NUCLEAR ENGINEERING INTERNATIONAL

Advanced Reactors & Fusion

PRISM: Waste not, want not

GE Hitachi Nuclear Energy have developed the sodium-cooled fast reactor PRISM to advanced conceptual design, and the design is ready to start undergoing the regulatory process. Once this is completed, it will be available for deployment. Eric Loewen, chief consulting engineer for GE Hitachi Nuclear Energy, discusses PRISM with David Flin.

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Fast reactors on a closed fuel cycle use nearly all the actinides fed into them, while low energy reactors use only around one percent of the fuel. As a result, fast reactors have fuel requirements reduced by a factor of nearly 100. The volume of waste they generate would also be reduced by the same factor. While there is a huge reduction in the volume of waste from a fast reactor, the activity of the waste is about the same as that produced by a light water reactor.

GE Hitachi Nuclear Energy is developing the Power Reactor Innovative Small Modular (PRISM) reactor, which uses liquid sodium as a coolant. This coolant allows the neutrons in the reactor to have a higher energy that drive fission of the transuranics.

PRISM is a pool-type, metal-fuelled small modular Sodium Fast Reactor, with an electrical output of 311MW, with two reactors giving a power block of

622MWe. Each PRISM reactor has an intermediate sodium loop that exchanges heat between the primary sodium coolant from the core with water/steam in a sodium/water steam generator. The steam from the sodium-water steam generator feeds a steam turbine.

The Experimental Breeder Reactor II, which first began operating in 1964, provided the basis for the current PRISM. GE realised during the Clinch River Breeder Reactor project that trying to develop a sodium reactor along the same scale as a water reactor would not be optimal. As a result, it began to develop PRISM using a smaller, more appropriate design scale. By making it smaller, it is possible to carry out all the work in the factory, and this means that fabrication and welding can be carried out in the factory under controlled conditions.

In designing the PRISM, two design features were considered to be paramount:

- Safety in operation.
- Safety after shutdown.

The PRISM design has automatic control of power during operation and of heat generated from the fuel after shutdown.

During operation, when reactor power or outlet temperature increases, the reactor power reduces as a result of neutron leakage from the core, and this provides negative feedback and self-correction. Design to take advantage of the laws of physics enables the automatic removal of heat from the system even in the complete absence of power. As a result, if a

Fukushima-type incident were to occur, and all power supply is lost, the reactor will automatically shutdown and removal of the decay heat will occur safely.

The benefit of using natural laws of physics in the design is that the reactor is both cheaper and safer. It is cheaper because the need for fans and pumps is reduced or eliminated, requiring fewer mechanical parts. Because there are fewer such items, maintenance costs are reduced, in addition to the reduction in construction costs.

It is safer because while mechanical items can fail under catastrophic conditions, such as a loss of all electrical power onsite, PRISM is not dependant on these for a safe shutdown, so even a catastrophic situation will not result in a reactor meltdown.

Metallic fuel

All other sodium reactors use oxide fuels, while PRISM uses a metal fuel, an alloy of zirconium, uranium, and plutonium, and the fuel rods sit in a bath of liquid sodium at atmospheric pressure. This ensures efficient transfer of heat from the metal fuel to the liquid sodium coolant.

In the event of a temperature rise in the fuel, the metallic core, unlike oxide fuel, expands, and its density decreases slowing the fission reaction. Consequently, the reactor slows down and shuts itself down. Heat is dissipated very quickly through the highly conductive metal fuel and metal coolant.

The PRISM reactor vessel auxiliary cooling system can maintain reactor temperatures well below design limits using natural circulation to remove heat from limits using natural circulation to remove heat from the reactor module. Natural air flow around the lower containment vessel is all that is needed to keep the reactor fuel cool at all times.

The Argonne National Laboratory discovered that while metal fuel grows under use, it grows a certain amount, and then stops growing. Argonne took account of this growth, made allowance for it, and determined to what size the metal fuel would expand to. As a consequence, fabricating cladding slightly larger than the fuel results in the fuel expanding to the cladding, and then maintaining that size.

An additional feature of metal fuel use in sodium is that the fuel does not chemically react with the coolant compared to oxide fuel pellets which dissolve in high temperature sodium. This results in the metal fuel being safer in operation.

If a sodium cooled reactor core loses it coolant by a leak or boiling, voiding within the core causes a sudden increase in reactor power which could damage the fuel and core. While sodium boils around 900°C, most sodium reactors operate at 500°C. Because oxide fuel conducts heat at a lower rate, the centre of the fuel is above the boiling point of sodium. PRISM's metal fuel centre is below the boiling point of sodium.

Loewen also explained that another advantage that metal fuel has over oxide fuel is that oxide fuel contains a significant amount of stored energy, and the dispersal of stored energy is imperative in preventing a reactor meltdown.

Recycling waste and used fuel

One of the big advantages offered by the PRISM reactor is that it offers a considerable advance in the ability to recycle used fuel and plutonium. LWR used nuclear fuel is composed of 95% uranium, one percent transuranics, and four percent fission products. Many of these transuranic isotopes have very long half-lives, which can create long-term engineering challenges for geologic disposal, as well as a problem with public perception of the issue of waste disposal.

By using electrochemical separations, PRISM is designed to perform the recycling of the 96% of the fissionable material remaining in used nuclear fuel. Because PRISM fuel is metallic, a simple electrometallurgical process can be used to recover the elements that fission or can be made to fission and put the waste products into a very stable waste forum of a metal allow and robust ceramic.

Loewen said that when using a water reactor, it was only possible to recycle fuel twice, while PRISM can re-use fuel many times. There are a number of consequences to this ability to undertake multiple recycling.

- Waste discharge is in metallic or ceramic forms, which is easier to contain.
- Waste with extremely long half-lives is converted to isotopes with much shorter half-lives, of the order of 300 years.
- It improves the efficiency of use of uranium from our current use of one percent to achieving around 99%.
- PRISM will be a disruptive technology.

PRISM is able to include weapons-grade plutonium as

part of the fuel mix, which helps reduce plutonium stockpiles. The UK Government, through the Nuclear Decommissioning Authority (NDA), is considering the use of PRISM to reduce its stockpile of 112 tons of plutonium stored in Cumbria. If this were to go ahead, then the plutonium, currently in powder form in sealed cans at Sellafield, would be downblended with uranium powder, and then turned into a binary metal alloy. After this, the fuel would be fabricated into fuel bundles weighing around half a ton, which are used in the PRISM reactor.
The options for disposition of plutonium in the UK are essentially:

- Storage.
- Mix it with concrete prior to storage.
- Using it as fuel in a reactor ("reuse").

GE Hitachi Nuclear Energy claims that, unlike alternatives, PRISM fuel can either be recycled to completely consume and eliminate the plutonium, or disposed of in a proliferation-resistant manner.

According to Mark Lynas, an environmentalist: "The most compelling reason to look seriously at the PRISM is that it can burn all the long-lived actinides in spent nuclear fuel, leaving only fission products with roughly a 300 year half-life. This puts a very different spin on the eventual need for a geologic repository."

Loewen said the NDA and the Department of Energy and Climate Change (DECC) in the UK have a number of potential options to deal with the plutonium stockpile against the alternative of permanent storage. Their clear conclusion is that plutonium reuse is the best option for Britain. Loewen agreed, saying that permanent storage imposes permanent costs, creates a permanent security and proliferation threat, and misses the opportunity to generate low carbon electricity from the held plutonium. It is possible to regard plutonium as a resource, as well as a challenge.

PRISM's efficiency in use of plutonium allows a range of flexible commercial models which could work in any one of a number of ways. The key proposition made to the UK Government and the NDA is that PRISM could work on a "payment by results" model, involving payment per ton of plutonium dispositioned, supported by a secondary revenue stream from the sale of low carbon electricity onto the grid. This model, if chosen, transfers risk away from the UK Government, with industry taking a lead for managing the UK's plutonium stockpile, and the UK taxpayer only paying as plutonium is dispositioned. In this scenario, the UK Government would neither own nor operate the facilities, so risk to the UK taxpayer is minimised.
The use of sodium coolant rather than a water coolant enables higher burn-up. Water-cooled reactors can typically achieve a burn-up of around five percent, whereas PRISM's metal fuel can achieve a burn-up of around 20%.

One fact that Loewen pointed out that enabled greater fuel use by the PRISM (or any fast spectrum reactor) is that all neutron cross-sections are one Barn. By contrast, the neutron spectrum for low energy reactors can range widely, anything from one to 200,000 Barn. As a result, low energy reactors need a very specific fuel composition.

Another interesting design feature is the lack of a PRISM spent fuel pool. Previous reactors used a pool of liquid sodium metal. PRISM puts the used fuel from the core into the upper portion of the reactor vessel. It is placed there for about two years and cools as the short-term radioactivity energy dissipates. After that, the cooled spent fuel is removed, cleared and stored using natural air flow for cooling.

New ideas

There are a number of new ideas being developed, and the advancement of these is being carried by young engineers. These engineers have a great deal of energy and enthusiasm for developing new ways of thinking and concepts. This is encouraging, and a hopeful sign both for the industry as a whole, and for the future development of the PRISM.