Aide to presenter of EPR ECCS 3

Slide 1 ECCSs

The fission in a nuclear fuel core provides an enormous amount of heat in a relatively small space. Circulating pressurised cooling water uses the heat to raise steam, which powers a turbo-generator.

The SZB public inquiry considered the efficacy of its emergency core cooling system (ECCS) in preventing the uranium fuel core from melting in the event of a break in the cooling circuit. The inspector was convinced of its ability so to do and the application to build was passed.

An ECCS will be provided for the two EPRs under construction at Hinkley Point C.

There was an ECCS at Three Mile Island 2, but it was not activated by misled operators and the core partially melted.

ECCSs were started at Fukushima, but failed with the subsequent station blackout and the subsequent run down of the batteries.

An ECCS is needed when a system component fails and coolant is lost, but there is no proof that it will actually work, for as yet one hasn't run full course.

Its concept is to inject water from an emergency source into the reactor vessel system once it has been depressurised to below the injection pump head or boric acid accumulator pressure.

Slide 2 EPR

In this simplified diagram the core is shown in light brown inside the coolant circuit shown in dark red. The circuit consists of the reactor vessel, four circulating pumps, four tube bundles in four steam generators and a pressuriser. Just one pump and one steam generator is shown for simplicity.

The steam is shown in yellow going to the turbine and to the condenser. The feed water, shown in light blue, is then pumped back into the steam generator to be returned to steam by heat from the circulating water in the tube bundle.

Slide 3 Reactor vessel (RV)

The reactor vessel is a forged carbon steel vessel with a stainless steel liner to resist attack by its boric acid neutron absorber.

It contains the fuel core consisting of enriched uranium fuel pellets in zirconium alloy cans containing 63,865 fuel rods to produce 4,500 MWth power. Neutron absorbent control rods are moved down and up by drive mechanisms to control the power and drop to shut the reactor down.

The cooling system has 8 inlet/outlet connections to the RV and from them to 4 circulating pumps, 4 steam generators and a pressuriser.

On the RV head are mounted 89 control drive mechanisms to drive 89 control rods.

Slide 4 Core meltdowns Three Mile Island 2 and Fukushima

TMI 2 suffered a partial core meltdown when there were no available feed water pumps, so that pressure rose in the cooling system, a relief valve stuck open leading to a depressurisation.

Operators failed to activate the ECCS as it was thought the core was covered, but this was with an increased volume of steam/water mix unable to cool the core and it suffered a partial melt. It's shut down and TMI 1 runs after operator training.

Fukushima 1,2 and 3 had full meltdowns, while hydrogen exploded in 4's building marooning the spent fuel tank on an upper floor. Although shut down, in the total blackout causing the loss of all cooling, the decay heat was sufficient to cause the meltdowns and produce the explosive hydrogen.

As part of the ECCS, the steam-turbine injection pumps worked until the batteries ran out.

Slide 5 Three Mile Island

At Three Mile Island Unit 2 an incident led to a partial meltdown of the core. After it, the unit was shut down permanently.

It started when a steam generator feed pump failed while the standby pumps were undergoing maintenance. Because the heat in the cooling circuit was not absorbed by a steam generator with no feed water, the core decay heat remaining in the cooling circuit caused a rise in pressure in the system which lifted the relief valve.
The relief valve seized in the open position leading to a depressurisation in the reactor vessel. The operators were unaware of this because the feedback switches monitoring the relief valve position failed to signal its open status.

The depressurisation caused the high-temperature hot water in the RV to flash to a steam/water mix, which increased its volume so that the top surface of it rose above the core. A level probe misled the operators to believe the core was covered and they failed to activate the ECCS!

The heat transfer from the fuel cans to the steam/water mix is poorer than through the high pressure water, so the can surface temperature rose and the fuel inside them started to melt. The zirconium in the can alloy made an ion exchange with the steam to form hydrogen and zirconium oxide. The hydrogen left the relief valve into the containment where it exploded, but the containment held.

Slide 6 Fukushima

The Fukushima reactors are boiling water reactors with no steam generators, so the steam from the top of the reactors goes directly to the turbines. The control rods are pushed up from the bottom by stored energy in nitrogen accumulators.

When the grid tripped out the control rods were applied and the reactors shut down, but the decay heat remained. When the tsunami flooded the standby generators the ECCS stopped and when the batteries ran out the steam turbine-drive cooling water injection pumps lost their controls and stopped. Also the whole stations were plunged in total darkness.

When Fukushima One's RV's internal pressure rose dangerously it was reactor was depressurised, the high temperature hot water turned to a steam/water mix which led to the hydrogen production, which exited the relieved valves into a service floor and when it exploded destroyed it.

Slide 7 Hydrogen generation

The hot water in the reactor vessel and its associated cooling circuit is at a high pressure and a high temperature, hot enough to raise steam in the steam generators. At the high temperature the water would be steam if it wasn't kept at a high pressure, so if there is a leak or a deliberate depressurisation, the hot water "flashes" into a steam/water mix - with initially tiny bubbles of steam in the water, (nucleate boiling) - which when it leaves the leak, or vent, it will be mainly steam, while carrying hydrogen as explained further on Slide 8.

The heat transfer from the fuel cans' surfaces to the steam/water mix is poorer than to the hot water, so the surface of the cans heats up. This leads to an ion exchange between zirconium in the can alloy and the hot steam to produce hydrogen.

The hydrogen leaves with the steam into the containment.

Slide 8 Hydrogen explodes

The can surface, with the poor heat transfer, rises in temperature to between 1,000°C-2,000°C, which is needed for the ion exchange of the zirconium and steam to hydrogen and zirconium oxide. This means that the hydrogen leaves at more than 585°C, its auto-ignition temperature.

The explosive limits in air of 18.3% - 59% hydrogen means that once the hot hydrogen content in the air rises to be within the limits it explodes.

At TMI 2 the containment held: will that of the EPR?

At Fukushima at Units 1 and 3 the service floors were destroyed and hydrogen leaked from Unit 3 into 4's building and exploded.

Slide 9 Why EPR ECCs can't work

The reactor vessel cooling system needs to fall by half, from 15.5 MPa to >8 MPa to allow the borated contents of the accumulator and the ECCS emergency water from the injection pumps to enter. So the RV has to be depressurised below this. If the leak is severe, this may happen without intervention.

The depressurisation leads immediately to flashing and the coolant volume expands preventing emergency water from entering, while the flashed steam and hydrogen are released from the leak.

The with the poor heat transfer from the can surface the rise in temperature generates hydrogen, which when released into the containment air explodes. The un-cooled core melts, partially or fully and if fully will melt through the bottom of the vessel to the corum catcher.

Slide10 EPR Design

Double concrete walled containment with corum catcher requiring massive civil engineering.

Un-affordably, expensive construction to cater for failed ECCS.

Radioactivity from the meltdown is contained, but EPR permanently shut down.