StarCore Design

The provision of clean energy at remote off-grid communities in the far North of Canada - above the 60th parallel - is a difficult challenge; with no grid connectivity the options are limited to some form of carbon-based fuel shipped to the site or the use of “renewables” - wind, solar, or hydro-electric power. And the same difficulties apply in some form in every remote community around the world, where people face life without power, water and the fundamental necessities taken for granted by those of us living in a technologically advanced nation. It might seem that “renewable power” would be ideal for these communities, but it is expensive and requires the right environmental conditions for deployment which are often not available. And there is always the problem of the reserve power need to support the community needs when the renewable power fails. In the past this has always been provided by diesel or natural gas, but in the face of global warming this is not an attractive - or morally acceptable - long-term solution. StarCore Nuclear is a Canadian start-up nuclear power company with the specific goal of providing clean power, potable water and thermal energy to these remote communities.

Our design is for a small scale plant (Small Modular Reactor, or SMR) that will fulfill local energy needs without requiring an extended power transmission infrastructure; that can be certified as a design and constructed inexpensively and in multiples on an assembly line, then simply assembled on site; that is designed to be fully automated in operation and completely fail safe; that provides clean power, safe water, super-heated steam and thermal energy as standard outputs; that will be leased to the local communities instead of requiring them to provide funds for purchase, licensing, operations and decommissioning, and monitored by StarCore through a triple-redundant fail-safe satellite network.

Our plant is a High Temperature Gas Reactor (HTGR) based on the Pebble Bed Modular (PBMR) reactor design originally developed in Germany in the 1960’s; this design has a very steep negative thermal gradient that causes the reactivity to decrease as core temperature increases, thereby automatically driving the plant into a quiescent state if any failure occurs. We have modified the design to simplify operation and added additional automatic fail-safe control elements to allow the plants to be pre-fueled and shipped in the quiescent state.

The design is a new class with a static bed and modified fuel packaging which allows us to optimize the core for both improved thermal stability and increased nuclear efficiency.

The reactor uses TRISO (TriStructural Isotropic) fuel in the form of micro-spheres of less than 1 mm diameter, and which are them formed into Fuel Compacts. There are approximately 2,000 microspheres in each fuel compact, and around 60×10^6 in the core. The reactor uses a Rectilinear Core - this is a new StarCore design that uses a fuel compacts in the from of Truncated Cuboctahedrons, which look alike a cube with the corners cut off. This design has the advantage of allowing the fuel packing density and gas channels to be optimized, as well as providing a stable self-supporting matrix in the core.

The core is nominally 1.5 metres in diameter and 2.5 metres high, with 18 control rods and 12 stowable reflectors with neutron-absorbent cores. These are pneumatically operated (at 6 MPa) by the gas pressure of the first stage Energy Transfer System (ETS-1), as are the automatic gas shut-off valves at the base of the Rector Pressure Vessel (RPV), which is 2.5 metres in diameter and 6.5 metres high. They can also be closed pneumatically by command from the control center. The core also has reflectors and burnable poisons embedded in it to maintain the reactivity within design limits from the five-year life span.

The reactors will be built on an assembly line at the StarCore factory, and when they are installed onsite the reactivity will be trimmed by means of setting stops on the reflector/absorber assemblies so that it is within the design limits.

One of the main advantages of the HTGR design is, of course, that it is thermally self limiting. As the core temperature increases so does the neutron energy levels; this reduces reactivity since fast high-energy neutron do not cause fission in 235U. The result is that - to use the words in the recent IAEA TecDoc 1674 - “The HTGR is a inherently safe nuclear reactor concept with an easily understood safety basis that permits substantially reduced emergency planning requirements and improved siting flexibility compared to other nuclear technologies”.

In a recent test at the HTR-10 reactor in China the control rods were withdrawn and the all coolant systems shut down. The reactor reached effectively zero power output in about 6 minutes, and then thermal stasis after about two hours. At this time the power level settled at about 200 kW, which was mainly driven by the energy transfer rate out of the RPV. StarCore initial estimates show that the power levels will stabilize at around 500 kW in the StarCore reactor under similar conditions.

In addition StarCore uses automatic control rods and stowable reflectors with a neutron absorbent core. These are operated pneumatically by gas pressure (at 6MPa) in the first stage energy transfer system; they can also be operated by command from the control rooms.

Because of this unique characteristic of HTGRs StarCore has three levels of operational safety; it is Actively Safe, in that the reactor can be shut down by operational command; Passively Safe, since the reactor will shut down automatically if there is loss of gas pressure; and finally it is Inherently Safe since it will reach thermal stasis even if all controls fail and all gas pressure is lost.

At the site, the nuclear reactors are installed 57 metres underground in a double-walled stainless steel containment structure with passive thermal management of heat output, and with double-walled high performance concrete silos extending to the surface. The plant uses a three-stage energy transfer process from helium to nitrogen, and then from nitrogen to an external combustion air-breathing gas turbine to generate electricity. This three stage process allows StarCore to prevent helium migration at the first stage heat exchanger by balancing pressure across this interface; in addition we have designed a passive fractional scrubber and condenser in the first stage system to remove any radioactive trace elements in the form of dust or heavier gaseous isotopes that may occur. The first stage ETS-1 uses helium gas at 7.5 MPa; this ends at the first Intermediate Heat Exchanger (IHX-1) where the second stage (ETS-2) takes over the transfer process. This system uses Nitrogen pressurized at 6.8 MPa to minimize pressure gradient across IHX-1, and then takes the hot gas to the co-generation heat exchanger (IHX-2) which produces super-heated steam, and then to the third heat exchanger (IHX-3) in the gas turbine.

The Energy Transfer Control System (ETCS) controls the amount of energy that is passed to the turbine or routed to IHX-2 to allow rapid electrical output load following. Long-term load following is controlled by the mass transfer rate of ETS1 and 2 and results in the reactor following the negative reactivity gradient (the less power is required, the hotter the reactor operates, and the less power it makes) and so produce only the energy required to stabilize the output.

The reactor is designed to operate in only two fully automatic and inherently safe states; Shut-Down and Load Following, and requires no day-to-day control. Although we expect to have local monitoring personnel at the sites for a considerable period, the reactors are designed to be fully automatic with operational data and keep-alive signals transmitted by satellite to the StarCore Nuclear control center; the only local controllers will be those required to determine electrical and thermal output and distribution. The data links will be by a continuous broadband C-band link to a GEO satellite and by store-and forward backup links through LEO satellites.

Helium does not become radioactive in use since any trace elements are removed by the Fractional Scrubber and Condenser, so that even venting all the first stage gas to atmosphere will not cause any radiation and a total loss of first stage integrity would only cause the reactor to automatically shut down in a completely safe condition from which it could be recovered to normal operation when the gas is recharged. This allows us to meet one of the key requirements levied by the Business Plan - that the reactors be able to maintain integrity even under the most severe and destructive natural or man made events. Even the complete destruction of all above ground facilities will not cause any radian leakage or loss of reactor integrity.

The StarCore plant is designed to minimize both environmental and social impact. The reactors are installed in silos 57 metres deep and 13 metres in diameter, made form double-walled high performance concrete with a steel canister silo at the base. The turbine room is 10 metres high internally and the building in 100 metres long and 30 metres in width. There is access to the two silos by means of personnel access tunnels from the turbine room, and there is an interface room at the top of the silo for reactor replacement operations. The reactors will be delivered to the site in modified fuel shipment containers on special transport vehicles, and the containers will then be installed vertically on the top of the silo pads. The vehicles will also provide a special-purpose winch which will be install and remove the reactors from the silos.

StarCore will use an advanced highly automated Instrumentation and Control System that was initially developed for the control of launch vehicles and satellites. This system defines operational states as regions of n-dimensional space; a simple example of a 3D space could consist of data from a coolant pump and include bearing temperature, power input and pressure variance across the pump. The standard operating state would be found at the loci where all the three dimension were within the design parameters.

Any State Loci in nSpace can also be defined as a vector of the same dimensionality as the space - a HyperVector - and this is the reason for the full name of the system; StarCore HyperVector Instrumentation and Control System.

It may be considered that the states are similar to the conventional operational “limits” of the component or system; this is true, but they are far more powerful. For limits to work the state of the component or system must be known; this is often not the case if a failure occurs. HyperVector Control turns this concept upside-down, and identifies the state from the incoming data. The “limits” are now represented by the state boundaries. In a complete system there are typically thousands of dimensions representing all the real time, stored, derived, specification-based, historical and analytical data. Each state also has a probability defined for the data elements, so that it can be thought of as being a probabilistic region in nSpace.

The distance and rate from the state locus to the nearest state boundary can also be calculated, and this time the represents the predicted time to failure of that system or component. The result is that this form of control system will always predict the failure time of every system or component in the whole plant; the shortest time and associated system will be presented to the operators.

The States are connected by State Transition Vectors which represent the correct - and certified - path to change the state of the entire plant or subsystem. The Transition Vectors also produce real time cost information in the form of either Time to Transition or Cost to Transition, as well as a mechanism to react automatically to system failures or operational schedules operation if desired. nSpace control systems have been used on many hyper-complex applications over the years, including LEO, GEO and Deep Space Missions; Launch Vehicle Countdown, Ignition and Flight Safety Systems; Nuclear and Power Systems Control, and many others.

Inherently safe. Passively secure. Totally green. With two StarCore Reactors installed 57 metres (190 feet) underground in double-walled steel and high performance concrete silos that provide third and fourth level containment and security, the site is completely accessible to the public with no other overt security fences or guards. A single StarCore plant includes two totally separate units that together provide 20 MWe of load-following electricity, potable water and 10 MWt energy for use in other secondary processes.

Safe power and potable water from clean energy, produced by a plant that is designed to blend into the local environment and on a site designed to be integrated into community activities. This is a vision worth pursuing, I think.

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