22.39 Quiz

Open Book, Take Home Examination

Nov. 14, 1 pm – Nov. 15, 5 pm

Motivation for the Question

A significant impact on global warming would require nuclear to produce 40% or more of global electricity demand by 2050. Assuming mid to upper range growth estimates, the 40% level requires deployment of 3000 GWe by 2050. However, the rate of plant construction has been limited historically to 20 to 30 units per year globally. With a 3-year construction period and an optimistic start by 2010, about 1100 units (30/yr for 37 years) can be deployed by 2050. Hence, for the 40% level, plants of rating at least 2.7 GWe are required. To surpass the 40% level as is desirable, even larger plant power ratings are desirable.

Question

In this question you are asked to propose and justify the key design features of a pressurized light water cooled reactor (PWR) with a power rating of 3000 MWe.

Rules for preparation of your solution:

You may consult any written material you choose. You should not consult any person (a student in 22.39 or anyone else) in the preparation of your solution. Your solution must be your own independent work product.

Requested Characteristics of Your Solution

1) Your solution text should not exceed 8 pages total. Figures and calculations are not restricted within this 8 page limit.

2) As a minimum establish basic features of the following components and systems of your plant:
   - Core
   - Reactor vessel
   - Primary system
   - Secondary system
   - Containment concept and containment building
3) For each component and system you need only specify those characteristics you feel are necessary to confirm the feasibility of your design approach. In establishing these features identify and evaluate neutronic, thermal-hydraulic, structural, materials and other disciplinary considerations you feel are relevant. Strive to identify as many relevant considerations as possible.
4) Further for the features in 1) and the plant as a whole, present the safety criteria and licensing approach you recommend. Here focus your presentation on differences from the criteria and approach which have been adopted for the current PWR Generation III+ concepts. For example, consider topics such as the siting criteria, allowable CDF and LERF values, impact on bleed-and-feed cooling, etc. In particular, the "etc" in the last sentence is yours to elaborate upon.
5) An acceptable answer can be based on extrapolation of current practice maintaining all current design margins. A superior answer would include unique design features which you would propose and justify as capable of achieving regulatory approval.

<u>Grading Criteria to be applied</u>

10% 1. Clarity of presentation of plant design features
30% 2. Scope of design features specified
40% 3. Justification of design features specified
20% 4. Scope and justification of safety criteria and licensing approach presented

Assumptions you should adopt:

- Power cycle thermal efficiency 33%
- Plant produces electricity only
- Heat removal capability from containment must match the decay power curve starting at 2% of rated thermal power (of course it then decreases with time)
- The reactor vessel cylindrical section is to be made of a single piece from a forging. The maximum forging mass available is 600 metric tonnes.
- Size all vessels at 110% of your selected operating pressure, i.e.
  design pressure = 1.1 times operating pressure

Geometry	Materials Properties
Containment Maximum steel wall thickness = 4.45 cm (1.75 inches) (to avoid on-site annealing of welds)	Reactor vessel and containment wall material design stress is 184 MPa (26700 psi) (this material is SA-508 Grade 3, Class 1 at design temperature of 371°C (700°F))

Operating Conditions

Containment – heat removal rate from containment surface by water film = 1.17 watts/cm^2 (3700 BTU/hr ft^2)

Structural Analysis

Hoop stresses for thin walled structures

Cylinder $$\Delta p = \frac{\sigma t}{R}$$

Sphere $$\Delta p = \frac{2\sigma t}{R}$$

Useful parameters for US Standard 4 Loop PWR, EPR and AP1000 Plants

Selected Plant Parameters

Parameter	US 4-Loop	EPR	AP1000
Design Life, yrs	40	60	60
Net Electric Output, MWe	1100	1600	1100
Reactor Power, MWt	3411	4500	3400
Hot Leg Temperature, ^{o}F	617	622	610
Number of Fuel Assemblies	193	241	157
Type of Fuel Assembly	17x17	17x17	17x17
Active Fuel Length, ft	12	13.78	14
Linear Hear Rating, kw/ft	5.58	4.99	5.71
Control Rods / Gray Rods	53 / 0	89/0	53/16
Radial Reflector	no	yes	no
Pump Flow, Thermal Design, gpm ea	98,000	125,000	75,000
Steam Generator Surface Area, ft2 ea	75,000	85,700	125,000
Pressurizer Volume, ft3	1800	2649	2100

	EPR	AP1000
Country of Orgin	France/Germany	U.S.
NSSS Designer	AREVA	Westinghouse
Electrical Power Out, Mwe	~1600	~1100
Number SGs / RCPs	4 / 4	2 / 4
Containment	pre-stressed concrete	steel
Additional Shield Building	reinforced concrete	reinforced concrete
Safety System Type	active	passive
Number Mechanical Trains	4	na
Number EDG / SBO DG	4 / 2	none
I&C / MCR Type	digital / compact	digital / compact
PRA CMF calc	1.4E-6/yr	5.1E-7/yr
LRF calc	?	5.9E-8/yr
Core Melt Debris Cooling	ex-RV spreading	IVR
Construction approach	stick built	many modules
Construct Time, 1st Concrete - Fuel	45	36
First Project, Operational Date	Finland - 2009	?

	AP1000
Reactor Vessel	
Cylindrical Height, m	13.0
Inner Diameter, m	4.04
Containment Vessel Size	
Cylindrical Height, ft	75
Hemispherical Cap Radius, ft	122.5
% Free Volume	80%
Primary System Volume	
Total, ft^3	10,500
Reactor Vesset, ft^3	7000
Pressurizer, ft^3	1400
Each Loop, ft^3	1050
Pressurizer Normal Liquid Volume	45%