OPERATING REACTOR SAFETY
22.091/22.093

Final Exam is 1 week after Ses #26

Open Book	**Final Examination**	3.0 Hours

Problem # 1 (15%)

Assume you have a pressurized water reactor operating at full power for some time. The power distribution has been unchanged for months. Assume one group diffusion theory.

a. Write an equation for the change of power as a function of time should the operator decide to reduce power by rapidly inserting a regulating bank of control rods into the core. The insertion drops power to 80% of its initial value. Briefly define the terms and give values for a typical thermal reactor.

b. Upon reducing power to 80%, briefly describe what happens in the core in terms of temperature and power distribution. Write the equation for the feedback effects expected and incorporate them in equation written in the answer to (a). Assume negative Doppler and moderator feedback coefficients..

c. If the operator maintains this position for 4 days without adjusting the position of the control rods what happens to the power level? Explain what happens mathematically and conceptually why. Show a qualitative plot of power versus time in your answer. What are the implications on other feedback effects during the fixed rod position period?

d. What would the operator have to do to maintain a constant power level?

Problem # 2 (20%)

A simple gas-steam cycle reactor power plant (Figure 1) uses helium as a reactor coolant. 7 x10^6 lbm/hr of helium enters the steam generator at 1420 F and leaves at 750 F. 1200 F steam is generated at 2,500 psia from the feedwater at 440 F.

1. Assuming no heat losses, find the temperature difference at the pinch point in the steam generator.
2. Show the plot and explain what is happening in this counter flow steam generator.
3. Draw the T-S diagram for the cycle.
4. Calculate the efficiency of the cycle assuming a condenser pressure of 1 psia.
5. Calculate the electric power output of the plant assuming isentropic conditions but an electric generator efficiency of 90 %.

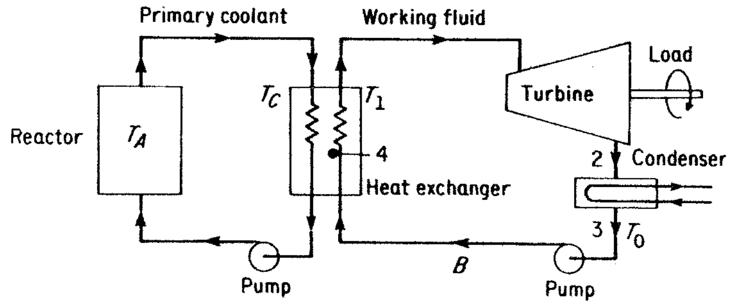

Figure 1

Problem # 3 (40%)

a. One of the concerns about nuclear plants in light of the September 11th, 2002 terrorist attacks is the vulnerability of these plants to a major release of radioactive material should the aircraft crash into the plant. While a great deal of analysis has shown that the containment would not be penetrated, the collateral damage in terms of structural failure of the equipment outside the plant and resulting fire has not been widely discussed. Given your knowledge of nuclear plants and the important safety functions that need to be maintained, provide your analysis of vulnerable systems and why they impact the safety of the plant. Use as an example the attached plant schematic diagram to illustrate your points.

Consider the following systems:

a. High pressure safety injection
b. Low pressure safety injection
c. Emergency electrical power
d. Reactor coolant system including the pressurizer
e. Availability of sources of cooling water (Refueling water storage tank (RWST), Condensate Storage Tank (CST), Containment recirculation)
f. Containment Spray Functions
g. Reactor Protection System
h. Feed and bleed using the charging pumps and pressurizer
i. Main and auxiliary feedwater system.

To structure your answer, assume that the plant is automatically shutdown due to the impact of the crash.

- What functions must be assured?
- What systems are required for those functions?
- What are the vulnerabilities of those systems due to debris and fire?
- How sensitive is the location of the equipment relative to angle of impact?

c. Chapter 15 Safety analysis assumes certain initiating events such as a steam line break or a loss of primary coolant flow with certain systems available to respond, how are these accident sequences and resulting analyses affected by the air crash? There is no need to calculate numbers but explain your answers using an event tree or logical damage sequence analysis.

See attached site plan of a typical plant.

Use information found in Table IV-1 of Knief for a Westinghouse PWR if needed and Figure 8-5 to identify interrelated systems.

b. What can be done to mitigate the consequences of such an attack should it occur?

c. How likely do you think that a core melt will occur given the crash? Clearly state your assumptions.

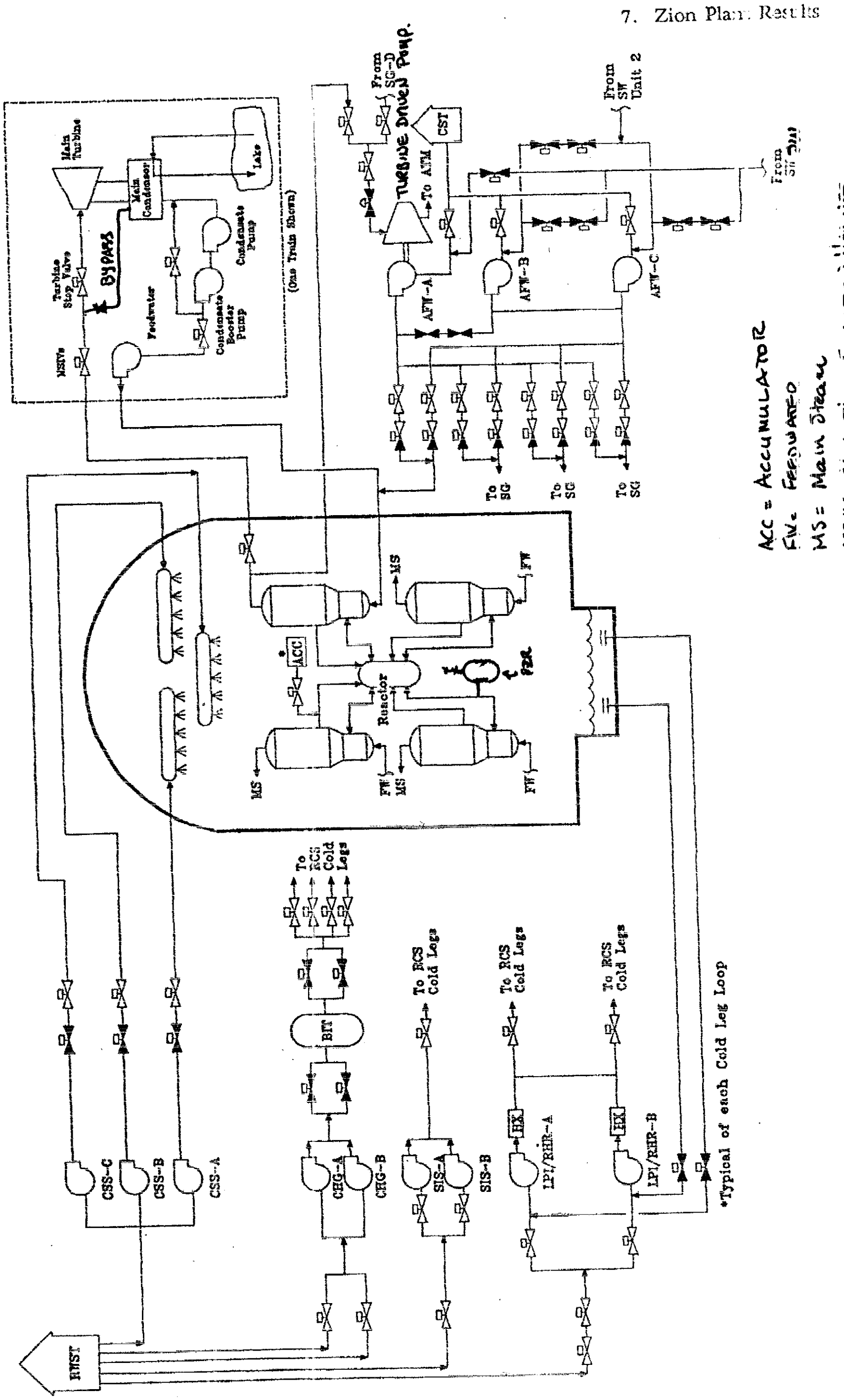

Figure 7.1 Zion plant schematic.

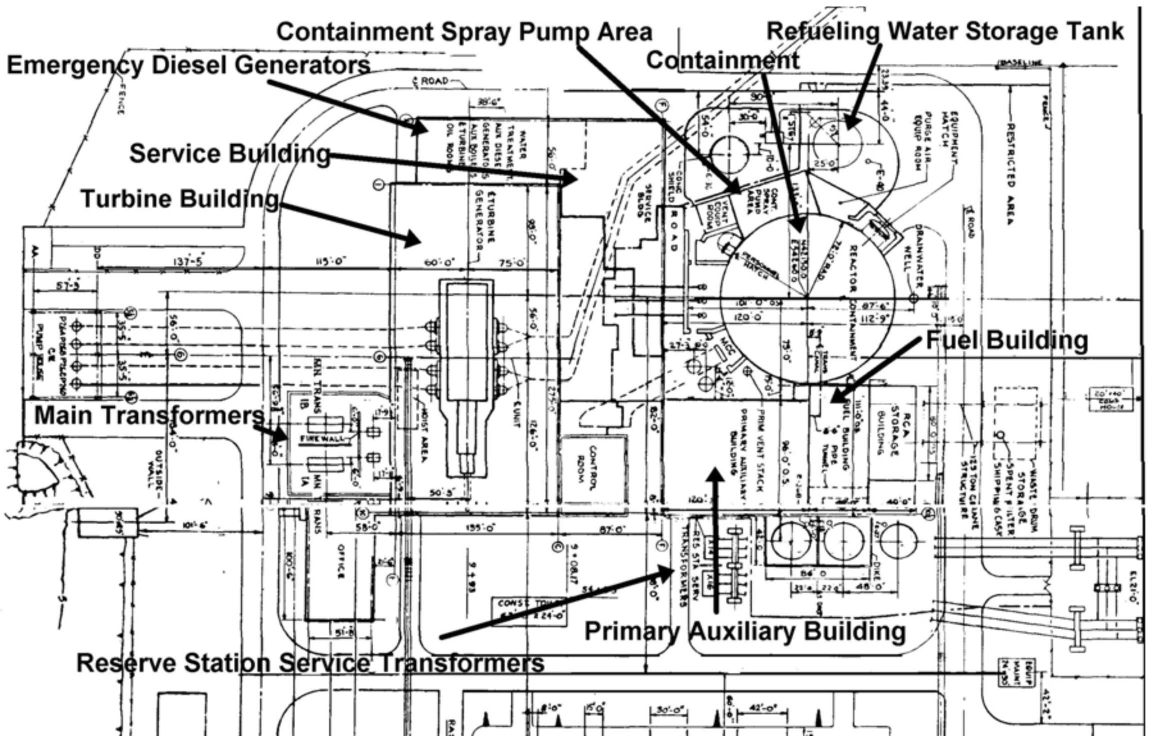
Containment Spray Pump Area
Refueling Water Storage Tank
Emergency Diesel Generators
Containment
Service Building
Turbine Building
Fuel Building
Main Transformers
Primary Auxiliary Building
Reserve Station Service Transformers

Table 7.1 Summary of design features: Zion Unit 1.

Primary Auxiliary Building (PAB)	1. High-Pressure Injection	a. Two centrifugal charging pumps. (CHG) b. Two 1500-psig safety injection pumps. (SIS) c. Charging pumps inject through boron injection tank. (BIT) d. Provides seal injection flow. e. Requires component cooling water. (CCW)
Primary Auxiliary Building (PAB)	2. Low-Pressure Injection [HPI = HIGH Pressure Injection RCS = Reactor Cooling System]	a. Two RHR pumps deliver flow when RCS is below about 170 psig. (Low Pressure INJECTION — LPI) b. Heat exchangers downstream of pumps provide recirculation heat removal. c. Recirculation mode takes suction on containment sump and discharges to the RCS, HPI suction, and/or containment spray pump suction. d. Pumps and heat exchangers require component cooling water.
Service Building	3. Auxiliary Feedwater (AFW)	a. Two 50 percent motor-driven pumps and one 100 percent turbine-driven pump. b. Pumps take suction from own unit condensate storage tank (CST) but can be manually crosstied to the other unit's CST.
Diesel Generator Building plus underground cables (manholes)	4. Emergency Power System	a. Each unit consists of three 4160 VAC class 1E buses, each feeding one 480 VAC class 1E bus and motor control center. b. For the two units there are 5 diesel generators, with one being a swing diesel generator shared by both units. c. Three trains of dc power are supplied from the inverters and 3 unit batteries.
Service Building	5. Component Cooling Water	a. Shared system between both units. b. Consists of 5 pumps, 3 heat exchangers, and 2 surge tanks. c. Cools RHR heat exchangers, RCP motors and thermal barriers, RHR pumps, SI pumps, and charging pumps. d. One of 5 pumps can provide sufficient flow.
	6. Service Water	a. Shared system between both units. b. Consists of 6 pumps and 2 supply headers. c. Cools component cooling heat exchangers, containment fan coolers, diesel generator coolers, auxiliary feedwater pumps. d. Two of 6 pumps can supply sufficient flow.
	7. Containment Structure	a Large, dry, prestressed concrete. b. 2.6 million cubic foot volume. c. 49 psig design pressure.
Containment Spray Building	8. Containment Spray (CSS)	a. Two motor-driven pumps and 1 independent diesel-driven pump. b. No train crossties. c. Water supplied by refueling water storage tank. (RWST)
Ventilation Building	9. Containment Fan Coolers	a. Five fan cooler units, a minimum of 3 needed for post-accident heat removal. b. Fan units shift to low speed on SI signal. c. Coolers require service water.

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