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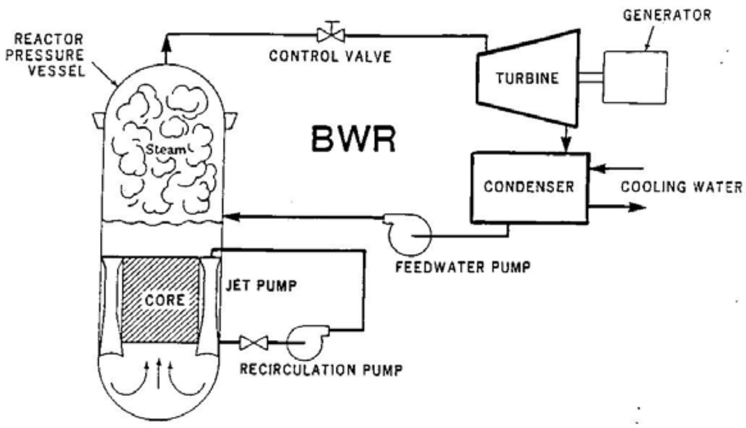
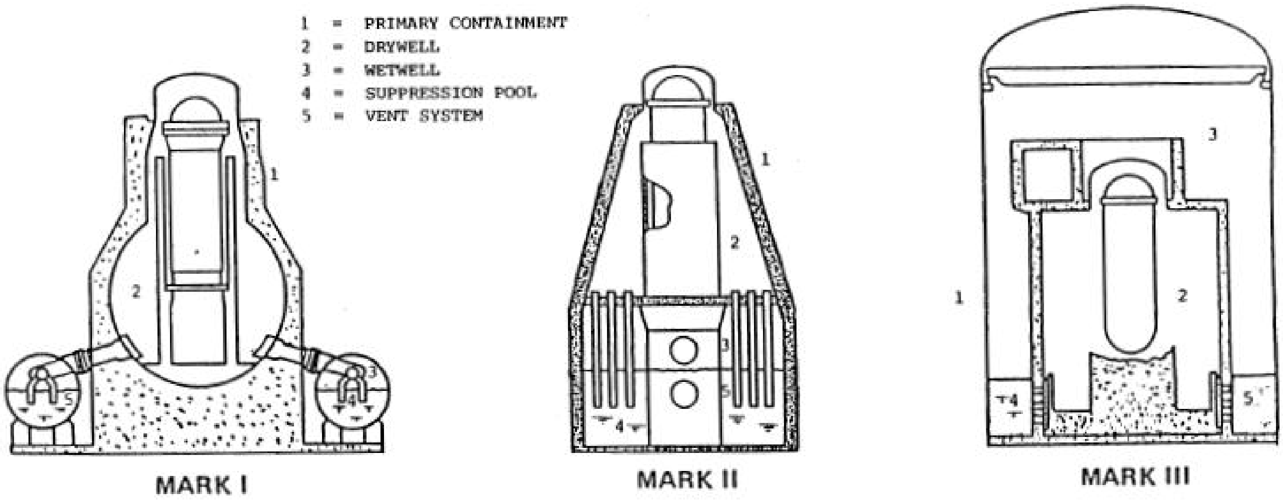
BWR Containment Overpressure

A boiling water reactor (BWR) splits atoms to release nuclear energy. This energy is removed from the reactor core during normal operation and used to spin turbine blades connected to a generator that produces electricity. A nuclear power plant has entire systems designed to match the energy produced by the reactor core with the energy removed. This balance is extremely important because the reactor core can overheat and release large amounts of radioactivity when more energy is produced than removed.



To protect the public if the energy balance is not maintained, BWRs feature a pressure-suppression containment system. In the United States, three versions of the BWR pressure-suppression design are used. They are called the Mark I, Mark II, and Mark III designs. In all three designs, the reactor vessel is housed within a primary containment structure. The primary containment consists of three parts: the drywell, the wetwell, and a connecting vent system. Water fills the suppression pool that is part of the wetwell. The following graphic illustrates the major features of the three BWR containment designs:



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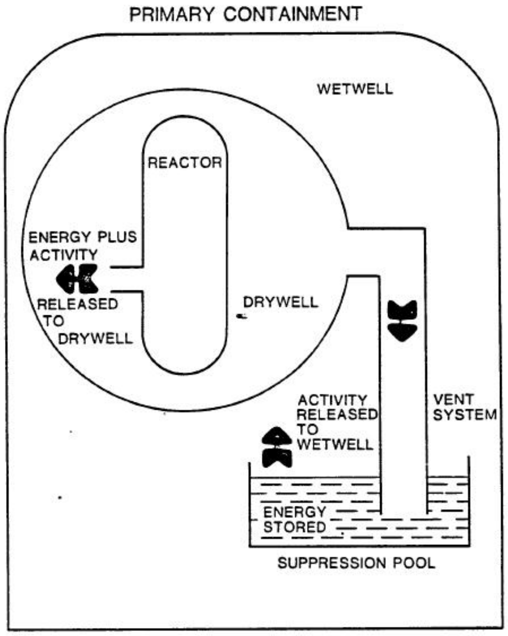
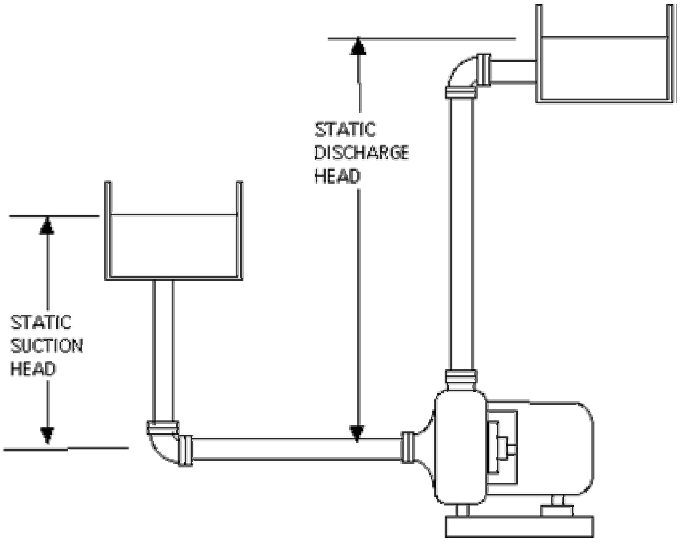
This primary containment design earns the pressure-suppression label by how it is supposed to function in event of an accident. As shown in the mimic, the energy produced by the reactor core no longer gets carried off to make electricity when a pipe connected to the reactor vessel breaks. The energy flows out through the broken pipe into the drywell portion of primary containment. This energy flow increases the pressure within the drywell and forces air and steam to flow through the vent system into the wetwell. The vent system exhausts below the surface of the water in the suppression pool portion of the wetwell. The water condenses the steam and cools down the air bubbling to surface of the suppression pool. The suppression pool water serves as an “energy sponge” to soak up energy (heat) released into primary containment during an accident. It heats up to nearly 200ºF during the course of an accident. Without the pressure suppression function of the water, the primary containment would either have to be built far stronger or far larger so as to handle the energy released during an accident.



The suppression pool water has another equally important job. The emergency core cooling system (ECCS) pumps take water from the suppression pool and supply it to the reactor vessel to prevent overheating (melting). Makeup water to the reactor vessel is crucial in restoring the energy balance. The water entering the reactor vessel gets warmed by the decay heat from the core and then spills out through the broken pipe into the drywell. When the ECCS functions properly, sufficient makeup water enters the reactor vessel to carry away the core’s decay heat.



The ECCS pumps are typically located below the level of the suppression pool. The difference between the surface of the suppression pool water and the inlet to the pump is called the static suction head, or static head, as shown in the graphic.

Net positive suction head (NPSH) is a key parameter in determining whether the ECCS pumps will be able to provide the necessary cooling water flow to the reactor vessel. The NPSH depends on factors like the static head (height of water), discharge head, water temperature, flow rate, and length of piping.

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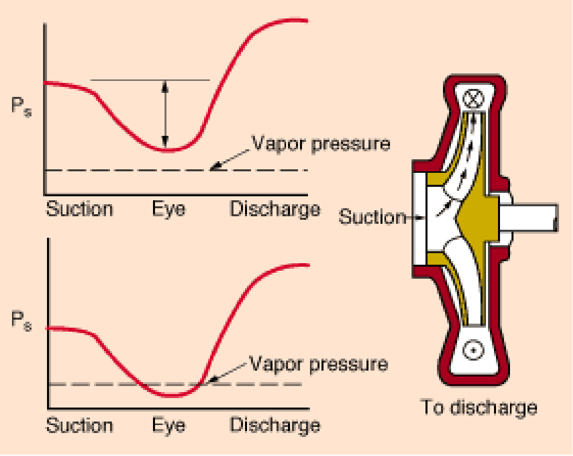
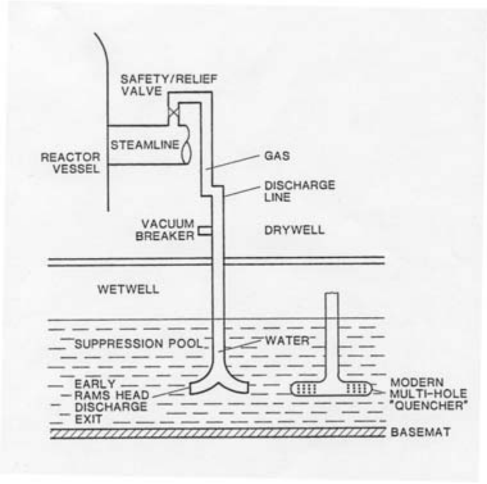
The water temperature determines the vapor pressure, or the pressure at which the water boils. Water at sea level boils at 212ºF. It boils at lower temperatures when pressure is lower than that at sea level (for example, water boils in Denver – the mile high city – at slightly less than 212ºF) and boils at higher temperatures if the pressure is greater than that at sea level.

Turning on an ECCS pump "pulls" water from the upstream pipe and "pushes" it into the downstream pipe. The water pressure inside the pump drops as it gets closer and closer to the impeller (the "eye" or spinning vane that moves the water) and then rises to a peak at the pump's outlet as shown in the graphic. When water inside a pump drops below the vapor pressure, the bubbles formed by boiling water can disable the pump or impair its ability to supply the necessary flow rate. When pumps have adequate NPSH, the pressure inside the pump stays above the vapor pressure.



The NRC's long-standing requirement has been that the static head alone provides adequate NPSH for the ECCS pumps for all their safety functions. In other words, the static head ensures that the water pressure inside the pump remains above its vapor pressure like the upper curve in the graphic. If the ECCS pumps have insufficient NPSH and run in a degraded state or cease to run altogether, it may be impossible to maintain the vital balance between the energy produced by and removed from the reactor core.

Some nuclear plant owners, like that for Vermont Yankee, seek to take credit for containment overpressure in order to meet the NPSH requirements for the ECCS pumps at uprated power levels. Containment overpressure is the pressure above atmospheric inside the containment caused by the energy released during the accident. That pressure, when added to the static head, can keep the water pressure inside the pump from dropping below the vapor pressure, avoiding the situation shown in the lower curve in the graphic. The plants were originally built and licensed for static head alone to keep pressure above the vapor pressure. But higher suppression pool water temperature and/or higher ECCS pump flow rates at power uprate levels drop the pressure below the vapor pressure – unless containment overpressure is available.



However, there are several reasons why the containment overpressure may not be available. The accident scenario outlined above involves a pipe breaking inside containment. The energy released from that broken pipe pressurizes the drywell first and very quickly thereafter heats up the suppression pool water. Assuming no other complications, containment overpressure is virtually guaranteed because its arrival precedes that of the warmed suppression pool water.

Other possible accident scenarios yield different outcomes. One such scenario involves a stuck-open relief valve – a very real part of the very real meltdown at the Three Mile Island nuclear plant. When a safety/relief valve opens, energy "bypasses" the drywell to flow directly through the vent system (labeled discharge line in the graphic) into the suppression pool water in the wetwell. The suppression pool water gets heated *before* the drywell gets pressurized. Containment overpressure is definitely *not* guaranteed for this scenario.

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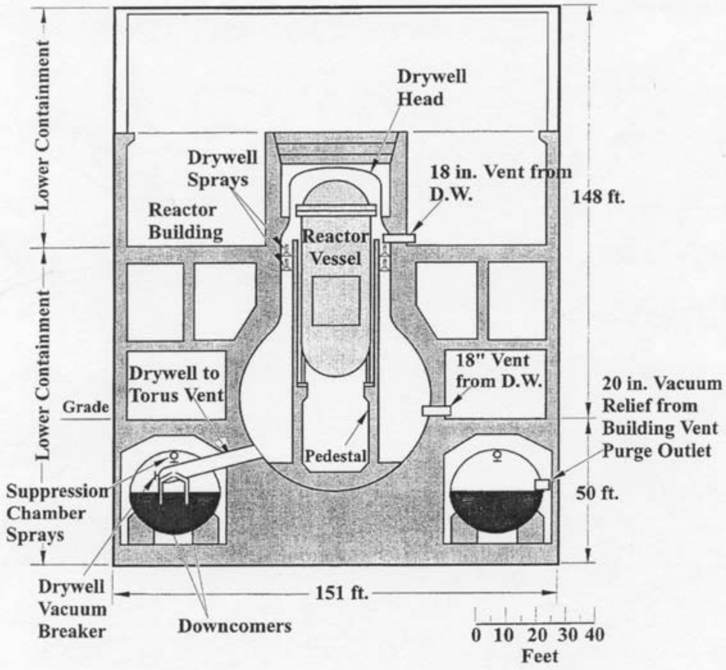

Typical BWR Mark I containment

Another possible accident scenario where containment overpressure might not be available involves the containment spray system. Two carwash-styled piping rings, labeled Drywell Sprays, are shown in the cross-section view of a Mark I containment like the one at Vermont Yankee. The containment spray system sends water out through nozzles in these piping rings to cool down the sauna-like conditions inside the drywell following an accident. The containment spray also tends to cool down the suppression pool water. But anyone who has spent a day at the beach and experienced the air temperature swing from cool to hot to cool while the ocean temperature stays constant can appreciate that the suppression pool temperature is slow to change after containment spray initiation. Thus, if the containment spray is inadvertently initiated, whether caused by equipment failure or operator error, the containment overpressure condition may suddenly end.

There are other events that could result in the loss of containment overpressure are commonly referred to as single failures. Such failures – including valves not closing properly, pipes leaking, or the wetwell's walls cracking – may breach primary containment and end the overpressure condition. NRC's regulations are very clear that nuclear plants must be designed to tolerate any single failure and still have the ability to cool the reactor core. Regulations are also clear in that the three barriers protecting the public (i.e., the integrity of the fuel cladding, reactor coolant pressure boundary, and containment) must be independent of each other. Relying on containment overpressure removes this independence and safety margin because the fuel barrier integrity depends on the integrity of the containment. If the containment fails, reactor core damage soon follows.

Rather than take credit for containment overpressure and hope that one of these possible scenarios doesn't occur, the NRC should protect the public by insisting that adequate NSPH for ECCS pumps be guaranteed by static head alone. Anything less means that public protection standards are being sacrificed at the corporate profit altar. Greed is insufficient reason to abandon this long-time safety principle.

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