October 1999

Ph.D. Qualifying Examination
Fission Engineering

1. (20 min.) This question deals with the primary coolant of a typical, commercial PWR which is operating in equilibrium at 100% power.

   (a.) (30%) Primary coolant enters the reactor vessel at 286°C and exits at 324°C. Calculate the ratio of the coolant velocity at the exit to that at the entrance. You may assume that the piping cross sectional areas at entrance and exit are the same.

   (b.) (70%) The reactor experiences a partial Loss of Flow and full scram. Two minutes after the scram primary coolant flow is steady at 20% of full flow. Estimate the ΔT of the core. State your assumptions regarding reactor power level.

   Please see the attached pages.

2. (25 min.) A fuel pin is operating at a linear power of 300 W/cm with 4 % enriched UO_2 fuel. The diameter of the fuel pellet is 1.2 cm. The fuel surface temperature is 350°C. It is proposed to reduce the fuel diameter by 9 % but keep the fuel centerline temperature and the fuel surface temperature the same. What will be the new enrichment for the fuel? Assume that the scalar flux remains the same in the fuel pin.

3. (15 min.) Consider a loss-of-coolant accident in an advanced Westinghouse AP-600 MWe pressurized water reactor. As the reactor depressurizes, cold water is injected into the core through the passive safety systems. To perform an analysis for this event, would it be best to use a homogeneous, drift-flux, or two-fluid two-phase models? Justify your selection.

4. (30 min.) An advanced boiling water reactor operates at an electrical output of 1000 MWe. Its thermodynamic efficiency is 32 %. The core inlet enthalpy is 1200 kJ/kg, and the inlet mass flow rate is 1.25×10^4 kg/s. The reactor pressure is 7.0 MPa.

   (a.) Find the average core outlet enthalpy.
   (b.) Find the average outlet quality.
   (c.) Find the total steam flow out of the reactor.
   (d.) Under the assumption of homogeneous flow, what is the outlet void fraction? To what flow regime does this correspond?

5. (10 min.) Two independent pumps provide redundancy for an emergency cooling system. The probability that they would fail to start is 0.09 for Pump1 and 0.05 for Pump2. What is the probability that at least one pump (i.e., any one pump OR both pumps) will start? (Hint: You may find a Venn diagram useful for addressing this question.)

6. (20 min.)Consider a "once-through" counter flow steam generator operating at a steady-state thermodynamic equilibrium condition (Figure 1) where,

- the "hot" (or primary) side flow rate is m_A (kg/s) and it enters and exits the steam generator as subcooled liquid at temperatures T_1 (C) and T_2 (C), respectively.
- the "cold" (or secondary) side flow rate is m_B (kg/s) and it enters the steam generator as subcooled liquid at temperature T_3 (C) and exits the steam generator as slightly superheated vapor flow at temperature T_4 (C).

Assume that the amount of superheat in the secondary flow is Δh (kJ/kg). Also, assume that the average specific heats at constant pressure are: for the subcooled primary flow, cp_A; for the subcooled secondary flow, cp_B; and for the superheated secondary flow, cp_{SH}.

(a.) (50%) Define the "pinch point" for a heat exchanger or steam generator.

(b.) (50%) Write an expression for the temperature difference between the primary and secondary temperatures at the pinch point of the steam generator in Figure 1 in terms of the parameters defined above.

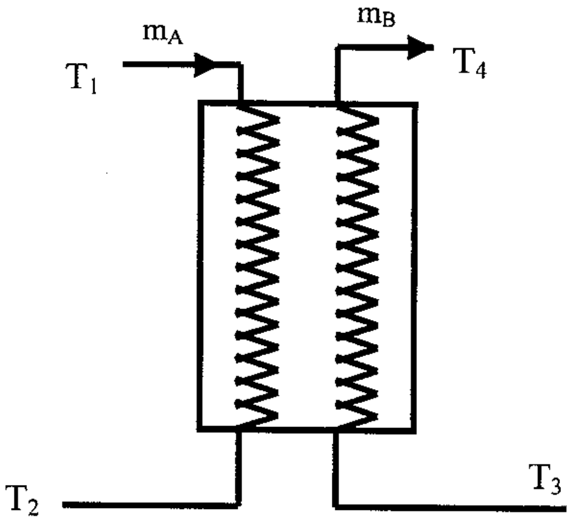

Figure 1. Once-Through Counter Flow Steam Generator

Decay Heat Rate

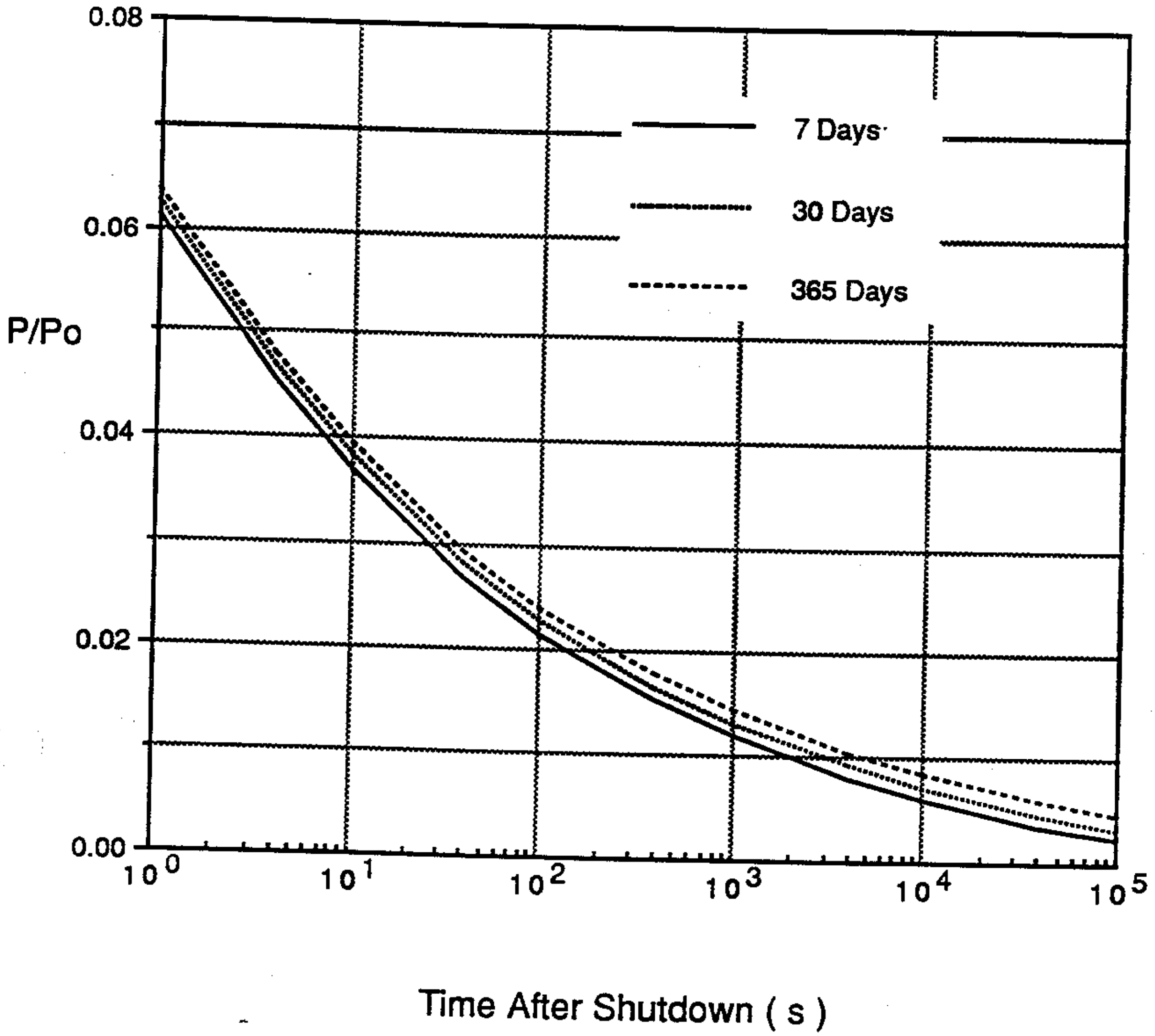

Table E-1 Saturation state properties of steam and water

Temp. (°C)	Pressure bar	Specific volume (m^3/kg)		Specific enthalpy (kJ/kg)		p_s (bar)
		Water	Steam	Water	Steam	
0·01	0·006 112	1·000 2 × 10^{-3}	206·146	0·000 611	2501	0·00611
10	0·012 271	1·000 4 × 10^{-3}	106·422	41·99	2519	0·01227
20	0·023 368	1·001 8 × 10^{-3}	57·836	83·86	2538	0·02337
30	0·042 418	1·004 4 × 10^{-3}	32·929	125·66	2556	0·04241
40	0·073 750	1·007 9 × 10^{-3}	19·546	167·47	2574	0·07375
50	0·123 35	1·012·1 × 10^{-3}	12·045	209·3	2592	0·12335
60	0·199 19	1·017 1 × 10^{-3}	7·677 6	251·1	2609	0·19920
70	0·311 61	1·022 8 × 10^{-3}	5·045 3	293·0	2626	0·31162
80	0·473 58	1·029 0 × 10^{-3}	3·408 3	334·9	2643	0·47360
90	0·701 09	1·035 9 × 10^{-3}	2·360 9	376·9	2660	0·70109
100	1·013 25	1·043 5 × 10^{-3}	1·673 0	419·1	2676	1·01330
110	1·432 7	1·051 5 × 10^{-3}	1·210 1	461·3	2691	1·4327
120	1·985 4	1·060 3 × 10^{-3}	0·891 71	503·7	2706	1·9854
130	2·701 1	1·069 7 × 10^{-3}	0·668 32	546·3	2720	2·7013
140	3·613 6	1·079 8 × 10^{-3}	0·508 66	589·1	2734	3·6138
150	4·759 7	1·090 6 × 10^{-3}	0·392 57	632·2	2747	4·7600
160	6·180 4	1·102 1 × 10^{-3}	0·306 85	675·5	2758	6·1806
170	7·920 2	1·114 4 × 10^{-3}	0·242 62	719·1	2769	7·9202
180	10·027	1·127 5 × 10^{-3}	0·193 85	763·1	2778	10·027
190	12·553	1·141 5 × 10^{-3}	0·156 35	807·5	2786	12·551
200	15·550	1·156 5 × 10^{-3}	0·127 19	852·4	2793	15·549
210	19·080	1·172 6 × 10^{-3}	0·104 265	897·7	2798	19·077
220	23·202	1·190 0 × 10^{-3}	0·086 062	943·7	2802	23·198
230	27·979	1·208 7 × 10^{-3}	0·071 472	990·3	2803	27·976
240	33·480	1·229 1 × 10^{-3}	0·059 674	1037·6	2803	33·478
250	39·776	1·251 2 × 10^{-3}	0·050 056	1085·8	2801	39·776
260	46·941	1·275 5 × 10^{-3}	0·042 149	1135·0	2796	46·943
270	55·052	1·302 3 × 10^{-3}	0·035 599	1185·2	2790	55·058
280	64·191	1·332 1 × 10^{-3}	0·030 133	1236·8	2780	64·202
290	74·449	1·365 5 × 10^{-3}	0·025 537	1290	2766	74·861
300	85·917	1·403 6 × 10^{-3}	0·021 643	1345	2749	85·927
310	98·694	1·447 5 × 10^{-3}	0·018 316	1402	2727	98·700
320	112·89	1·499 2 × 10^{-3}	0·015 451	1462	2700	112·89
330	128·64	1·562 × 10^{-3}	0·012 967	1526	2666	128·63
340	146·08	1·639 × 10^{-3}	0·010 779	1596	2623	146·05
350	165·37	1·741 × 10^{-3}	0·008 805	1672	2565	165·35
360	186·74	1·894 × 10^{-3}	0·006 943	1762	2481	186·75
370	210·53	2·22 × 10^{-3}	0·004 93	1892	2331	210·54
374·15	221·2	3·17 × 10^{-3}	0·003 17	2095	2095	221·2

Source: From *U.K. Steam Tables in S.I. Units*. London: Edward Arnold, 1970.
1 bar = 10^5 N/m^2.

1 K pa = 0·01 bar.