CHAPTER-1

INTRODUCTION

1.1 GENERAL

Electricity is one of the most important blessings that science has given to mankind. Electricity has become an important feature of everyday life and no one can imagine of a world without it. There are three major electric energy sources in the world (i) Fossil fuels (petroleum, coal, natural gases) (ii) Renewable energy (hydro power, solar energy, wind energy, biomass) and (iii) Nuclear energy (nuclear fission). The energy demand will be increased in coming years because of the high rate of population growth in the world. The pollution of atmosphere depends on the energy demand.

Nuclear energy produces massive amount of carbon free electricity, that minimize the pollution. As nuclear energy does not have to combust anything to produce energy, greenhouse gas emissions such as methane or CO_2 are not released. According to the World Nuclear Organization, nuclear power provides about 15 percent of the world's energy. The total 442 number NPP reactors are generating approximate 424 GWe of power, the world's second-largest low-carbon power source. There are many types of power reactors, but only one is commonly used, the light-water reactor (LWR). The LWR has two basic categories (1) boiling water reactor (BWR) (2) pressurized water reactor (PWR).

The working mechanism of BWR is to heat water to spin turbines and produce energy until it boils. In case of PWR, it heats up water before injecting this water into a separate supply to near the boiling point. Basically, steam is used in this compartment to run a turbine.

There are different types of material available in the world which can be used as fuel of a reactor but the most frequently used fuel in nuclear reactor is uranium. Unlike solar and wind, nuclear energy is a continuous, sustainable source of energy that can operate for a year without interruptions. NPP reactors are quite efficient in producing electricity power, able to operate for several months, if not years, 24 hours a day, without interruption, regardless of the weather or season. In addition, most nuclear reactors can run in many situations for very long periods of time, over 60 years. The following are the benefits of nuclear power plants: -

- Compared with other power plants, it uses less space.
- The operating cost is low.
- It releases an enormous amount of energy in the phase of each nuclear fission.
- This doesn't emit harmful gasses.
- It takes less fuel to produce enormous electricity.
- It is highly economical and produces massive electrical power.
- It is very clean and organized as compared with steam power plants.
- These plants are situated near the load center as there is no massive fuel demand.
- It is quite neat and clean.

After 1950, the nuclear reactor was largely developed and since then modified. Inside of a NPP reactor, nuclear fission takes place. The center of a reactor is called core that contains uranium radioactive material as fuel. A typical block diagram of NPP is shown in Fig.1.1.

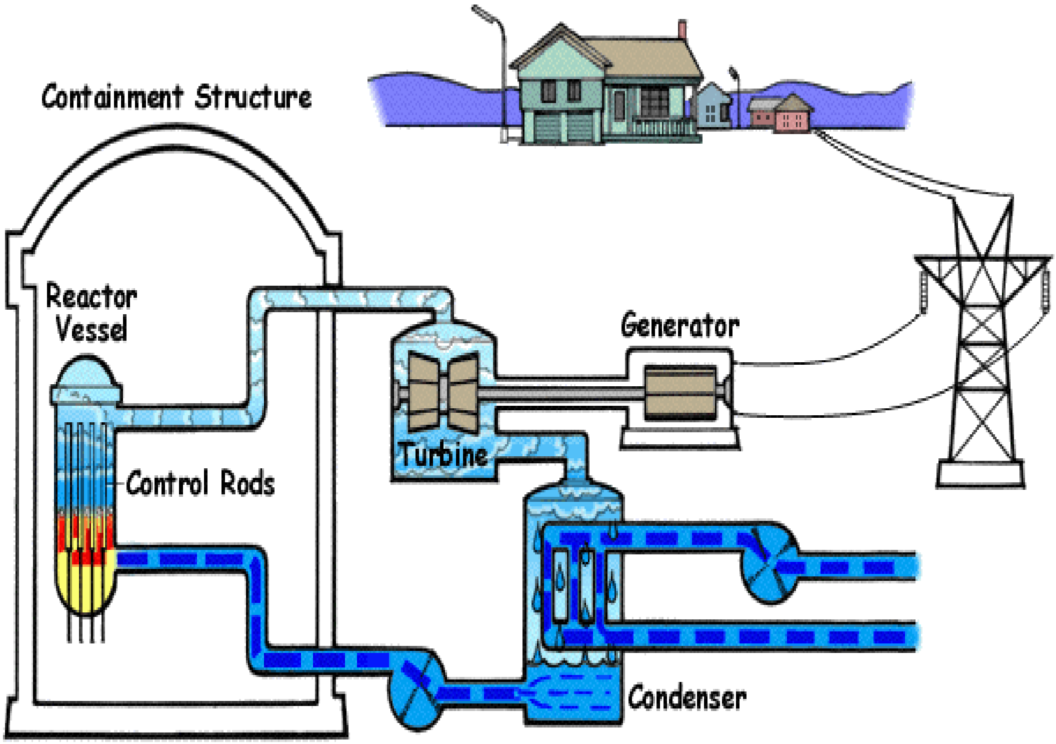

Fig. 1.1 A typical Block diagram of Nuclear Power Plant, (www.elprocus.com)

1.2 NUCLEAR POWER PLANTS WORLDWIDE

In 1950, the idea of NPP containment started in U. S. A. and was widely adopted throughout most of the country. After Fukushima accident in Japan (2011) and Three Mile Island accident in U. S. A. (1979), severe testing of Western-style containment systems initiated. In the world, the USA has 96 number of operating nuclear power plants that is maximum in a single country. All together, they have a capacity of 97,565 megawatt (MW), and around 20% of the country's electricity production is generated by nuclear energy (up to 2019 data). France has 58 nuclear plants, generating about 75% of the country's electricity. The top five countries are using nuclear energy for electricity production which are U. S. A. (96), France (58), China (48), Japan (37), and Russia (36). Mostly nuclear power plants are situated in North America and Europe (Fig. 1.2). The country wise nuclear power plants in world have been shown in Fig. 1.3.

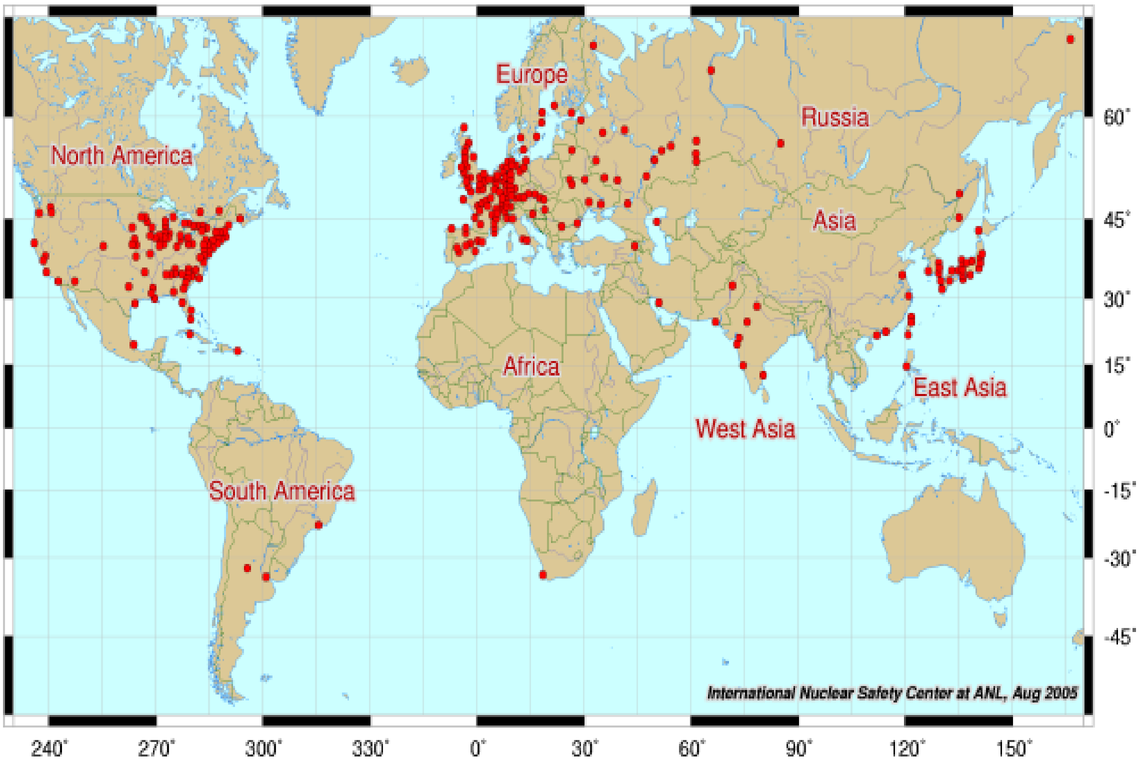

Fig. 1.2 Total number of Nuclear Power plant stations in world (home.olemiss.edu)

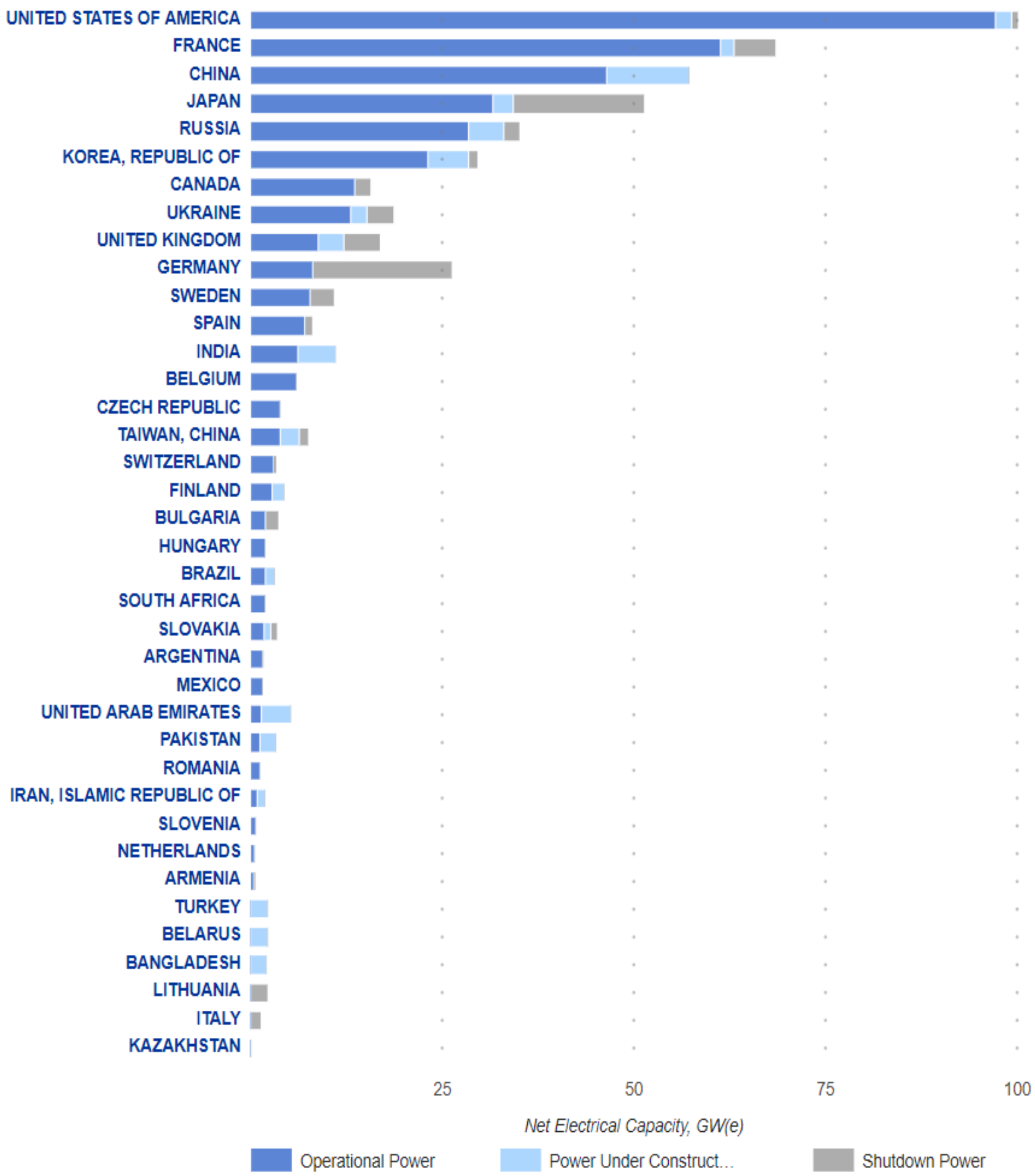

Fig. 1.3 Country wise nuclear power plants (pris.iaea.org)

Worldwide, there are more than fifty nuclear reactors under construction, mostly in China. The amount of electricity production in nuclear reactor is increased in last ten years in the world. At present time, the total number of nuclear power plant in the world is about 442. The efficiency of 442 operable NPP reactors was 392 GW (gigawatt) in the world at the end of 2019 but this value was 397 GW at the end 2018. The reason for decreasing the value is 13 reactors have been closed, 4 of which have been in Japan and have not produced energy since 2011, and 3 have been closed unnecessarily in Taiwan, Germany and South Korea because of political phase-out policies. The most commonly used power plant reactor is PWR and BWR which has been given in the Table 1.1.

Table 1.1 Types of Reactor with capacity

Reactor Name	Full name	Reactors (numbers)	Total Electrical Capacity (MW)
BWR	Boiling Water Reactor	65	65604
PWR	Pressurized Water Reactor	299	283798
FBR	Fast Breeder Reactor	3	1400
PHWR	Pressurized Heavy Water Reactor	48	23875
GCR	Gas Cooled Reactor	14	7725
LWGR	Light Water Graphite Reactor	13	9283
Total		442	391685

1.3 NUCLEAR POWER PLANT (NPP) CONTAINMENT

Basically, nuclear reactors are huge kettles and they have various sizes and shapes. Most of the NPP has cylindrical wall with circular dome. Sometime, the image of large cooling tower is used as a symbol of nuclear power plant. The real images of some existing power plants have been given in Fig. 1.4.

Fig. 1.4 Some actual nuclear power plants(www.shutterstock.com)

The containment wall around the NPP reactor designed to prevent it from external impact or any external accident. The containment wall is also working as a safety wall in case of any inside disaster (leakage of radiation). The structure around reactor is generally a thick concrete and steel structure. The structure of NPP containment must be at least generally airtight to prevent the leakage of nuclear radiation. The NPP containment building must also defend unavoidable situation such as tsunamis, tornadoes, and airplane crashes. There are very large quantities of radioactive isotopes in nuclear reactor. If this nuclear radioactivity spreads from the reactor, it would have a significant effect on the citizens around. The harmful effects of radioactive material are cellular damage, risk of cancer, developmental irregularities in babies etc. For this purpose, it should be confirmed that the leakage of radiation does not occur as a result of any accident situation and it is the primary concern when constructing a reactor. Some actual aircraft crashes have been shown in Fig. 1.5.

Fig. 1.5 Some actual aircraft crashes (from internet sources)

After all, the endorsement of a safety requirements for nuclear power generation continues a major issue. NPP produces radioactive liquids and gases, as well as small quantities of harmful radiation. Nuclear radiation has dangerous effects on human beings for long term because the radiation may cause fatal diseases. So, it is a very important issue to safety check of nuclear containment structures in any adverse situation. Complete and partial failure of nuclear containment structures can cause radiation leakage if targeted during wartime and terrorist attacks in a particular sensitive location of the containment.

The deliberate crashes of large commercial aircraft on NPP structures and other important national structures have drawn much consideration around the world at the beginning of 21st century, particularly after September 11, 2001, terrorist attack. Before 11 September incident, the safety of nuclear structures was not considered to withstand any external thrust for a small or large commercial aircraft.

The nuclear wall typically has two types, one indoor and the other outdoor. internal wall purpose is to regulator the outflow of radioactive energy while the external wall offers protection from external threats. Experiments are very costly to obtain the reaction effect of the NPP wall. So, some researchers simulated the containment wall model numerically to find out the containment behaviour. There are currently 64 expanding and under-construction nuclear reactors, the majority of which are located in Asia. A well-made reinforced concrete (RC) container vessel can effectively prevent damage from external events such as earthquakes to nuclear reactors.

In countries with high air traffic volume, there may be a serious risk of accidental and deliberate commercial and fighter aircraft crash. In addition to the accidental crash, the nuclear containment structures are also subjected to many intentional attacks. In order to withstand a deliberate aircraft crash, several countries have reconsidered the design requirements for nuclear power reactor buildings in order to withstand the current circumstances. The Nuclear Regulatory Commission (NRC) has proposed changes to the containment structural design. According to the Federal Register Notice (2009), in order to study the behaviour of NPP containment against the direct external impact due to large aircraft the applicants for NPP necessity to carry out a design-specific review of the current guidelines of the commission.

The NPP containment structure subjected to aircraft crash is an extremely complicated phenomenon which involves high strain rate, large deformation, high temperature, and many mechanisms of failure. Both kinds of nonlinearity, i.e., geometric, and material nonlinearity are involved in this problem. Even on a small scale, it is extremely uneconomical to perform such experiments. In addition, several assumptions have also been suggested in numerical/analytical methods in order to minimize complexity. The modeling of NPP containment and aircraft is very complex and time consuming in this analysis. Aircraft loading is obtained via the aircraft's crushing strength and impact energy which is documented in the form of force-time history curves. In literature, the force time history curves for different aircraft at different impact velocities are available. To predict a reasonably precise response of the NPP structure against an aircraft, these reaction curves can be used. The aircraft accident scenario cannot be neglected because every year it is occurred. From the previous data of aircraft accidents and fatalities it can be observed aircraft accident cannot be ignored.

In the present study, the behaviour of nuclear power plant containment structure subjected to any accidental or deliberate aircraft crash has been carried out. As the experimental cost is very high to address the actual response of containment, the model of NPP and aircraft has been simulated using ABAQUS finite element solver (for numerical simulation). Initially several analyses are carried out to validate the results with the existing results in literatures. There are very few numbers of literature in this field. When any aircraft impact on NPP containment, the fuel spread out immediately. To get actual the behaviour of NPP containment, the impact load and induced fire effect must be taken into consideration. In the existing literatures, the NPP containment structures were analyzed only for impact load. Most of the Aircraft have their fuel in the wings. When the aircraft comes in contact with the target, the fuel will be spread out and the scattered fuel catches fire very fast. So, to get the actual behaviour of an NPP containment structure for an aircraft crash, it is mandatory to consider the fire-induced stress with the stress due to impact. So, the main aim of this work is to get the actual behaviour of NPP containment by coupling the impact and fire effects. Generally, the containment structure and aircraft body are made up of reinforced cement concrete and aluminium alloy respectively. For selection of material models, a proper investigation is performed and it is found that damage plasticity model (DPM) is the good for concrete behaviour and Johnson Cook model (JCM) is good for steel rebar and aluminium behaviour. As the material strength decreases with increasing in temperature therefore in heat transfer and thermal stress analysis, the parameters and properties of the material (steel and concrete) at different temperatures are taken from Euro-code 2. At first a PCC flat plate and then a RCC flat plate is simulated to validate the results and finally the most well-known 4 NPP containment structure i.e. Creys-Malville Reactor (CMR), Fessenheim and Bugey

Reactor (FBR), Boiling Water Reactor (BWR Mark-III) and Three Mile Island Reactor (TMIR) containment are considered. The aircraft Boeing 707-320, Boeing 767-400, Airbus A320, and Phantom F4 have been selected to get response of NPP containment wall subjected to impact load. As Boeing 707-320 is the benchmark of Boeing group, many authors tried to give the response of containment using this aircraft. Out of these four, the Phantom F4 is a fighter jet whereas all other three aircrafts are commercial aircrafts. In the present study it is also observed that the deformation and stress in impact location depend upon various parameters such as impact velocity, impact angle, % of steel reinforcement, thickness of NPP wall. Finally, it may conclude that the induced fire and impact together, however, has not been found to affect the NPP containment structure's global behavior.

1.4 THESIS ORGANIZATION

This thesis is organized as follows:

- The introduction and organization of thesis on present study has been discussed in ***Chapter 1.*** Complexity and importance of different issues related to the problem have also been discussed in this chapter.
- The review of literature is divided in three categories i.e., analytical, numerical and material behaviour. Detail reviews on the behaviour of Nuclear power plant containment wall under impact loading due to aircraft crash and the concrete and steel reinforcement behaviour under high rate of loading and elevated temperature has been given in ***Chapter 2.*** The research gaps and scope of the present study has also been provided in this chapter.
- The mathematical formulations and the strength properties of concrete and steel reinforcement at high impact load and at elevated temperature is given in ***Chapter 3.***
- The geometrical dimensions and meshing details of aircraft and NPP containment wall is discussed in ***Chapter 4.***
- The analysis of some hypothetical target and some real NPP containment wall subjected to aircraft crash and compared the results with existing literature is given in ***Chapter 5.***
- Evaluation of reaction-time curve on rigid and deformable target with different impact angles and the area of impact is discussed in ***Chapter 6.***
- Thermal stress analysis of Three Mile Island Reactor (TMIR) containment by coupling the impact and crash induced fire is given in ***Chapter 7.***
- Finally, conclusions and scope of future studies is listed in ***Chapter 8.***