22.06 ENGINEERING OF NUCLEAR SYSTEMS - Fall 2010

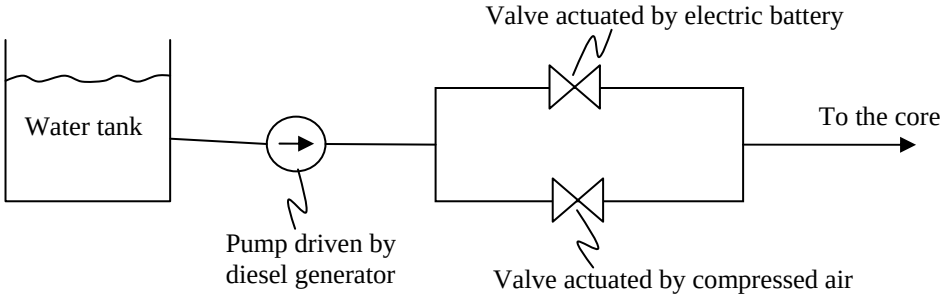
Problem Set 9

Nuclear Safety

1) Consider the classification of design-basis accidents presented in class. How would you classify the following abnormal events?

   - Inadvertent dilution of boric acid concentration in PWR primary coolant
   - Closure of BWR main steam isolation valves (i.e. completely chocking the steam flow to the turbine) while the reactor is operating at full power
   - Malfunction of online refueling machine in CANDU, resulting in significant spill of primary coolant
   - Blockage of intakes of seawater used as condenser coolant in a CANDU station
   - Trip of primary sodium pumps in SFR
   - Trip of pumps in secondary sodium loop of SFR

2) The schematic below shows a safety system meant to supply 100% capacity of low-pressure emergency coolant to the core of a PWR in case of a LB-LOCA. Does the system satisfy the requirements of redundancy, diversity and physical separation for engineered safety systems in nuclear power plants? If not, propose appropriate design modifications to meet such requirements.



3) Compute the energy sources in a typical PWR, which the containment might have to accommodate following a LB-LOCA:

   i Stored energy in primary coolant. Should enthalpy or internal energy be used?
   ii Decay Heat – integrated release over a one hour shutdown period after infinite operation.
   iii Chemical Reactions –
      a. Reaction of 75% of the zirconium clad with water coolant.

b. Reaction of 25% of the zirconium clad with CO_2*. Assume this reaction is constrained only by amount of zirconium available.

iv Combustion of hydrogen product in (iii.a) above.

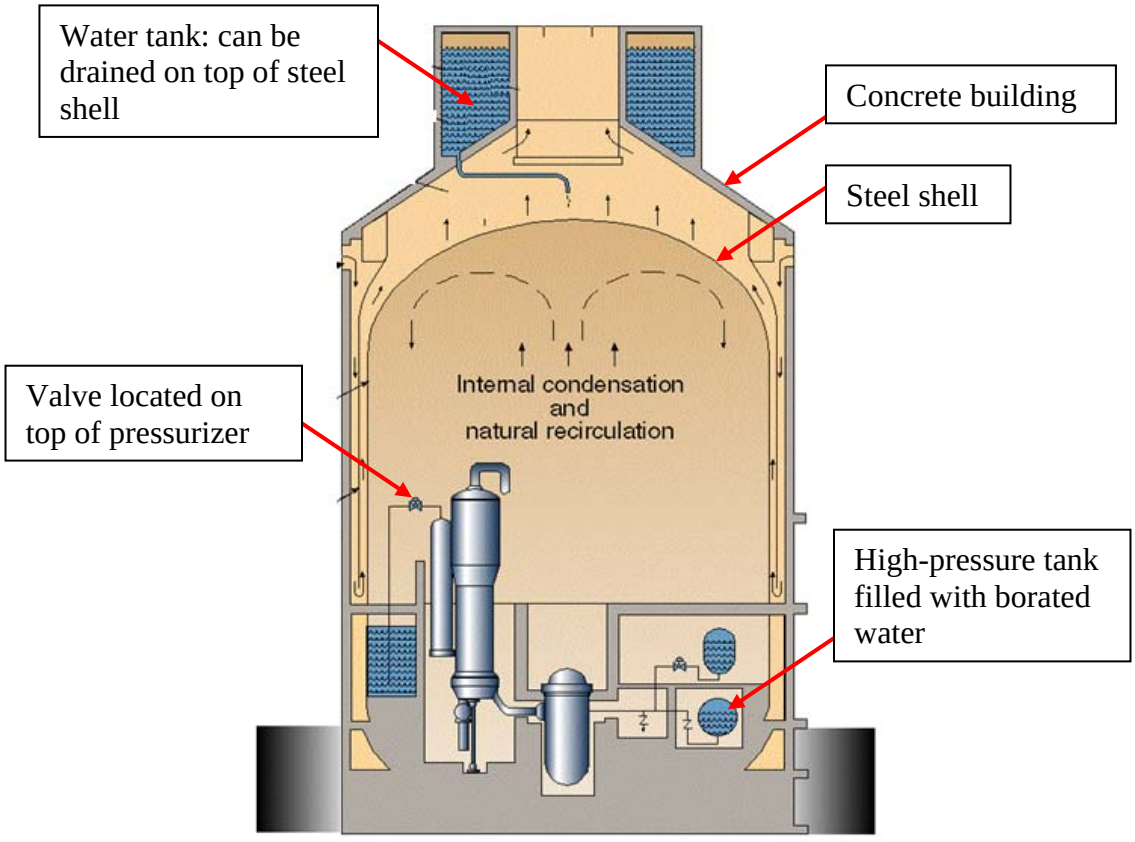
Assumptions

Primary System: 306 m^3 of coolant at 15.5 MPa and 305°C
Reactor Power: 3411 MW_t
Number of 17x17 fuel assemblies: 193
Fuel pin geometry: 9.5 mm (OD), 0.57 mm (clad thickness), 4 m (length)

Chemical Reactions

$Zr + 2\ H_2O \rightarrow ZrO_2 + 2\ H_2 + 6.057x10^5$ J/mol of Zr
$Zr + CO_2 \rightarrow ZrO_2 + C + 7.05x10^5$ J/mol of Zr
$H_2 + ½\ O_2 \rightarrow H_2O + 2.4x10^5$ J/mol of H_2

4) The figure below shows the containment and nuclear island of an advanced PWR design (Westinghouse's AP1000). Identify the function of each component indicated by the red arrows and described in the text boxes.



Courtesy of Westinghouse. Used with permission.

* CO_2 comes from thermal decomposition of concrete in the containment basemat. This would occur during a hypothetical severe accident for which the core melts completely, penetrates through the bottom of the pressure vessel and finally relocates in the containment basemat.

22.06 Engineering of Nuclear Systems
Fall 2010