Safety features of new reactor designs

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Nuclear power proponents reiterate the safety of the existing Generation II plants. But the new designs proposed in the U.S. follow Generation III and Generation III+ designs that incorporate enhanced safety features that build on lessons learned from the current generation of commercial power reactors.

In the U.S., several Gen III+ designs await design certification from the NRC. GE-Hitachi's Advanced Boiling Water Reactor, a 1,350 MWe Gen III design, has received certification from NRC. And Westinghouse's 1,154 MWe AP1000 is the first Gen III+ design to receive final design approval from NRC. France-based Areva is still waiting for approval on its 1,650 MWe Gen III+ EPR. So is Mitsubishi's 1,700 MWe Gen III+ US-Advanced Pressurized Water Reactor and GE-Hitachi's Gen III+ 1,600 MWe Economic Simplified Boiling Water Reactor.

"A lot of the philosophy between the operating Gen II fleet and the new Gen III reactor is similar with redundancy and reliability," said Bruce Bevilacqua, vice president of New Plants Engineering for Westinghouse Electric Co. "But how we achieve some of the functions is different."

Passive Cooling

A common feature on the new reactor designs is passive cooling. In the current Gen II operating fleet, operators managing an unexpected incident inject water with pumps to cool the reactor. This process is known as active cooling. The multiple pumps involved in active cooling are powered by AC power. Even if AC power is lost, the plants are designed to have multiple emergency diesel generator backups that can come online and power the pumps. One issue is the reliability factor with the diesel generators such as when and how quickly they will turn on, and how quickly they will power up. In order to maintain their reliability, diesel generator testing is done regularly.

"The philosophy in the current fleet is redundancy of systems, redundancy of pumps, redundancy in backup power sources and highly trained operators with appropriate procedures to take action relative to different events," said Bevilacqua.

In new Generation III and Generation III+ designs, passive safety, also known as passive cooling, requires no sustained operator action or electronic feedback to shut down the plant safely in the event of an emergency. Bevilacqua said the AP1000 is equipped with water tanks, which can be emptied into the reactor vessel itself if necessary or into containment to flood in and around the reactor vessel. Instead of relying on pumps, the operator can rely on gravity once the fail-safe valve is opened.

"The number of operating components is simplified and the redundancy philosophy is maintained" with the number of and number of systems to cool the reactor, Bevilacqua said.

Similar to Westinghouse, Areva and GE developed passive cooling systems in their EPR and ESBWR designs. The EPR possesses an in-containment storage of water. The dual housing containment is so large that operators get a convection flow inside containment from the hot-low to a cool-high, which condenses on the walls of containment and runs down to the reactor vessel in the event it starts to warm up.

"We can go for a few days without doing much of anything inside the buildings to pump water," said Mike Rencheck, chief operating officer for Areva Inc.

Core Catcher

The EPR is also equipped with what Areva refers to as a "core catcher." If the fuel cladding and reactor vessel systems and associated piping become molten, these first two safety mechanisms will fall into a core catcher which holds the molten material and has the ability to cool it. This, in turn protects the third barrier, containment.

Similarly, the ESBWR has a passive isolation condenser system that will remove heat from the reactor after it is shut down with no electrical power. Combined with its passive containment cooling system that removes heat from the containment, the system allows for 72 hours of no operator actions and no external power for the power plant to remain in a safe mode. Additionally, part of the passive system is a gravity-driven cooling system which provides return water to the reactor core.

"From an operations standpoint, ESBWR utilizes natural circulation in its day-to-day operation where the ABWR relies on pumps to drive water flow through the reactor core," said Brian Johnson, vice president of Domestic Markets for New Plants for GE-Hitachi.

Johnson said the ABWR still brings a lot of safety improvements over previous generations of plants.

"It was the result of incorporating the 40 years of operational experience from the existing power plants in terms of material characteristics, operability characteristics and inserting the latest technology through digital controls and proving a level of automation again to reduce any reliance on operator actions," he said.

Preventing Loss of Power

In the case of Fukushima Daiichi, the plant had a loss of AC power and could not start the needed diesel generators to cool the reactors. In the AP1000, for example, for the first three days after an unplanned event the operators do not need to rely on AC power to place the plant in a safe shutdown condition. Instead of relying on active components such as diesel generators or pumps, the AP1000 relies on gravity, natural circulation and compressed gases to keep the core and containment from overheating. Battery-powered systems then would be used to maintain safe shutdown until AC power is back online with the help of multiple diesel generators.

"From day 3 to day 7, the operators can maintain that plant in safe shutdown with very little AC power," said Bevilacqua. After day 7, operators are monitoring the plant, which by then should be in safe shutdown mode. Ideally, by the seventh day all power is completely restored to support recovery actions

Control Room Upgrades

To operate the plant safely and securely, the plant also must be equipped with a reliable control system within the control room. One lesson learned from the 1979 Three Mile Island accident was that there was a need for a better design of the control room to account for human factors, said Jon Johnson, senior vice president of Lightbridge Corp., a nuclear consulting firm. Modern control rooms are designed much better from a man-machine-interface standpoint.

"Operators are still observing parameters, temperatures, flows and pressures," he said. "They have to monitor these instrumentations (switches and dials) and operate the plant."

Lightbridge's Johnson, former deputy director of the NRC’s Office of Nuclear Reactor Regulation, said the front control panels must be lined up properly with the way the components are laid out in the plant, such as the valves, pumps, and so on. Today, control rooms are conceived to achieve just that.

“Operators still have to study and train on (control room systems) just as much,” he said.

Both the ABWR and the ESBWR, as well as the US-APWR, EPR and AP1000, have fully digital control rooms that are based on human factors to improve the operator interface with the systems and make the operations and actions more user friendly.

And in the event of a release of radiation, control rooms are being equipped with separate air tanks that connect to air delivery lines not affected by the release. The AP1000 control room can run on battery power for 72 hours. After 72 hours, an air filtration system provides cooling and air injection to keep the room at a reliable temperature for extended occupancy.

“At the end of 72 hours the operators do not have to evacuate, said Bevilacqua. “They are set up for indefinite occupancy."