Article 3: Safety

During regular operations, nearly all the radioactivity produced in a nuclear reactor remains within the reactor. As a result, the radiation dose to the public from routine operation of nuclear power plants is small, measured, for example, against the radiation received from radon gas in homes, cosmic rays from space, and medical procedures. The situation is dramatically different during severe accidents, such as those that occurred in March 2011 at multiple reactors at Fukushima in Japan. Radiation was released and dispersed widely, resulting in the evacuation of an estimated 160,000 people, the deliberate destruction of contaminated crops and food, and widespread anxiety and depression among survivors. One large direct cost came from shutting down 48 nuclear power plants in Japan; plants seeking permission to resume operation will need to install safety upgrades. Four years later, no reactor has resumed operations, work at the site to decommission the facility is still under way, and over 100,000 citizens still cannot return to their homes.

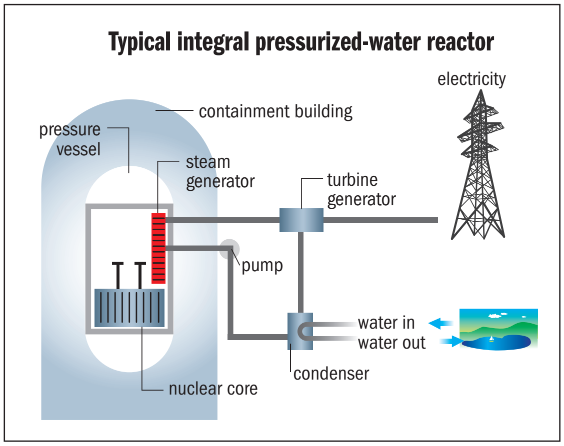

Figure 3.1: Schematic of integral pressurized-water reactor. In conventional, non-integral reactor designs, the steam generator (shown in red) is outside the pressure vessel.

The standard approach to lowering the risk of a catastrophic nuclear accident is to choose reactor designs that have a very low probability of undergoing certain kinds of accidents and to include multiple redundant safety features to prevent the release of radioactive materials. For example, the cladding surrounding the fuel would have to give way, the integrity of the pressure vessel would have to be lost, and the containment structure that surrounds the reactor would have to be breached before a radioactive release from the reactor core could occur. Safety is also enhanced through the establishment of emergency planning zones around the reactor, from which evacuation is pre-planned.

In some respects, small reactor size provides additional safety opportunities. Any accident at a single small reactor will have less impact than the same accident at a large reactor simply because the small reactor will generally have a smaller in-core inventory of radioactive material and less energy available for release during an accident.

Smallness also permits certain design modifications that could enhance safety. For example, for small pressurized-water reactors, Family 1 in our categorization system, it becomes feasible to place the high-pressure primary cooling loop entirely inside the pressure vessel, which means that a break in that loop should not result in a loss of cooling function for the reactor (see Figure 3.1). Doing the same in currently deployed large pressurized-water reactors would require substantial enlargement of the pressure vessel, which could impact its structural integrity. For larger pressurized-water reactors, such a “loss-of-cooling accident” resulting from a failure in the primary cooling loop has long been a focus of attention. The cooling water for the reactor comes in at high pressure, and if the pipe carrying this cooling water were to break, the water would blow out of the hole in the form of steam and the reactor would lose its cooling. The reactors in French submarines already incorporate a primary cooling loop entirely within the pressure vessel.

A second advantage of smallness arises for reactors that strive to be passively cooled in the event of an accident. Passively cooled reactors aim to operate without the need for external inputs, such as electricity for fans or pumps to drive water or air, after the plant shuts down; instead, the heat that builds up in the reactor in an accident might be cooled convectively by natural ventilation or there might be a large pool of water that boils off, carrying away heat from the reactor in the process. China is building a small modular reactor (210-megawatt capacity) whose fuel is in the form of small balls (pebbles) with special coatings (a “pebble-bed reactor”). The idea is to limit by passive means the maximum temperature that the pebbles can attain, even during an accident, to below the temperature at which the coatings fail and radioactive fission products can escape from the pebbles. A larger reactor of this kind could not be passively cooled without design modifications.

Even when a single small reactor has safety advantages over a single large reactor of the same kind, there is still the question of whether several small reactors are safer than a single large reactor when both have the same total capacity. Depending on the relative levels of safety, it is possible that the likelihood of an accident at one of the five small modular reactors may be larger than the likelihood of an accident at the large reactor, even if each individual small modular reactor is safer than the large reactor.

Further, an accident at one unit may make it harder to prevent an accident at a second one, for example, if the units have been put at risk for a common reason, like an earthquake. At Japan's multiple-reactor Fukushima Daiichi plant, explosions at one reactor damaged the spent fuel pool confinement building in a co-located reactor. Radiation leaks from one unit made it difficult for emergency workers to approach the other units.

Around each reactor site is an emergency planning zone whose size has an impact on reactor siting and operating costs. A typical emergency planning zone for a large nuclear plant in the United States extends to about 10 miles from the reactor. The analogous term used by the International Atomic Energy Agency and many other European countries is "urgent protective action planning zone," and this varies from a few miles to up to 15 miles, depending on the characteristics of the plant. Operating costs are affected by the size of the emergency planning zone because the reactor owner is required to pay to maintain the capability of the local government and local population within the emergency planning zone to respond to an accident. Typical costs include the costs of training emergency service providers so that they are prepared to implement protective actions such as the evacuation of citizens.

Substantial effort is being directed by small modular reactor vendors toward the objective of being allowed to have a smaller emergency planning zone than that of a large nuclear plant. Some of these vendors argue that the zone need not extend beyond the site boundaries of the small modular reactor power plant. An open question in the United States today is whether the Nuclear Regulatory Commission will allow such shrinkage of the emergency planning zone. Other countries, including China and South Korea, have seen less debate over this question, with the regulatory authorities and small modular reactor designers agreeing to continue with the same rules as for large reactors, at least initially.

The emergency planning zone discussion is one of many where the issue is how to distribute the safety advantages of small modular reactors between public and private interests. Another example where rules bearing on safety and security are under discussion addresses the number of units that can be managed from one control room. At one extreme, the entire safety benefit accrues to the public, which sees no dilution of the safety-related rules already established for large nuclear plants. At the other extreme, safety-related costs are reduced until small modular reactor operation is less safe than large-reactor operation, making the industry more profitable at the cost of increased public risk. More generally, shrinking the emergency planning zone and augmenting the tasks assigned to a single control room are examples of rule changes that may reduce operating costs but increase operating risks.