power density would represent a marked improvement over conventional light water reactors, whose power densities range from just 5 to 25 MW/cm (Figure 3). Compact low-power (1 to 1,000 kW) HTR generators could be produced for a variety of stationary and potentially even mobile power applications. The U.S. could become the world's leading exporter of energy instead of its leading importer, shifting the balance of trade and reinvigorating our economy.

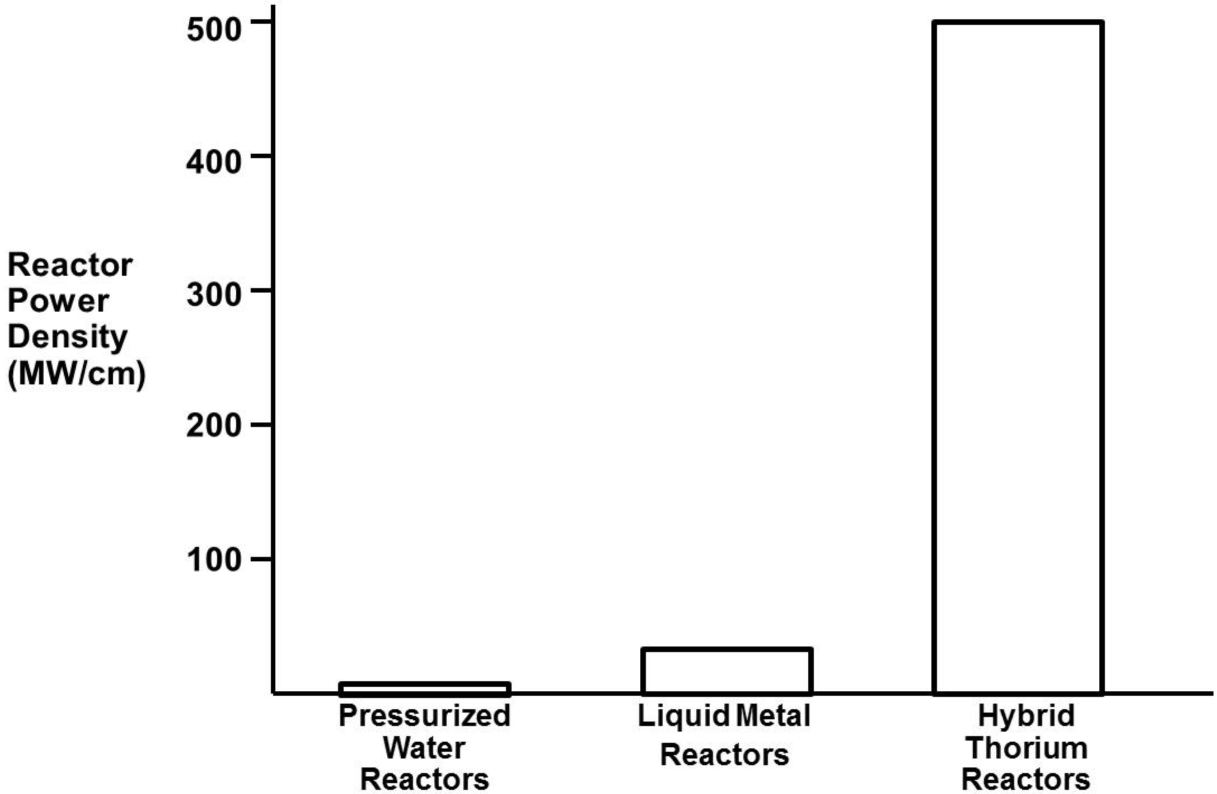

Figure 3. Hybrid thorium power density as compared with conventional nuclear reactors.

In addition to these applications and the many benefits already described, HTR generators could potentially revolutionize the design of long-distance aircraft and spacecraft; in fact molten salt reactors that could use thorium as a fuel were evaluated by the U.S. Government for use in strategic bombers in the 1950s, before ballistic missiles made such exotic airplanes unnecessary. While a longer term prospect than using HTR for terrestrial energy, new spacecraft using lightweight HTR reactors could someday replace the chemically-fueled rockets used since the days of Sputnik. By greatly reducing the amount of fuel required to achieve orbital altitudes or escape velocity, HTR technology would enable use of reusable, single stage, airplane-like vehicles that could use standard runways. This would greatly reduce the cost of space flight and enable large numbers of people to participate in space travel.

Technical Description

The GDM (Figure 4), located on the axis of a cylindrically shaped reaction chamber, can provide containment for either a deuterium or deuterium-tritium plasma at the temperature and density necessary for the required neutron flux. Accelerators provide an alternative means for generating neutrons, but the GDM requires several times less energy per neutron. The GDM is also attractive because it operates continuously; other fusion approaches, such as tokamaks or laser detonation, provide pulsed output. In addition, the GDM is linear and less susceptible to plasma instabilities than other magnetic containment mechanisms.

The fission reaction is what produces the huge energy output, only a small amount of which must be used to heat the fusion plasma. The reaction takes place in a solid or liquid thorium shell that surrounds the GDM, while the magnets that generate the containment field are external to the thorium shell. As discussed previously, the thorium cycle cannot sustain a chain reaction and requires an external source of neutrons to maintain it, so a reactor doesn't need control rods and other costly safety features, and produces a much higher net power density. Ironically, the need for an external neutron source is a principal reason the thorium cycle has not seen wider use. In the case of the HTR, this becomes a major safety and cost attribute.

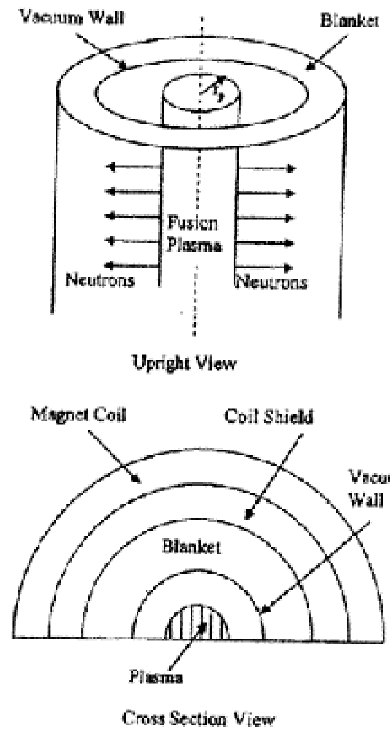

Figure 4. GDM & thorium shell.

While the hybrid reactor theoretically provides enormous amounts of power, converting the reactor heat energy into usable energy remains a major engineering challenge. This is one of the key focus areas of TransPower's proposed research – along with validating and perfecting the GDM fusion device and updating the designs of thorium fission reactors. Maintaining a solid thorium shell requires limiting its temperature to around 3,500 deg K, which would require circulation of a coolant at an extremely high rate. Maintaining the thorium in a liquid state would enable temperatures to be raised to about 4,400 deg. K, and the liquid thorium itself could potentially be used to transfer heat from the reactor.

Proposed Research

The proposed HTR initial stage research can be divided into four principal tasks:

<u>Task 1: Project Management (TransPower Lead)</u> – This work will include the following: (1) coordination of all project tasks; (2) technical and financial reporting; (3) maintenance of the project Work Breakdown Structure (WBS) and cost data base; (4) business planning and private capital-raising; and (5) marketing communications, including maintenance of the project website.

<u>Task 2: Reactor Design And Development (University of Michigan Lead)</u> – Proposed research will consist of fuller analysis and definition of the reactor, resulting in a conceptual design and cost estimate. It will include the following: (1) determination of requirements for the GDM; (2) analysis of reaction rates and selection of optimal fusion reactants; (3) optimization of the composition of the thorium blanket and power distribution within the blanket; (4) calculation of the time required for steady-state energy production based on creation and destruction rates for U_{233}; (5) analysis of modifications to the neutron energy spectrum that will occur in the blanket; and (6) analysis of shielding requirements based on radiation flux and heat decay rate. Once sufficient funds are available, the research will include experimental research using the GDM at Marshall Space Flight Center in Phase II studies.

Task 3: Energy Conversion System Design And Development (TransPower Lead, with General Atomics Support) – Proposed research will consist of: (1) analysis of heat transfer requirements including choice of coolant, calculation of mass flow rate, and determination of size, shape, number and density of cooling channels; (2) conceptual design of devices for generating electric power, (3) choice of conducting fluid and conversion of coolant thermal energy to conducting fluid kinetic energy; (4) analysis of potential terrestrial and space applications.

Task 4: Applications Analysis (Boeing Lead) – Proposed research will consist of: (1) identification potential civilian and military applications for HTR, including potential aviation and space applications; (2) development of HTR-based aircraft, spacecraft, and propulsion system concepts; (3) systems engineering support for HTR reactor design efforts; and (4) preliminary system cost estimates and technology roadmaps.

Successful completion of these tasks would establish the foundation for future phases of development, currently envisioned as proceeding along these lines: Phase II – an experimental one-year effort to test the GDM and measure neutron production; Phase III – a two-year effort to develop a detailed design of the prototype reactor; Phase IV – construction and testing of a prototype reactor; and Phase V – construction of operational reactors for initial terrestrial applications. Collectively, it is expected that Phases I through IV could be completed within the next 8-10 years, potentially enabling operational reactors to be built and in operation by the end of this decade.

Team Experience and Capabilities

TransPower recognizes that the HTR is a challenging concept whose full-scale development could rival the scope of past national initiatives such as Project Apollo and the Manhattan Project. Accordingly, TransPower has assembled a world-class team that brings together the requisite scientific and engineering capabilities. TransPower Project Manager Dr. Mark Stull, Chief Scientist Dr. James Burns, and VP Advanced Technologies Dr. Paul Scott have more than a century of combined experience in energy, transportation, and aerospace research, and TransPower CEO Michael Simon managed key NASA advanced transportation studies in the 1980s and 1990s prior to becoming a successful entrepreneur. The University of Michigan's efforts will be led by Dr. Terry Kamash, a world renowned expert in nuclear engineering for 40 years and one of the world's foremost authorities on hybrid nuclear technology. Under Dr. Kammash's guidance, UM has already developed a working GDM and performed the calculations that have suggested the tremendous potential of hybrid nuclear power based on the thorium cycle. General Atomics' efforts will be led by Dr. Leo Holland, director of advanced programs in GA's Energy and Electromagnetic Systems Group, which conducts world-leading R&D in both fusion and fission, including maintenance of the National Fusion Center and its tokamak reactor in La Jolla, CA. Boeing's contributions will be led by Thomas Kessler, a manager with more than 30 years experience in advanced spacecraft design. As a company, Boeing's combination of experience in aerospace, commercial aircraft design, and energy systems in unrivaled.