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Safety Issues of Boiling Water Reactors

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Abstract

The world nuclear share of electricity generation is increasing day by day. A nuclear reactor is a complex system in which the energy produced by fission nuclear reactions and the chain reaction are kept under control. Nuclear reactors can be divided into several different categories. Nuclear power is a viable, economically competitive and safe option to contribute to the high electricity demand expected for the next decades. Currently, nuclear energy is the largest source of electricity without emission of greenhouse gases. The Bangladesh government has planned to setup 4000 MW nuclear power station by 2030. In several countries, for electricity generation, the capacity factors are the highest for any type of fuel and, at same time, production costs from nuclear power are the lowest. However, public acceptance is still a major issue to overcome before nuclear power can be exploited to its fullest. Issues as nuclear plant security, waste management and reactor safety are constantly being debated by civil society. The boiling water reactor (BWR) is a type of light water nuclear reactor used for the generation of electrical power. It is the second most common type of electricity generating nuclear reactor. The Boiling water reactor safety systems are nuclear safety systems constructed in order to prevent or mitigate environmental and health hazards at the time of reactor operation as well as at the time of emergency condition. Both common and special safety features of different types boiling water reactor are discussed in this paper.

Keywords: *Boiling crisis, Boiling water reactor, Nucleate boiling, Passive Safety Systems, Emergency Core Cooling System.*

1. Present Status of Nuclear Power Plant Worldwide

Because of the high performance operation of current nuclear power plants, high and volatile price of natural gas and oil, and because nuclear energy is the largest energy source without emission of greenhouse gases, nuclear power electricity generation has regained attention from the energy industry. The world nuclear share of electricity generation was about 16% during 2003. The total number of nuclear power plants worldwide generation at least 30 net MWe during this time period was 438. These power plants generated 65,852 net MWe. Compared to 2002, these were a generation increase of 2008 MWe, although there was six nuclear power plants more operating in 2003. Safe operation of nuclear plants is its highest level of priority; general public opinion still shows clear concerns regarding nuclear reactor safety. In order to provide an understanding of the safety issues during design and operation of commercial nuclear reactors, a short description of the main design and operation parameters related to nuclear reactor safety are presented here.

Nuclear safety is a set of actions taken to protect individuals, society, and the environment against radiation risks. These actions can be divided into three general groups: (a) safe normal operation of nuclear facilities; (b) prevention of transient events and accidents; (c) mitigation of the consequences of the transient events and accidents that could occur.

For a nuclear power plant, the set of actions related to safe operation imply that normal operation must be performed within specific limits and conditions. Besides normal operation, it also includes maneuvering during reactor startup, power increase and decrease, shutdown, maintenance, test and transients, which are events expected to occur to take actions to prevent significant damage to reactor components or to avoid reaching accident conditions.

The prevention of transient events and accident conditions in a nuclear power reactor is accomplished by the use of components, system and procedures, all related to safety. Accident prevention is the top priority for reactor designers and operators. Operating personnel are required to have strong commitment to the culture of safety. Means of accident prevention include: 1) technical aspects, as emergency system used to control conditions that could lead to accident scenarios, 2) an in-depth defense strategy, which prevents the release of radioactive material by using a series of physical barriers, 3) inspections and tests, which are regularly performed on systems and components to reveal any possible malfunction or degradation.

2. Nuclear Reactor Designs

The main difference between a typical large nuclear power plant and one using fossil fuels is the energy source; the former involves nuclear fission and the letter chemical combustion. The other major components of the power plants are basically the same, as a steam supply system, turbine and condenser, and the electrical generator, as shown in Figure 1. Another major difference between fossil-fueled and nuclear reactor plant is that the latter have redundant safety systems.

Excluding graphite-moderated light water-cooled nuclear reactors, more than 400 reactors are cooled by gas or water. If heavy water is used as coolant, this type of nuclear reactor is referred as to Heavy Water Reactor (HWR), whereas the term Light Water Reactor (LWR) is applied to a nuclear reactor cooled by ordinary water. Two types of LWR exits: Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR). 81% of all nuclear reactors in the world are LWR type and they produce about 87% of the total nuclear power. In this paper safety aspects will be focused on LWR nuclear power plant, and more specifically in BWR plants.

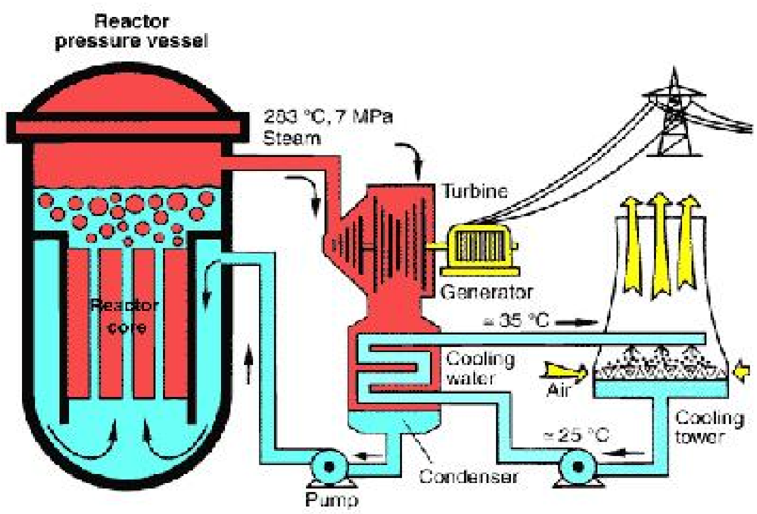

Fig. 1. Typical Boiling Water Reactor Power Plant [3]

3. Nuclear Reactor Safety Design

The nuclear aspects of the design of a nuclear reactor core are highly dependent on other areas of design of the power plant, as thermal hydraulics, structural analysis, economic performance, etc. Thus, the overall design of a large commercial nuclear plant is an enormous complex task that involves that involves coordination among several diverse disciplines. The design is not at all a one time, static process, but an iterative one, since the design is refined through several steps to identify and satisfy constraints, safety issues, and economic performance.

The major safety concern for a commercial nuclear power plant is to avoid the release to the environment of the large inventory of radioactive fission products accumulated in the nuclear fuel, for any foreseeable accident. To avoid such fission product escape, several safety engineering barriers exits: first the fuel pellet itself keeps the solid and some of the gaseous products in the matrix. Then, the next barrier is the fuel rod cladding, which keeps those fission products accumulated in the fuel rod gap from reaching the core coolant. Figure 2 shows the schematic of typical BWR fuel element.

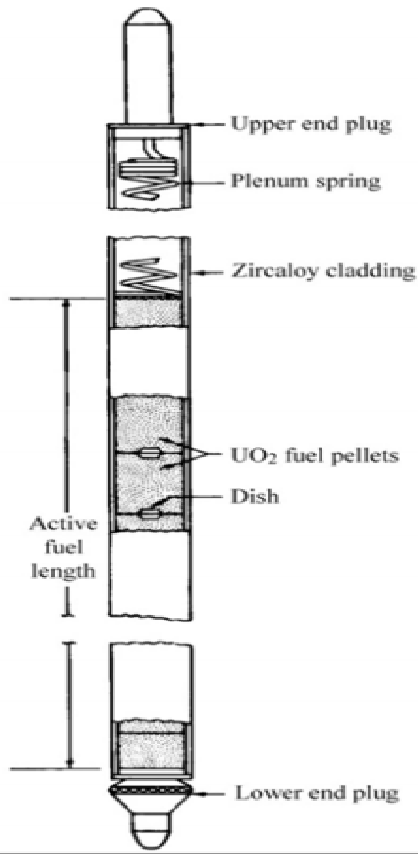

Fig. 2. Typical Boiling Water Reactor fuel element [1]

If some fission products could leak out through the fuel rod cladding into the coolant system, the next barrier is the reactor primary system, which is the coolant piping system and the pressure vessel. If a catastrophic situation is considered, the pressure vessel could fail, and then the containment structure, that is the reactor building, is the last barrier that the fission products need to leak out through to, finally, reach out to the power plant surrounding environment. Figure 3 shows all the typical safety barriers and their features of modern BWR design.

The design of the above mentioned safety engineering barriers involves choosing the correct construction materials for each of the barriers, except, clearly, the fuel pellet, since the environment in a nuclear reactor is characterized by very high pressures, large thermal gradients, and an intense nuclear radiation field. Therefore those materials employed for the safety barriers are required to have nuclear quality, since nuclear radiations alert the properties of such materials, besides the demanding thermo-mechanical stresses.

Although the engineered safety barriers are intended to physically contain the fission products, there are additional operational measures and systems designed to take preventive action, in the event of abnormal behavior of the nuclear reactor. Separate safety systems have primarily to keep the reactor core cooled, and fully covered at all times, in case of accident. Even when the reactor is shut down, the remaining decay heat needs to be removed from the core to avoid core meltdown. These safety systems include control rods and an Emergency Core Cooling System (ECCS). The ECCS mainly includes high and low pressure coolant injection systems to keep the core fully covered.

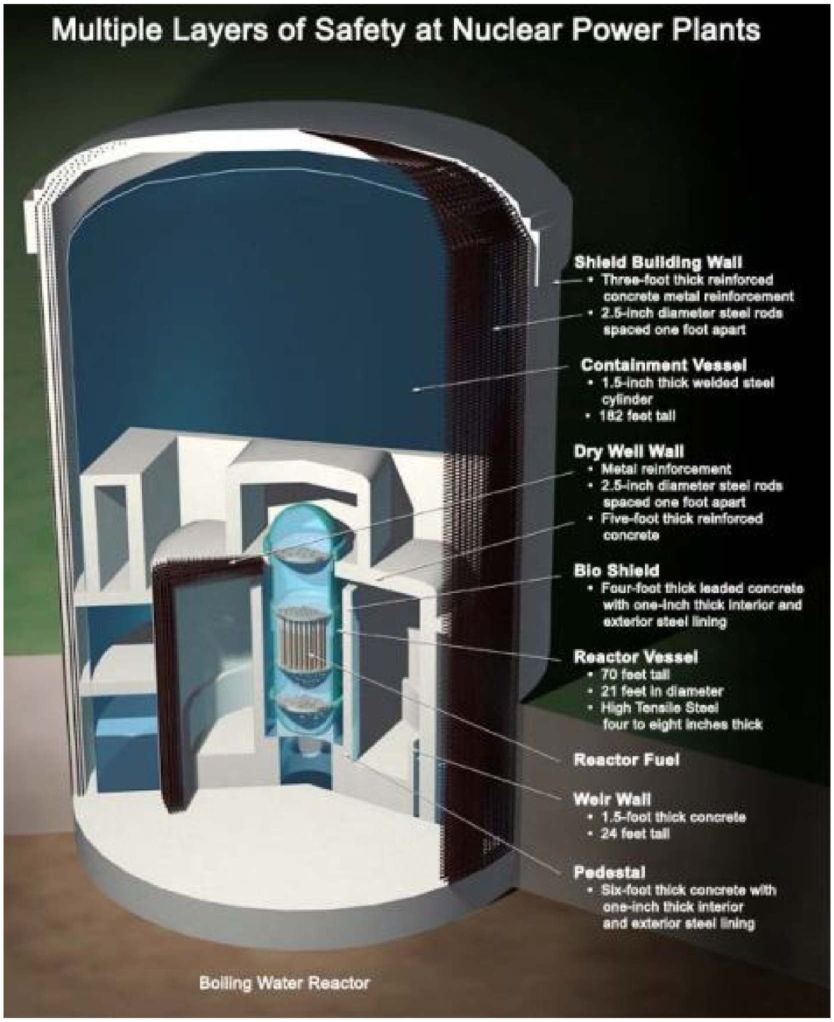

Fig. 3. Multiple layers of safety of Modern BWR [2]

4. Safety Systems of Advanced Boiling Water Reactor (ABWR)

ABWRs are Generation III reactors based on the boiling water reactor. ABWR has three completely independent and redundant divisions of safety systems. The systems are mechanically separated and have no cross connections as in earlier BWRs. They are electronically separated so that each division has access to redundant sources of ac power and, for added safety, its own dedicated emergency diesel generator. Divisions are physically separated. Each division is located in a different quadrant of the reactor building, separated by fire walls. A fire, flood or loss of power which disables one division has no effect on the capability of the other safety systems. Finally, each division contains both a high and low pressure system and each system has its own dedicated heat exchanger to control core cooling and remove decay heat. One of the high pressure systems, the reactor core isolation cooling (RCIC) system, is powered by reactor steam and provides the diverse protection needed should there be a station blackout. The safety systems have the capability to keep the core covered at all times. Because of this capability and the generous thermal margins built into the fuel designs, the frequency of transients which will lead to a scram and therefore to plant shutdown have been greatly reduced (to less than one per year). In the event of a loss of coolant accident, plant response has been fully automated. Any accident resulting in a loss of reactor coolant automatically sets off the Emergency Core Cooling System (ECCS), made up of multiple safety systems, each one functioning independently. ECCS also has its own diesel-driven standby generators that take over if external power is lost.

High Pressure Core Flooder (HPCF) and Reactor Core Isolation Cooling (RCIC) systems: These systems inject water into the core to cool it and reduce reactor pressure.

Low Pressure Flooder (LPFL) system: Once pressure in the reactor vessel is reduced, this system injects water into the reactor vessel. The reactor core is then cooled safely.

Automatic-depressurization system: Should the high-pressure injection system fails, this system lowers the reactor vessel pressure to a level where the LPFL system can function.

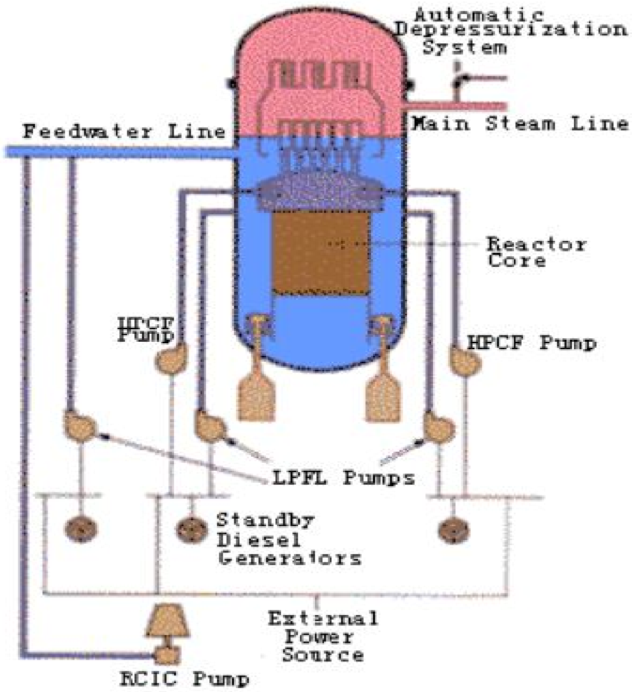

Fig. 4. Emergency Core Cooling System (ECCS) [2]

5. Safety Systems of Economic Simplified Boiling Water Reactor (ESBWR)

The Economic Simplified Boiling Water Reactor (ESBWR) is a passively safe generation III+ reactor which builds on the success of the ABWR. Natural circulation is consistent with the key objectives of the ESBWR program: a passive safety design with simplification achieved by evolutionary enhancements.

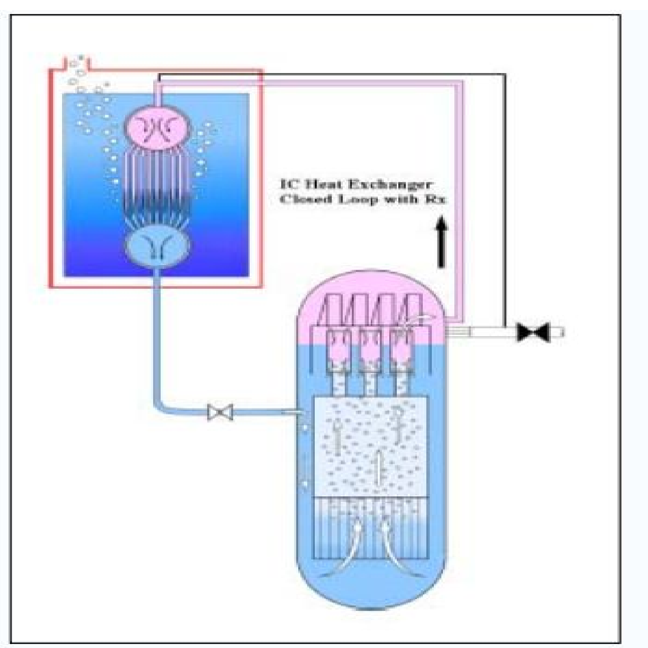

Fig. 5. Isolation Condenser System [3]

Most of the components in the ESBWR design are standard to BWRs and have been operating in the commercial nuclear energy fleet for years. The passively safe characteristics are mainly based on isolation condensers, which are heat exchangers that take steam from the vessel (Isolation Condensers, IC) or the containment (Passive Containment Cooling System, PCCS), condense the steam, transfer the heat to a water pool, and introduce the water into the vessel again. This is also based on the gravity driven cooling system (GDCS), which are pools above the vessel that when very low water level is detected in the reactor, the depressurization system opens several very large valves to reduce vessel pressure and finally to allow these GDCS pools to reflood the vessel.

6. Summary and Closing Remarks

(1) Safety of nuclear power plant is an on-going concern. Safety is an essential and critical issue of engineering design, and safety tends to receive greater emphasis when failure could have serious consequences.

(2) The design of the containment not letting the radiation to escape in the atmosphere is still under research. Different composite materials that can be used in designing the containment to absorb the maximum amount of radiation are currently on progress and also have been applied in modern advanced reactors.

(3) The materials which are employed for the safety barriers are required to have nuclear quality, since nuclear radiations alert the properties of such materials, besides the demanding thermo-mechanical stresses.

(4) In modern nuclear reactors active safety systems along with passive safety systems have been inherently mobilized to mitigate the critical situations.

(5) All types of safety system should be kept in proper check-up and maintenance for the assurance of their operation on due time.

(6) More research should be going on for the invention of new safety systems and for the development of the existing types.

(7) For the enhancement of safety issues, importance should be given on thermal hydraulics characteristics of nuclear reactors.

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