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SEVERE ACCIDENT SEQUENCE OVERVIEW IN INDIAN PHWRS

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1 ABSTRACT

Nuclear reactors have traditionally been designed in a deterministic way. This implies that design provisions are made to cope up satisfactorily with all accidents that could arise within the design basis of the plant. Severe accidents can be defined as those events beyond the design basis which could lead to highly unsatisfactory consequences involving severe reactor damage, high risks to plant personnel and in worst cases large releases of radioactivity to the environment. Keeping in view the TMI and Chernobyl accidents it is no longer possible to limit nuclear safety considerations to the design basis accident. Hence there is a need to explore to a reasonable depth, the development of the design basis accident to verify that no 'precipice' lay just beyond the bounds of design basis accident. In this paper, the inherent design features relevant to severe accident and an anticipated sequence of events following a severe accident are described for the case of Indian PHWRs and procedures to mitigate the consequences of a severe accident.

2 INTRODUCTION

The Indian Nuclear Power Programme is based on natural uranium fueled heavy water moderated, heavy water cooled reactors(1). These reactors are of the pressure tube type with a power output of 220MWe. Each reactor consists of several hundred pressure tubes each of which contains twelve or thirteen short(0.5m)fuel bundles. These pressure tubes pass through a large horizontal vessel, called calandria, containing heavy water moderator and reflector. Surrounding each pressure tube is a calandria tube, the gap between them being filled with an insulating gas(dry CO_2) which reduces the heat loss to the moderator. Pressurised heavy water coolant is pumped through the pressure tubes, cooling the fuel and transferring the heat from the fuel to the outlet header and to the steam generators. The calandria vessel is located in a calandria vault containing light water.

Severe accidents occur undera rare combination of equipment and system failures or violation of operating guidelines or in the case of catastrophic events. In this paper, the inherent design safety features of the Indian PHWRs which prevent and/or reduce the possibility of severe accidents are indicated. A typical sequence of events leading to a severe accident is described.

3 INHERENT DESIGN SAFETY FEATURES

3.1 Core reactivity

The use of natural uranium fuel and heavy water moderator leads to more efficient fuel utilisation compared to LWRs and low excess reactivity. Low excess reactivity means that accidental reactivity excursions can lead to utmost mild power pulses that can easily be arrested by any of the two independent shutdown devices. The moderator temperature is independently controlled and hence only the fuel and the coolant undergo any significant temperature changes when the reactor power level is changed. Thus the temperature reactivity coefficients are small. This means that only moderatrely strong reactivity control devices are needed for power maneuvering and

reactor protection purposes.

3.2 Fuel cooling

Due to physical separation of coolant and moderator, the latter operates at relatively cool temperatures of about 65 deg.c. The cool moderator can act as heat sink in a severe loss-of-coolant accident, removing the decay heat from the fuel channels, even if they contain no coolant at all. Fuel would be severely damaged, but would not melt. The moderator is thus a low pressure emergency heat sink surrounding each fuel channel that would prevent fuel melt in a severe accident scenario. The large inventory of light water inside the calandria vault can prevent and/or delay the melt-through of the calandria vessel.

The shutdown cooling system is provided for normal decay heat removal and for cool down below 150 deg.c. This system can also operate at full primary heat transport pressure and temperature and therefore can be used as an emergency heat sink from hot shutdown, full pressure conditions, should the boilers be unavailable (3).

Two separate ECCS systems are provided for handling small LOCAs and large LOCAs. Small LOCAs are handled by this system without downgrading of heavy water. In case of large LOCAs, light water injection takes place from the accumulators followed by pumping of light water from the suppression pool in the recirculation mode. Fire water system run by separate diesel engine driven pumps can also provide a supply of water to the boilers independent of the normal and auxiliary feed water. It can also be used as an emergency heat sink should normal and auxiliary feed water and the shutdown cooling system, all be unavailable.

3.3 Shut down system

Two independent, diverse and fast acting shutdown systems have been provided to ensure that plant transients requiring prompt shutdown of the reactor will be terminated safely. Shutdown system No.1 consists of mechanical shut off rods (14 for 220 MWe and 28 for 500 MWe reactor) of cadmium sandwitched in stainless steel and makes reactor subcritical within two seconds. The second shutdown system of 220 MWe comprises of twelve liquid poison tubes which are filled with lithium pentaborate solution under helium pressure.

In 500 Mwe reactors, the second shutdown system quickly terminates the chain reaction by injecting concentrated gadolinium nitrate solution into the bulk moderaor through six horizontally located injection tubes in the calandria vessel. Each shutdown system is, independently, fully capable of shutting down the reactor for all accidents. All the reactivity control devices penetrate the low-pressure moderator but not the coolant pressure boundary. There is no mechanism for rapidly ejecting any of these rods, nor can they drop out of the core. This is a unie feature of the pressure tube design.

3.4 Containment

The containment system for the Indian PHWRs is rather unique in the sense that it uses a complete double containment philosophy with suppression pool concept. The space between the primary and the secondary containment is kept at a negative pressure ensuring that there will not be any ground level release during accident conditions. The containments are built sufficiently strong to take care of LOCA and seismic events occurring simultaneously. The primary containment is of prestressed concrete which is known to have forgiving behaviour even if it were to fail. Because of large containment volume the global concentration of hydrogen generated during a severe accident would not reach the flammability limit of 4%. Another reason for the low hydrogen concentration, even for LOCA plus failure of ECCS is that the cool moderator acts as an emergency heat sink and limits the pressure tube temperature below the level to which significant oxidation can occur. Thus the pressure tube metal does not contribute significantly to the hydrogen source term.

There is a huge suppression pool at the reactor building basement which condenses the steam released during a LOCA. The suppression pool system is an entirely passive system and does not perform any function during operational states. During LOCA conditions, the pool water is used for emergency core cooling in the long term recirculation phase. Should the ECCS, the moderator heat sink, and the vault cooling system all assumed to fail, the molten core debris would easily be cooled and contained in the suppression pool, thus ensuring containment integrity even under such severemost scenarios.

4 SEQUENCE OF EVENTS LEADING TO A SEVERE ACCIDENT

The event sequences of a severe accident in a PHWR reactor are profoundly influenced by abundance of water as given in TABLE 1.

TABLE 1. Inventory of water available to mitigate severe accident progression.

NO	SYSTEM	INVENTORY	
		220 MWE REACTOR	PROPOSED 500 MWE REACTOR
1	PHT	62,643 kg	125,000kg
2	CALANDRIA VESSEL	136,240 kg	260,000kg
3	CALANDRIA VAULT	420,000 kg	659,000kg
4	S.G.SECONDARY	71,000 kg	94,000kg
	TOTAL	689,883 kg	1,138,000kg

The total inventory as mentioned in TABLE 1, must boil off before the calandria vault is breached.

The following series of events have been considered for the severe accident scenario, that can initiate core damage:

1) total loss of process water
2) reactor trip and consequential loss of all electrical power
3)loss of S.G. inventory supply systems, including normal and auxiliary feed water supply.
4)loss of long term ECCS.

Soon after reactor trip and nonavailability of.a.c power, PHT flow will be maintained due to coast down and thermo-syphoning effect. Crash cooling will be initiated after the 6th minute. This will continue till the PHT temperature comes down to 150 deg.c. After this ASDVs will be opened manually till the secondary pressure falls below 4kg/sqcm. Thereafter, fire water injection to steam generator secondary is initiated. Fire water system is considered available as it is provided with separate diesel driven pumps. Fire water inventory is 450cu.m in sump. Fire water is supplied at the rate of 30 cu.m/hr. This water will last for about 14 hrs. Thereafter, steam generator secondary water boils off virtually dry resulting in complete stoppage of transfer of heat from primary to secondary. The primary coolant heats up and proceeds to boil off with relief at the relief valve set point to bleed condensor and eventually to containment (3). Partial inventory depletion leads to fuel heatup, which in combination with high circuit pressure leads few channels to fail. Blow down of the remaining coolant channels results in rapid primary system depressurisation. As long as there is adequate liquid in channels, the fuel will be cooled by either the liquid (sensible heat) or the steam generated (latent heat) and hence fuel damage will be minimal. Eventually, however, most of the liquid in the channels is boiled away and fuel temperature will rise.

Pressure tube temperature will start increasing as a result of the convective heat transfer from hot coolant and due to radiation from the overheated fuel bundles. When the pressure tube becomes hot enough, it will eventually balloon and establish contact with its associated calandria. A conductive heat transfer path is established through the calandria tube to the surrounding moderator. But before that due to non-uniform pressure tube strain, pressure tube would fail. Prior to contact with calandria tube, calandria tube could have failed. During this time the fuel sheaths are assumed to heat up enough to start to get oxidized with steam present in the channel. This phenomena will release significant amount of hydrogen and heat. Due to failure of some pressure tubes and calandria tubes hot coolant discharges through the failed channels to the moderator. This will result in moderator temperature rise and moderator will start boiling.

The decline in calandria water inventory uncovers successive rows of channels, the channels will sag, fail and dump fuel fragments at the bottom of the calandria. This will add stored heat and decay heat to the remaining moderator. Eventually, most of the moderator will boil away by about 24 hrs. The inventories of water are shown in TABLE 1.

The calandria vault water that surrounds the calandria vessel is still subcooled and it removes a large portion of decay heat from the dry debris bed inside calandria vessel. The boiling of calandria vault water removes the portion of core debris decay heat (conducted through the calandria shell) and increase steam concentration in the containment atmosphere).

The calandria vault water maintains the integrity of the calandria vessel until its levelsfalls below the level of the debris bed inside the calandria vessel at about 40 hrs. The calcualtions were performed assuming an area of 30 sq.m. in contact with vessel. The steady state heat flux to vault water through calandria wall is assumed to be about 500 kw/sq.m. Local heating of the calandria vessel wall at the upper surface of debris bed causes vessel penetration and eventual relocation of core debris into remaining water of calandria vault.

The molten core lying on the calandria vault floor may eventually penetrate the steel liner and begin to ablate the concrete. As a result, the calandria vault floor may be breached. Breach of calandria vault allows molten core to fall into the basement of the containment building. The debris heat is expected to conduct throgh the floor and wall of the small LOCA room below to the surrounding suppression pool contianing more than 320 tonnes of water which will ultimately quench the molten debris.

5 CONCLUSIONS

In most reactor types, severe accidents lead to a core melt. However in a PHWR, due to its inherent characteristics,the fuel does not melt. The inherent PHWR features namely 1) a cold moderator that acts as a dispersed emergency heat sink for fuel heat 2) the presence of water filled calandria vault that prevent a melt-through of the calandria, 3) a double containment that effectively stops release of radioactivity at the ground level and exhibits a forgiving behaviour under hypothetical over pressure conditions,4) a vapour suppression system/pressure suppression pool in the reactor building basement that can serve as an ultimate heat sink,
all contribute to design which would ensure that severe accident probability is very low and if it were to happen it can be fully

contained. The experience with the existing plants has demonstrated that the PHWR system is capable of operation with high reliability while ensuring the safety of plant personnel and the surrounding population.

6 REFERENCES

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