Nuclear Theory - Course 127

SAFETY CONSIDERATIONS

No combination of engineering know-how and protective devices will guarantee an accident-free station. However, first emphasis must still be placed on the prevention of accidents and the reduction of probability of hazards arising. In the event of failure of the measures taken to prevent accidents occurring, further consideration must be given to measures which can be taken to reduce the consequences of such accidents.

The description of the measures which can be taken may well be a summary of the various topics already discussed in the Nuclear Theory Course and therefore this final lesson may, to some extent, summarize aspects of nuclear theory which are pertinent to plant safety.

Classification of Hazards

Hazards to personnel and equipment have to be considered and these may have little or nothing to do with reactor regulation or protection. For convenience, three categories of hazards are defined as follows:

(a) Normal Hazards - These are hazards which are always present because of the character of a nuclear-electric generating station or because of conceivable errors in operation. Exposure to radiation is a typical example of this type of hazard.

(b) Minor Emergencies - Such emergencies are caused by malfunctioning of controls or by unexpected failures of components. An example of such a minor emergency is the drift that may occur in the set point of a tripping device. Another example is that of low flow in one reactor channel causing boiling which in turn causes a power transient because of the void coefficient.

(c) Major Emergencies - These are produced by circumstances beyond the control of anyone associated with the design, construction or operation of the station. They may be defined as a nuclear incident which could not be or was not stopped by the regulating or protective devices. Typical consequences of such emergencies would be the release of fission products inside and outside the station, or even the melting of the reactor core.

Avoidance of Normal Hazards

The occurrence of normal hazards can be reduced or eliminated by applying the following principles during the design, construction or operation of the station:

(a) Shielding around radioactive sources or areas should be such as to maintain personnel exposure to well below the allowable levels. An exposure bank or reserve can then be accumulated for maintenance or emergencies.

(b) Fixed area monitors should be installed or portable monitors carried which alarm when there is an unexpected increase in the radiation field.

(c) Door interlocks should be provided which prevent access to certain areas during periods of excessive radiation levels and which also prevent such excessive radiation levels when access to such areas are possible.

(d) Contamination of personnel must be kept to a minimum. Such factors as personnel monitoring, protective clothing, showers, and change room and laundry facilities, are important aids in this direction.

(e) Contamination levels throughout the station should be kept as low as possible. Swipe checks should be taken at regular intervals to ensure this. Regular cleaning and decontamination is required with spills cleaned immediately. Cross contamination is avoided by using a zoning system.

(f) Gaseous and liquid effluents must be carefully monitored and controlled.

(g) Adequate facilities should be available for transportation and disposal of spent fuel and radioactive waste.

(h) All operating and maintenance personnel should receive thorough training in all aspects of nuclear-electric generating station operations. Radiation Protection training should be included and all training should be slanted so as to develop a "safety attitude" in all station personnel.

(i) It is desirable that personnel, who will eventually operate the station, should participate in the commissioning and testing phase and that at least some should be closely associated with the design of the station.

Reducing the Probability of Minor Emergencies

The probabilities of minor emergencies occurring are, of course, reduced when normal engineering safety considerations are applied. Thus, only equipment and material should be used, the performances of which under various operational conditions are either accurately known or can be determined. There should obviously be strict adherence to applicable codes and regulations and inspection and testing should be a scheduled feature of procurement, construction and operation. In addition, the following principles should also be applied:

(a) Reactivity control mechanisms must be such as to prevent unsafe reactivity rates of increase or unsafe temperature increase rates.

(b) It is desirable that the reactor has inherently safe thermal nuclear characteristics, ie, the net temperature coefficient of reactivity is negative and the reactor at least partially self-regulating.

(c) Void coefficients should not be excessively positive or negative. Excessive positive coefficients cause large transient power surges during the void formation. Excessive negative coefficients cause the regulating system to make violent corrective adjustments when the void occurs, which result in a power surge when the void collapses or fills up.

(d) It is desirable that regulation should be on two channels to minimize the effects of instrument failures. It is an added advantage to be able to inspect and test regulating equipment regularly during operation. This makes it desirable to have triplicated regulating channels - adequate regulation being achieved on any two of the three channels.

(e) All operations of a reactor should be carried out according to a prearranged sequence. Interlock circuits are required to ensure that such a sequence is followed and that an improper sequence cannot be followed.

No operating sequence should be initiated unless sufficient indication is always available of the condition of the reactor. If necessary, additional instrumentation must be incorporated for the initial approach to critical.

(f) Audible annunciations and visual indications are necessary to show that unsatisfactory conditions exist or are developing.

(g) A protective system is required to trip the reactor when certain critical variables exceed or become less than a predetermined limit. Such variables (eg, neutron power, reactor period, high temperature, low pressure, etc) may exceed or become less than the predetermined level because of failure of the regulating system, lack of inherent safe characteristics or failure of components in any other system. The protective system should cause a rapid decrease in reactivity when such a variable causes a trip.

(h) Such a protective system should fail safe, ie, if an instrument or component in the system should fail, a reactor trip should be initiated. In order to prevent a single component failure from causing a reactor trip, and in order to enable regular testing to be carried out, three protective channels are an advantage, adequate protection being obtained when two out of three protective channels initiate a trip.

(i) Audible annunciation and visual indicators should show which variable caused a trip so that adequate investigation can be carried out following a trip.

Reducing the Consequences of Major Emergencies

The types of accidents which are likely to cause a major emergency are:

(a) Loss of coolant which might result from a failure or break in the heat transport system with a consequent appreciable leak of coolant. This would likely set up voids in the core with a resulting increase in reactivity and, if the loss is severe, the fuel elements and coolant channels would no longer be cooled and might melt.

(b) Loss of control on startup or on-power, due to the failure of the regulating system to operate in such a manner as to prevent a power excursion, and in addition the protective system fails to trip the reactor. It is likely that, under such circumstances, the coolant would boil causing steam-blanketing of the fuel. This in turn leads to sheath failure followed by melting or disintegration of fuel elements. If the fuel and coolant enter the moderator, enough heat might be provided to boil the moderator sufficiently to rupture the moderator system.

Such a loss of control can also occur from the shutdown state as distinct from during a startup. A reactor is in its most dangerous condition when it is shut down for the reasons listed in a previous lesson.

(c) Loss of cooling which does not involve the immediate disappearance of fluid from the heat transport system. It merely indicates a decrease or cessation of normal heat transport flow through any or all of the fuel channels, due to pump failure, channel constriction or inadvertent closure of isolating valves. Such a loss of cooling would tend to result in the formation of a vapour blanket over the fuel which, in turn, would cause excessive fuel temperatures.

(d) Loss of boiler water resulting from a break in the steam main or from feedwater pump failure. Such an incident would result in an immediate large drop in steam pressure. This would in turn cause a demand for increased reactor power, which should result in an overpower trip. If the trip fails to operate, coolant boiling would probably result which would again cause excessive fuel temperatures.

Measures which are taken to reduce the consequences of a major emergency include those already taken during the design and construction of the station and those which will be taken if and when the emergency arises. Possible measures which may be taken are, briefly, as follows:

(a) Use of Containment Systems

Containment starts at the fuel itself. Uranium oxide is able to contain a high percentage of the fission products formed in it because of slow diffusion rates through the high density oxide. The fuel is also sheathed and the sheath acts as a fission product container. On sheath failure, fission products are released into the heat transport system and the heat transport system acts as a containment system and should be leak-tight.

However, if a failure or break occurs in the heat transport system, additional containment may be required to prevent the spread of fission products, especially if the fuel melts or disintegrates as a result of loss of cooling. The reactor and heat transport system are located within a sealed containment shell designed to withstand any pressure buildup which may occur as a result of the accident. Since such a shell has to house the reactor boiler plant and the associated shielding and material-handling facilities, it would of necessity be very large.

The shell would have to be thick enough to withstand pressure increases of the order of 40 psia or more, and also to withstand the thermal stresses resulting from the heat released. It would be impossible to reduce leakage from such a vessel to zero under such pressures and therefore the station would still have to be located in an exclusion area large enough to allow radioactive fallout within this area. In general, the erection of such a vessel increases the plant cost by 3% to 5%.

(b) Use of Pressure Relief Systems

In this type of system the building itself may be used to contain the radioactive materials. However, to avoid the effect of the initial pressure increase on the structure, the initial blast resulting from the explosion is allowed to escape through a relief duct into the atmosphere.

Such a relief duct, as used in NPD, is shown in Fig. 1. This relief of pressure reduces the pressure buildup from the explosion and the structural thicknesses required to withstand such a pressure. It is assumed that the initial escape of steam and air only contains tritium, since fuel failure will only occur subsequent to the loss of heat transport fluid. Immediately following the initial blast, a door closes in the relief duct, preventing escape of fission products released after fuel failure.

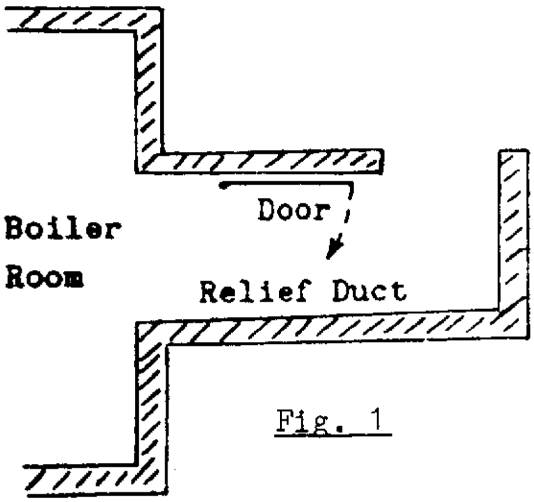

Fig. 1

Pressure relief may be used, as in Pickering G.S., as a means of reducing the pressure buildup even though a containment shell is used. Such a pressure relief would reduce the thickness of the containment shell required. The type of arrangement proposed is as shown in Fig. 2. Each reactor and associated heat transport system will be housed in a 4-ft thick cylindrical concrete containment building. The reactor buildings will connect, through ducts, to a relief vessel. This pressure relief vessel will be kept under a continuous vacuum. Any pressure increase in a reactor building will thus be relieved continuously into the relief vessel.

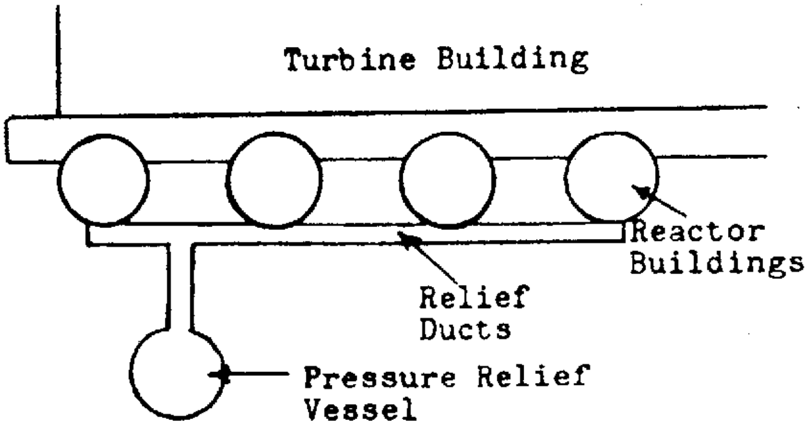

Fig. 2

(c) Use of Pressure Suppression

Since most of the accidents that can be contemplated result in a violent release of steam containing radioactive material, containment of the radioactive material is effected if all the steam can be condensed. Such pressure suppression can be obtained by allowing the pressure buildup to initiate a dousing system which spray-cools the steam. The dousing system may have to be used with a pressure relief system or a containment shell. However, the shell would be thinner and less expensive. It was estimated that, without dousing, a containment system for NPD would have to withstand a 40-psia increase in pressure with 10^6 Btu of heat released. In one Pickering unit, around 2.4×10^8 Btu of heat would have to be dissipated during the type of accident envisaged; yet at Douglas Point, with dousing but no pressure relief, the maximum internal pressure estimated in the containment vessel is only 6 psi. Consequently, the containment vessel walls can be made of 4-ft thick concrete with a corresponding thickness of steel in the dome. The leakage rate out of this enclosure can be kept down to 0.1% of the total volume per hour.

An alternative arrangement is that shown in Fig. 3. The reactor and heat transport system are contained in a dry well filled with air or carbon dioxide. The dry well vents to a water pool enclosed in a vapour-tight container. As pressure increases in the dry well, air and steam vent into the pool, where the steam is condensed.

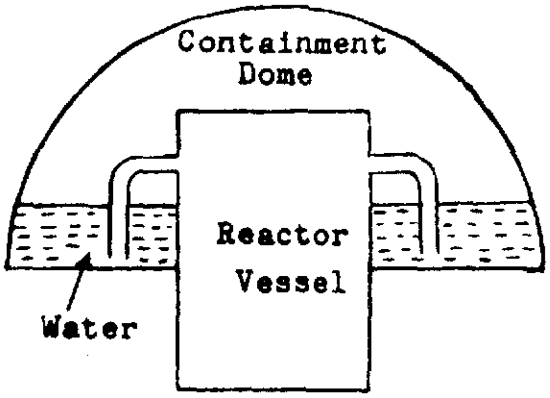

Fig. 3

(d) Use of Injection Systems

Fuel failure and resulting fission product release inevitably results from lack of heat removal. If the fuel can be prevented from rupturing or melting, then the core remains intact and the fission products are contained in the fuel. A system can therefore be designed so that additional fluid can be pumped into the system in the event of excessive leakage. In D_2O systems the initial injection would be of D_2O but should this be used up then to save the core, an auxiliary H_2O supply would be available as an additional measure.

(e) Use of Suitable Procedures

Despite the measures described above for reducing the consequences of a major emergency, it is still very necessary to establish a formal guide to cover the procedures that should be followed in the event of such an emergency. Such a guide, in the form of an operating manual known as Radiation Incidents and Emergencies, would indicate the general method of handling such situations and serve as a basis for training the station personnel and for carrying out emergency drills. Such a manual would:

(1) Ensure adequate local arrangements and make provisions for outside assistance.

(2) Indicate how to deal with the public and what post-incident evaluations are required.

(3) Give guidance on the classification of the emergency.

(4) Give guidance on the assumption of command, the setting up of command points, the setting up of sectors and the arrangements for surveying such sectors, the general action to be taken and the method of assembly of personnel.

Such a guide is discussed fully under Radiation Protection Procedures.

ASSIGNMENT

1. Briefly define the three categories of hazards.

2. As briefly as possible, list three factors, incorporated into the design of a station, which help to avoid normal hazards.

3. What three operational measures can be taken to minimize normal hazards?

4. List three "built-in" characteristics of a reactor or its associated regulating system that help to reduce the probability of minor emergencies occurring.

5. Why is it desirable to have triplicated regulating and protective systems?

6. (a) What basic principles should be followed, in reactor operation, to reduce the probability of a minor emergency?

6. (b) How is it possible to ensure that such principles are followed?

7. List the four likely causes of a major emergency.

8. (a) What are the various stages of containment of fission products that are usually present in a nuclear-electric generating station?

   (b) What additional method of containment could be used and what specifications would such a containment system have to meet?

9. Briefly describe three other design measures that could be used to reduce the consequences of a major emergency.

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