Nuclear Engineering 280
Spring Semester 1998
Final Examination

THREE HOURS. TWO $8\frac{1}{2}'' \times 11''$ SHEETS OF NOTES ALLOWED.
PLASMA FORMULARY ALLOWED. OPEN TEXTBOOK (CHEN ONLY).
ANSWER ALL QUESTIONS.

1. A fusion plant has a solid lithium oxide blanket with a 36-hour residence time for tritium. The plant generates 3000 MWth from DT fusion and has a blanket with a mulitplication factor T of 1.2. The tritium in the helium coolant and in the blanket can be considered to be uniformly dispersed throughout the 500 cubic meter volume. The exhaust temperature from the blanket is 330°C and the exhaust piping is a 50m long, 30 cm diameter pipe made of stainless steel of 5mm thickness. The Sievert law coefficients for stainless steel are $D_0 = 4.7 \times 10^{-7}$ m^{2}s^{-1}, $S_0 = 1.1 \times 10^{23}$ atoms m^{-3} pa$^{1/2}$, $E_s = 0.061$ eV, $E_d = 0.56$ eV.

   a. Find the production rate of tritium, in curies per day. note that the specific activity of tritium is 9.64 MCi per kg.

   b. Find the concentration of tritium in the exhaust helium gas, in curies per cubic meter.

   c. Find the tritium partial pressure in the exhaust pipe, in Pa. Note that 2.69×10^{19} molecules per cc = stadard atmospheric (pressure 1.013×10^5 Pa) at 298°K.

   d. Find the leakage rate of tritium through the pipe, in atoms per square meter per second, assuming the pipe is at 330°C.

   e. Assuming that all of this tritium loss over the length of the pipe is lost to ambient, calculate the tritium leakage rate to the atmosphere, in curies per year.

   f. Secondary containment for this pipe is probably required, i. e. the leakage rate that you calculated in part (e) should be unacceptably high. Assume that this exhaust pipe is nested inside an outer pipe which is 3 mm thick and 45 cm in diameter. Assume that the secondary pipe has a wall temperature of 25 °C. assume that the internal pressure in the secondary piping is kept at 0.1 Pa. Now calculate the leakage to atmosphere for the double-walled pipe.

2. A tokamak first wall is made out of vanadium ($T_m = 2192$°K, A=50.94) and is operated at 450°C. The wall is exposed to a flux of 14 MeV neutrons and plasma heat consistent with a 2400 MWth fusion power yield in a device which has a major radius of 7 meter, an aspect ratio of 3.0, and an elongation of 1.65. (Note that the perimeter of an ellipse with $b = 1.65a$ is $8.45a$.)

   a. Find the average 14 MeV neutron flux in the first wall, in neutrons per square meter per second.

   b. Which radiation damage mechanism (embrittlement, void swelling, or creep) will be dominant at this first wall temperature ?

   c. If the elastic scattering cross section is 3.0 barn and the displacement energy is 35 eV and the Linhard factor is 0.5, find the displacement cross section in for eleastic scallering in barns.

   d. If the total dpa cross section (including inelastic reactions) is 3000 barns, find the lifetime of the first wall to a criterion of 10 dpa=onset of failure.

3. A Nb-Ti superconducting magnet filament is fabricated with a square cross section of 12 mm on a side. The filament is eighty percent copper. The resistance of the copper in the filament (including magnetoresistance) at an operating field of is 46 nΩ per meter. The coil filament is cryogenically stable with a minimum helium cooling rate q'' of 0.19 watt per square centimeter.

   a. Find the maximum conductor current for stability.

   b. For this current, find the total number of turns required for a field of 4.0 T to be delivered at a 6.0 meter radius in a tokamak.

   c. If the maximum magnetic field which can be applied on the superconductor filament is 12.0 T, find the minimum radius at which the magnet filament can be located.

4. An ICF target has a compressed core which has an average density of 100 times liquid density for D-T ($\rho_{liq}(DT) = 0.22$ g cm^{-3}. The temperature of the core is 15 keV throughout. The density is not uniform over the spherical core, however, and the density follows a law

$$\rho(r) = \rho_0(1 - (r/a)^2) \quad .$$

   a. Find the rms density ρ_{RMS} useful for calculation of the fusion burn rate.

   b. Find the nuclear fusion yield from the pellet if this configuration is held static for 1 ns. Assume that the pellet has an overall $\rho_{avg}r$=10 g cm^{-2}.

   c. Find the total bremsstrahlung radiation lost from the core during the nuclear burn phase.

5. A magnetically confined plasma is heated at a frequency of 2.5 Ghz. The plasma has an electron density of 10^{20}m^{-3} and a magnetic field of 4.0 T. The plasma is DT (assume an average ion mass of 2.5 proton masses fot the equivalent single-ion-component plasma.)

   a. Find the ratio of the heating frequency used to the lower hybrid frequency in the plasma.

   b. If this rf energy is brought into the plasma using waveguides, what would the ideal waveguide dimensions be ? Assume rectangular guide with $a = 2b$.

c. If the maximum rf electric field desired in the guide was 10 kilovolts per inch, how many waveguides would be required to bring 2.0 MW of rf power into the plasma ?

d. What type of rf power-producing devices (e. g. triodes, pentodes, magnetrons, klystrons, gyrotrons, IR lasers, quasioptical devices) are available at this frequency ? If more than one type is applicable, give reasons for choosing between them.