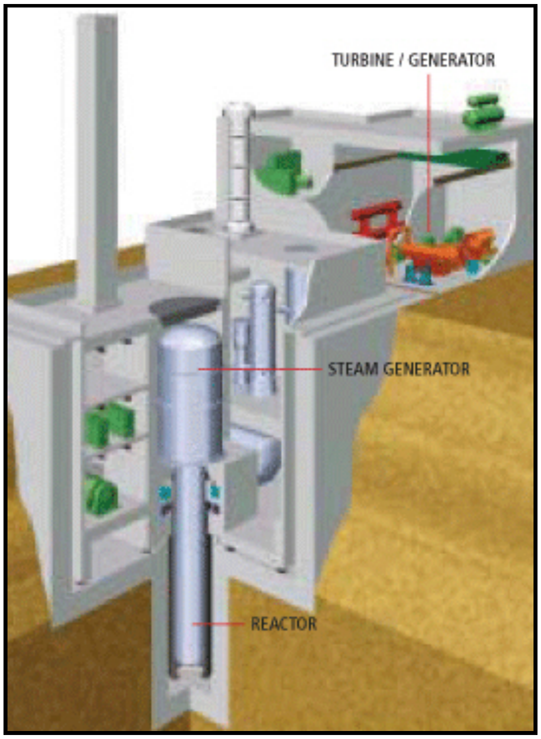
Under The Hood With Duncan Williams - Toshiba 4S

The Toshiba 4S

- By Duncan Williams -

In November of 2009, the U.S Senate Committee on Energy and Natural Resources introduced legislation that would provide funding to the Department of Energy for the development of small nuclear reactors. The Nuclear Power 2021 Act (S. 2812) would allow the federal government to fund 50% of the cost of the development and licensing of two different small modular reactor designs.



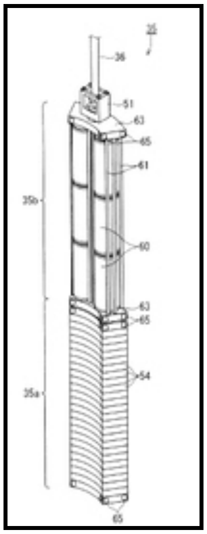
One of the co-sponsors of the bill, Senator Lisa Murkowski of Alaska, hopes that one of these new small reactor designs will be built in Alaska. In fact, the NRC has already met with the city manager and vice mayor of Galena, Alaska, in order to discuss plans for building a proposed small nuclear reactor there. Since the current bill requires that at least one of the designs must have a rated capacity of not more than 50 electrical Megawatts, a likely candidate for the Alaska site would be a design by Toshiba Corporation known as the Super-Safe, Small and Simple (4S) reactor. The 4S design has a capacity of 10 electrical Megawatts, and would therefore qualify for funding under the proposed legislation.

One of the most significant features of the 4S reactor design is that it could operate for 30 years without any refueling. Whereas most current reactor designs require refueling every 18-30 months, the 30-year lifetime of the reactor makes the 4S design ideal for countries in remote areas where it might be too dangerous to store nuclear fuel for the necessary periodic refueling.

The 4S reactor design is radically different from the reactors currently operating in America. Unlike conventional reactor designs which rely on low-energy thermal neutrons, the 4S reactor relies on high-energy fast neutrons in order to sustain a fission chain reaction. Nuclear reactors that utilize fast neutrons, like the 4S reactor, are known as fast reactors.

Since fast neutrons have such high energies, they are more likely to travel out of the reactor core instead of being absorbed by the nuclear fuel, and thereby sustaining a fission chain reaction. In order to stop these fast neutrons from escaping the reactor core, liquid sodium is used to redirect the neutrons back into the core so that they can be absorbed by the nuclear fuel and continue the nuclear fission chain reaction.

However, liquid sodium is so efficient at reflecting neutrons that other materials that are less reflective must be placed into the reactor. Otherwise, too many neutrons would be reflected back into the core causing the nuclear fuel to burnout long before the advertised 30-year lifespan.



U.S. patent Publication No. 20090190710, published on July 30, 2009, describes a component of the 4S reactor that is designed to allow neutrons to pass through it, allowing more of the fast neutrons to leak out of the core instead of being reflected back in. Six of these devices encircle the reactor core, displacing the liquid sodium that would normally reflect the neutrons back into the nuclear fuel.

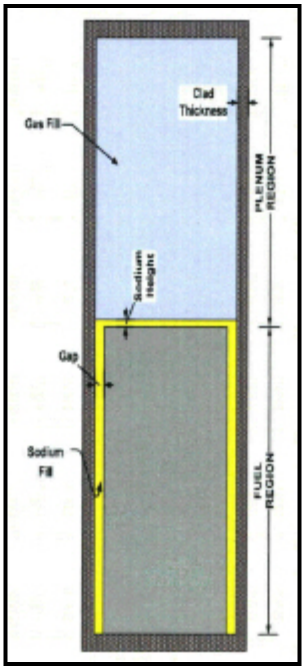
In order to startup the reactor, the device is withdrawn from the reactor forcing the neutrons to be reflected back into the core by the liquid sodium. This causes an increase in the number of neutrons in the reactor core, resulting in a sustained fission chain reaction.

In order to shutdown the reactor, the device is inserted into the core, displacing the liquid sodium and allowing neutrons to leak out of the core. This results in too few neutrons in the reactor core to maintain a fission chain reaction, effectively shutting the reactor down.

As previously mentioned, the device is made of materials that are essentially invisible to neutrons. For example, the lower half (35a) of the device consists of laminated metal plates (54) made from chromium-molybdenum steel, nickel steel, and inconel.

The upper half (35b) consists of cylindrical hermetically-sealed vessels (60) that may be filled with either helium or argon gas. The device is inserted into or withdrawn out of the core by the drive shaft (36) attached to the top of the device.

Documents submitted to the Nuclear Regulatory Commission by Hitachi indicate that the nuclear fuel used in the 4S reactor will be made of a metallic alloy consisting of 10 % zirconium and 90% uranium. The uranium will be enriched to between 17%-19% with uranium-235. In contrast, conventional thermal reactors typically use uranium fuel that contains about 5% uranium-235. Naturally occurring uranium contains only .7% uranium-235, and 99.3% uranium-238.



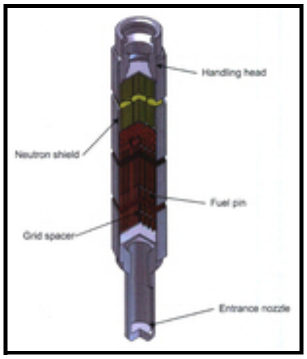
In order to be used in nuclear reactors, naturally occurring uranium must be enriched, which increases the uranium-235 content. The reason for this is that uranium-238 is not fissile, meaning that when uranium-238 absorbs a neutron, the resulting reactions are not likely to produce more neutrons that will sustain a fission reaction.

As can be seen in the diagram, the lower half of the fuel pin contains the nuclear fuel while the upper half is empty.

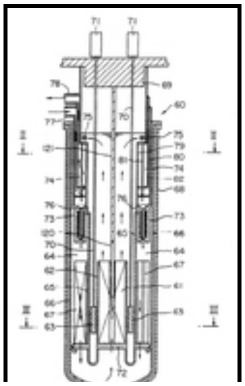
The entire fuel pin is surrounded by a 1.1 millimeter layer of HT9 steel, referred to as cladding. As can be seen in the diagram, a thin layer of sodium is placed around the fuel in order to improve the transfer of heat, produced from fission in the fuel, through the cladding. The entire fuel pin is 5 meters long, with the fuel portion measuring 2.5 meters. The 2.5 meters of empty space in the upper portion allows for the inevitable buildup of gases that will be released during the fission process.

The unusually large volume is necessary because of the 30-year expected lifetime of the fuel pin. In conventional thermal reactors, a much smaller amount of space is reserved for the buildup of fission product gases. This is because the fuel pins are typically removed every 18-30 months, well before the fission product gases causes the assemblies to swell and deform. As can be seen in the diagram, a plurality of the fuel pins are arranged into a fuel subassembly.

The fuel pins are held in place by a spacer grid located inside the fuel subassembly. A neutron shield is located above the fuel pins in order to reflect or absorb neutrons emitted from the fuel pins. As will be discussed in the next paragraph, liquid sodium flows into the fuel subassembly through the entrance nozzle at the bottom and exits through the top once it has absorbed heat from the fuel pins.



A description of the flow path of liquid sodium throughout the core of the 4S reactor is described in U.S. Patent No. 5,420,897, issued on May 30, 1995.



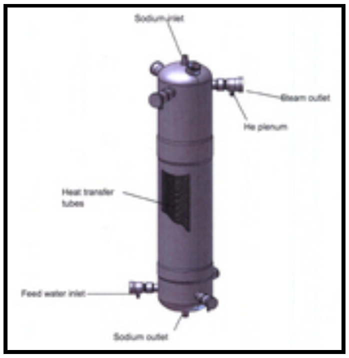
As can be seen in the arrows in the diagram from the patent, the electromagnetic pump (73) causes the liquid sodium to flow down through the coolant passage (64) and over the fixed neutron shield (67). The coolant passage (64) is defined by the annular cavity formed between the partition wall (65) and the reactor vessel (66).

The liquid sodium continues to flow downward through holes in the base plate (72) at the bottom of the reactor vessel. Next, the liquid sodium flows upwards through holes in the base plate (72) into the reactor core (61) and through the fuel subassem-

blies containing the nuclear fuel. After absorbing the heat generated by the fuel subassemblies, the liquid sodium continues to flow upwards and into the top of the intermediate heat exchanger (74) at the upper portion of the reactor vessel. The liquid sodium then transfers heat through the metal in the intermediate heat exchanger (74) to liquid sodium flowing through the heat exchanger on the secondary side of the heat exchanger.

As can be seen in the top left portion of the same diagram, the secondary liquid sodium enters the intermediate heat exchanger (74) through an inlet nozzle (77). The secondary liquid sodium first flows down to the bottom of the intermediate heat exchanger and then flows back up while absorbing heat transferred through metal by the liquid sodium on the primary side. After absorbing heat, the secondary liquid sodium exits the intermediate heat exchanger (74) via an exit nozzle (78) and then flows to a steam generator.

As can be seen in the diagram, the heated secondary liquid sodium enters an inlet at the top of the steam generator. The secondary liquid sodium flows downwards through tubes inside the steam generator in order to transfer heat through the metal tubes to water flowing on the opposite side. After the heat is transferred, the secondary liquid sodium exits the steam generator via an outlet at the bottom, and is then directed back to the reactor vessel to once again absorb heat from the intermediate heat exchanger in the reactor vessel. Feed water enters the steam generator via an inlet at the bottom left of the diagram.



As the feed water absorbs heat from the secondary liquid sodium, the water begins to boil and is converted to steam. The steam exits the steam generator via an outlet at the top right of the diagram, and is then used to spin the blades of a turbine-generator in order to produce electricity.

The 4S reactor design also includes a feature that protects the surrounding environment from neutrons which happen to escape the reactor core. U.S. Patent Publication No. 20100008463, published on January 14, 2010, and assigned to Hitachi, describes a fixed neutron shield for use in the 4S reactor.

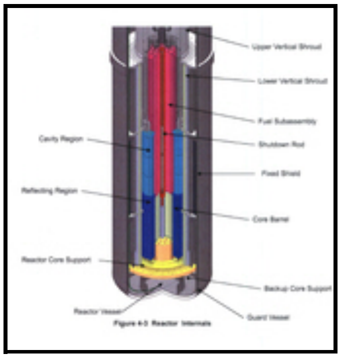
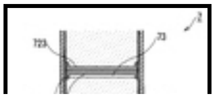
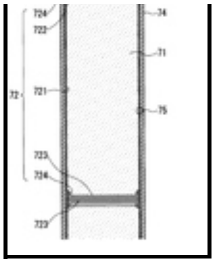


Figure 4-3 Reactor Internals

As can be seen in the diagram, the fixed neutron shield is embedded in the wall of the reactor vessel and surrounds the core which contains the nuclear fuel. The diagram also shows that the fixed shield is segmented, wherein each segment is stacked on top of one another. As can be seen in the blown up diagram, each segment is filled with powdered boron carbide (B4C) which absorbs neutrons that would otherwise leak out of the reactor.



A space (73) is located at the top of each segment in order to allow for thermal expansion of the boron carbide. Similarly, a clearance (75) of



about .5 mm is left in between the outer cladding tube (74) and the inner shroud tube (721) to also allow for thermal expansion.

Conclusion

The 30-year lifespan of this small modular design makes it particularly appealing for future use not only in America, but in other countries as well. Currently, Toshiba is working with the Central Research Institute of Electric Power Industry (CREIPI) in Japan to test the materials that will be used in the 4S design. The status of this testing is unknown. Toshiba began the pre-application process with the NRC in October of 2007, and is expected to submit a design approval application to the Nuclear Regulatory Commission in October of 2010. Aside from completing the testing at CREIPI, it is critical for Toshiba to obtain a potential licensee, such as the city of Galena, Alaska, before the deadline of October 2010.

Last Week's Column:

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GE Hitachi - PRISM Reactor - By Duncan Williams - One of the most vexing issues facing the nuclear power industry today is what to do with the spent nuclear fuel after it has been used in a nuclear reactor. Currently, used fuel is safely stored in pools of water or in dry casks at the nuclear plant site. But as for a ...

About Duncan Williams

Duncan Williams graduated from the University of Florida in 1994 with a B.S. in Physics, and a minor in mathematics. Upon graduation, he was commissioned in the U.S. Navy where he completed training in the Navy's Nuclear Propulsion program. He then served onboard an aircraft carrier, the USS Theodore Roosevelt, as a reactor control division officer. Onboard, he was responsible for the operation and maintenance of the electrical and mechanical components that make up the reactor control systems. This includes the control rod drive mechanisms, the reactor safety and emergency systems, the reactor coolant pump systems, and the ion exchangers. He also developed and implemented ship-wide reactor safety drills in order to educate sailors in reactor safety.

Duncan then transferred to the U.S. Naval Academy, where he served as a senior instructor teaching Thermodynamics to senior cadets. While serving as an instructor at the Naval Academy, Duncan attended night law school at the George Washington University Law School. After receiving his J.D. in 2004, he resigned his commission and began working as an intellectual property associate with Kenyon & Kenyon LLP. While at Kenyon & Kenyon, he drafted numerous patents relating to medical devices, electronic devices, telecommunications, as well as other technologies. He also has experience in all stages of patent litigation, and has represented numerous Fortune 500 companies in protecting their intellectual property rights. Duncan is currently an intellectual property associate at Blank Rome LLP.

If you have questions, comments, or know of a patent that you think Duncan should review E-mail Duncan Williams>> duncan@nuclearstreet.com

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ScottBrooks I hope TEPCO is not behind this reactor design.

Since sodium readily oxidizes with oxygen what precautions are there to prevent contact with the outside atmosphere? Is there an inert gas that would surround the core?

Of course this reactor would be not close to active fault lines or large bodies of water. At least it should be underground?

Also of concern, nature of waste and lifespan of nuclear facility.