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MAE 237D

Fusion Engineering and Design

FINAL EXAM

Take Home Exam

Due: Thursday, March 17, 2016
at 4:00pm
(Submit in 44-114 Eng IV to Emily or Jesse)

Attempt Only Six Problems

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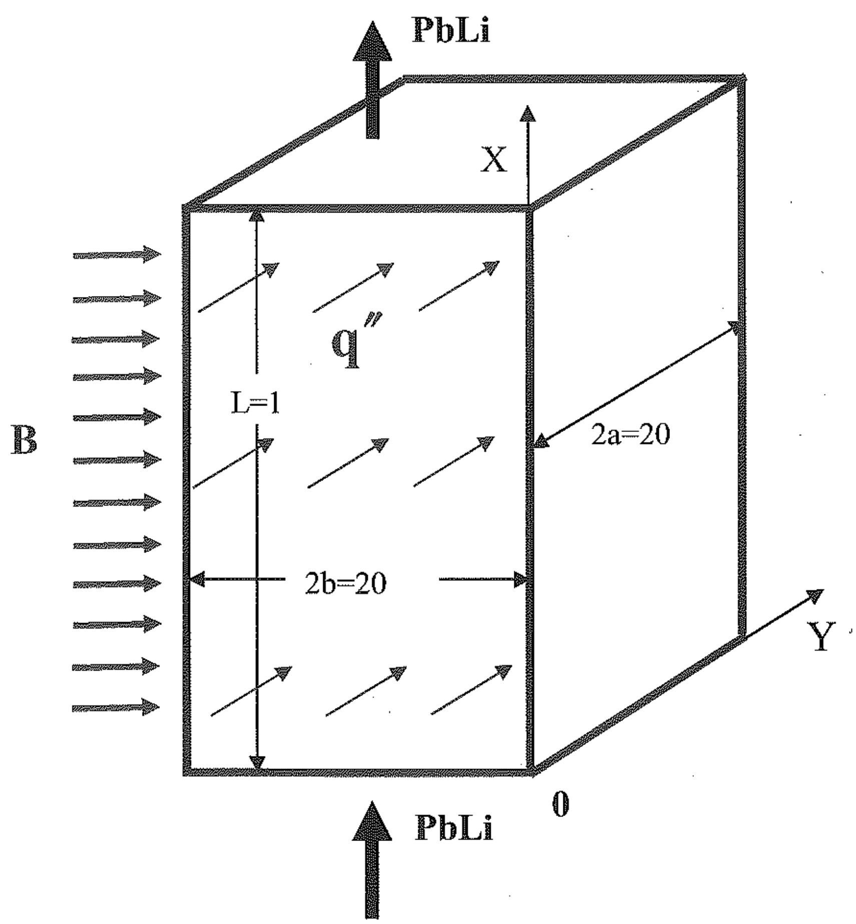
- **Include the details of your solutions**
- **Provide informal citations for any sources used**
- **Make, indicate, and justify any significant assumptions**
- **Please work independently**

Problem 1

In a self-cooled poloidal PbLi blanket, the liquid metal flows through rectangular ducts made of RAFM steel. The wall thickness of the duct is 2 mm. Consider one of the front ducts (facing the plasma), assuming idealized conditions when the duct is fully decoupled electrically from the rest of the blanket and also neglect heat exchange with all other ducts. The flow velocity is 0.5 m/s. The toroidal magnetic field is 5 T. The PbLi flow is exposed to volumetric heating that varies with the radial distance y as $q'''(y) = 30\times10^6 \exp\{-y/a\}$, W/m^3. The surface heat flux is 0.5 MW/m^2. The inlet temperature in the PbLi is 400°C. The internal duct cross-sectional dimensions $2a$ and $2b$ and the length L are shown in the figure.

a) Calculate basic dimensionless parameters: the Hartmann number Ha, Reynolds number Re, magnetic Reynolds number Re_m, interaction parameter N, and the wall conductance ratio c.
b) Estimate the MHD pressure drop without and with electrical insulation (assuming ideal electrical insulation).
c) What can you say about the shape of the velocity profile in the two cases: (1) if the duct is perfectly insulated; and (2) if there is no any electrical insulation?
d) What flow regime (laminar or turbulent) will likely occur?
e) Estimate temperature increase in PbLi: Tout-Tin.



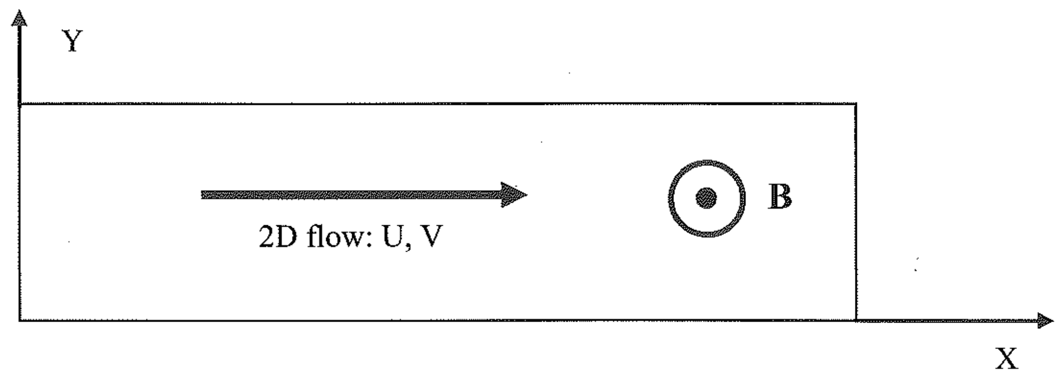
Physical properties

Fe: σ=1.4×10^6 1/Ohm-m, k=33 W/m-K, ρ=7800 kg/m3, C_p=750 J/kg-K

PbLi: σ=0.7×10^6 1/Ohm-m, k=15 W/m-K, ρ=9300 kg/m^3, C_p=190 J/kg-K, μ=0.001 Pa-s

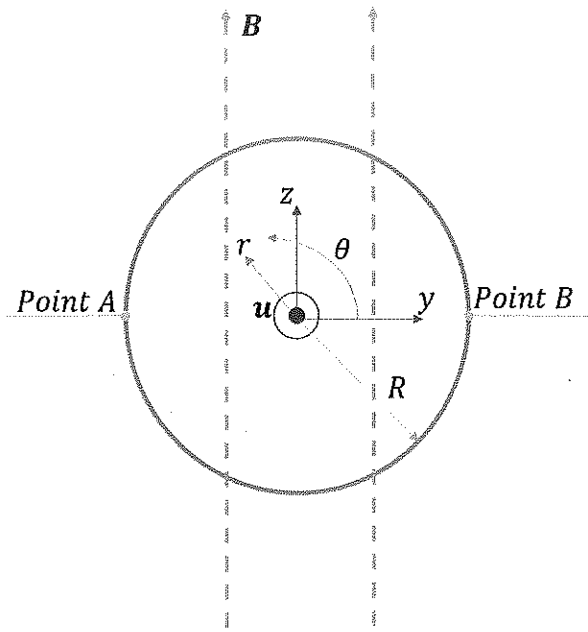
Problem 2

Derive the vorticity equation ($\omega = \frac{\partial U}{\partial y} - \frac{\partial V}{\partial x}$) for a 2D MHD flow (in the x-y plane) of electrically conducting fluid in a constant spanwise magnetic field (the field is in z direction). Based on this equation conclude what kind of MHD effect will be experienced by the flow.



Problem 3

Consider a fully developed MHD flow in a non-conducting circular pipe with radius R in the presence of a uniform magnetic field in the z-direction ($\boldsymbol{B} = B\widehat{e_z}$) as shown in the figure.



For such a configuration evaluate the following:

a) The distribution of electric potential along the wall (r = R) of the pipe for a given axisymmetric velocity profile $\boldsymbol{u}(r) = 2u_{avg}\left(1 - \frac{r^2}{R^2}\right)\widehat{e_x}$ (here u_{avg} is the average fluid velocity) by solving 2D Poisson equation for electric potential in the y-z plane with the assumption that the velocity profile is not affected by the magnetic field. *[HINT: Use the method of separation of variables.]*

b) Potential difference between points A and B for magnetic field strength B of 1 Tesla, average velocity u_{avg} of 10 cm/sec and pipe radius R of 10 cm.

Problem 4

a) Draw a schematic of a vertical cross-section of a tokamak reactor showing all major reactor components.

b) Describe concisely the functions of all components in (a) above.

c) What is the main difference between a tokamak and other toroidal confinement plasma devices?

d) Draw a unit cell of a DCLL blanket illustrating the primary geometric regions and materials.

e) Compare the features, advantages and disadvantages, of DCLL blanket to separately cooled PbLi blanket.

f) Discuss how tritium is extracted from ceramic breeder blankets.

Problem 5

A tokamak reactor with superconducting TF coils has a major radius of 6.8m, an aspect ratio of 3, and a neutron wall load of 3.6 MW/m^2. It has a breeding blanket that attenuates the neutrons by two orders of magnitude followed by 90 cm of 85% Pb+15% B_4C.

a) Calculate the reactor fusion power.

b) Calculate the total heat load into the cryogenic system.

c) Calculate the total power required to remove the nuclear heating deposited in the magnet.

d) Calculate the radiation-induced resistivity in the copper stabilizer at the point of maximum magnetic field after 4 years of continuous reactor operation.

e) If the tritium breading ratio is 1.15, calculate the rate of tritium production in the blanket in kg/s.

Problem 6

a) State and explain cryogenic stabilization criterion for superconducting magnet.

b) Discuss concisely radiation effects on components of superconducting magnets.

c) Compare the functions of bulk shielding, penetration shielding, and biological shielding in a tokamak fusion power plant.

d) What is the most promising structural material for a fusion DEMO? Why?

Problem 7

a) Calculate Q values for Li^6 (n, t) and Li^7 (n, n't), and specify if they are exothermic or endothermic.

b) If a 1 MeV neutron undergoes elastic scattering at 45 degrees with a Li^6 target in the blanket what is the heat deposited in the material per interaction?

c) An (n,α) reaction in a particular nuclide has a Q-value of -5 MeV calculate the neutron kerma factor for 14 MeV neutrons.

d) A particular shield composition has a total energy attenuation coefficient of 0.138 cm^{-1}, what is the shield thickness required to achieve energy attenuation of four orders of magnitude?

e) Write down the Neutron Transport Equation and describe the physical meaning of each term. Which term is the one that requires a more difficult mathematical treatment?

f) Neutronics calculations for a fusion blanket show the following reaction rates per fusion neutron:

REACTION	REACTION RATE Per fusion neutron	|Q| - VALUE MeV
V(n,2n)	0.1	13
V(n,γ)	0.05	8
^{6}Li(n,α)	0.80	4.8
^{7}Li(n,γ)	0.02	5
^{7}Li(n,n',α)	0.4	2.4

f1) Calculate the tritium breeding ratio.

f2) Calculate the energy multiplication factor

f3) If a tokamak reactor using the above blanket produces 3000 MW of fusion power and has a thermal conversion efficiency of 35%, calculate the reactor electric power output.

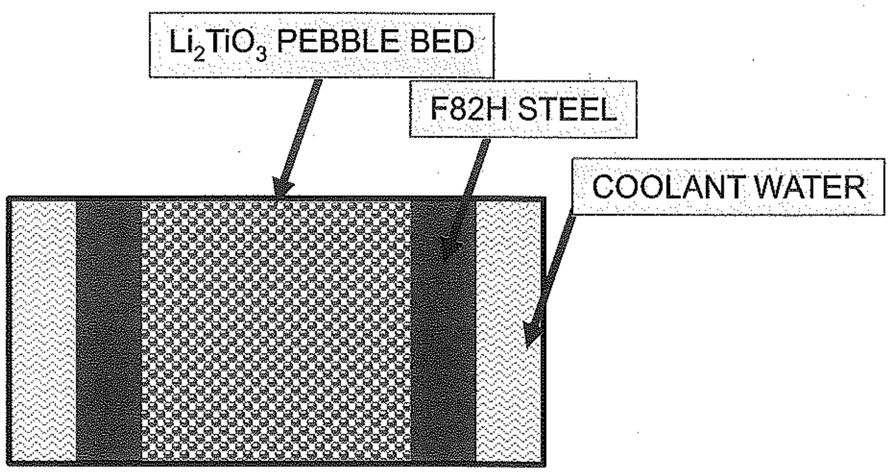
Problem 8

Consider a 1D, pebble bed-type blanket configuration with a 2-cm wide (along the tokamak's radial direction) breeder volume cooled on both sides by water at a bulk temperature of $T_f = 300$ °C. Water is flowing at 5 m/s through an equivalent hydraulic coolant channel of 1 cm with a structural wall thickness of 3 mm. (See the sketch below)

a) Calculate the temperature distribution across the pebble breeder element, structure, and water, considering the following:
   - Single size pebble bed of lithium Li_2TiO_3 pebbles of 1 mm diameter.
   - Constant volumetric heat generation rate in the breeder region of 8 MW/m^3
   - A temperature jump of 25 °C exists at the interface of pebble bed and steel
   - Use thermal properties of stainless steel for F82H

b) Calculate the purge gas pressure drop across a 1 meter tall pebble bed as a function of superficial purge gas velocity of 1, 5, and 10 cm/s for a single size bed of 1 mm pebble. Assume an average purge gas temperature of 600 °C and random packing of spheres.

c) How much tritium will permeate to the coolant from the pebble bed region through the F82H wall, if the superficial purge gas velocity is 1, 5, and 10 cm/s?
   - Assume diffusion limited control.
   - Average tritium generation rate in the breeder region= 1.21e-7 g/s.
   - Use bed average temperature for tritium partial pressure estimation.



Problem 1

a) $Ha = BL\sqrt{\frac{\sigma}{\rho\nu}}$, $\rho\nu = \mu$

Set $L = b$ $\Rightarrow Ha = (5\,T)(0.1\,m)\sqrt{\frac{0.7\times10^{6}\ \Omega^{-1}m^{-1}}{0.001\ Pa\cdot s}}$

$\boxed{Ha = 13229}$

$Re = \frac{UL\rho}{\mu} = \frac{(0.5\,m/s)(0.1\,m)(9300\ kg/m^3)}{0.001\ Pa\cdot s} = \boxed{4.65\times10^{5}}$

$Re_m = \frac{UL}{\eta}$, $\eta = \frac{1}{\sigma\mu_0} = \frac{1}{(0.7\times10^{6}\ \Omega^{-1}m^{-1})(4\pi\times10^{-7}\ N/A^2)}$

$= 1.1368\ \frac{\Omega\, m\, A^2}{N}$

$\boxed{Re_m = 0.044}$

$\boxed{N = \frac{Ha^2}{Re} = 376.4}$

$C_w = \frac{\sigma_w t_w}{\sigma L} = \frac{(1.4\times10^{6}\ \Omega^{-1}m^{-1})(2\times10^{-3})}{(0.7\times10^{6}\ \Omega^{-1}m^{-1})(0.1)} = \boxed{0.04}$

b) Without insulation: $\Delta p = L\sigma V B^2 C_w$

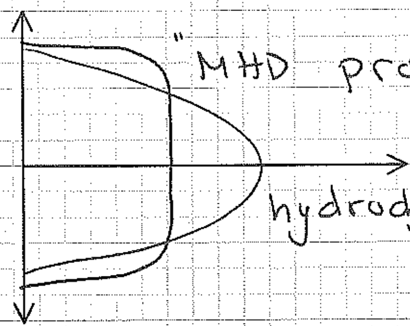
$= (0.1)(0.7\times10^{6})(0.5)(5)^2(0.04)$

$\boxed{\Delta P = 35\ kPa}$

With insulation: $\boxed{\Delta p = 0}$ because the net MHD body force is zero

c) 1. Insulated walls lead to essentially hydrodynamic velocity profiles, as shown below

2. Conducting walls lead to "MHD" profiles



d) $R = \frac{Re}{Ha} = \frac{4.65 \times 10^5}{13229} = 35.15 \Rightarrow \boxed{\text{laminar}}$

e) $q''(2bL) + \int q''' dV = \dot{m} c_p \Delta T = u\rho(4ab) c_p \Delta T$

$$(0.5 \times 10^6)(0.2) + 2bL \int_0^{2a} 30 \times 10^6 e^{-y/a} dy$$

$$= (0.5)(9360)(0.04)(190)\Delta T$$

$$0.2 \times 10^6 + 0.2\{-30 \times 10^6 (0.1)[e^{-2} - 1]\} = 35340 \Delta T$$

$$0.2 \times 10^6 + 1.04 \times 10^6 = 35340 \Delta T$$

$$\Rightarrow \boxed{\Delta T = 35 \text{ K}}$$

Problem 2

Start with Navier-Stokes equation for MHD

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u} = -\frac{1}{\rho}\nabla p + \nu \nabla^2 \vec{u} + \frac{1}{\rho}(\vec{j} \times \vec{B})$$

Take curl ($\nabla \times$) of equation to get vorticity

$$\underset{①}{\nabla \times \frac{\partial \vec{u}}{\partial t}} + \underset{②}{\nabla \times (\vec{u} \cdot \nabla)\vec{u}} = \underset{③}{\nabla \times \left(-\frac{1}{\rho}\nabla p\right)} + \underset{④}{\nabla \times (\nu \nabla^2 \vec{u})}$$
$$+ \underset{⑤}{\nabla \times \left(\frac{1}{\rho}\vec{j} \times \vec{B}\right)}$$

1. $\nabla \times \frac{\partial \vec{u}}{\partial t} = \frac{\partial}{\partial t}(\nabla \times \vec{u}) = \frac{\partial \vec{\omega}}{\partial t}$

2. $\nabla \times \left[(\vec{u} \cdot \nabla)\vec{u}\right] = \nabla \times \left[\frac{1}{2}\nabla |\vec{u}|^2 - \vec{u} \times \vec{\omega}\right]$

Use identity $\nabla \times \nabla \phi = 0$, ϕ = scalar field

$$\Rightarrow \nabla \times \left[\frac{1}{2}\nabla |\vec{u}|^2\right] = 0$$

3. Similarly, $\nabla \times \left(-\frac{1}{\rho}\nabla p\right) = -\frac{1}{\rho}\nabla \times \nabla p = 0$ $\underline{\text{if } \nabla \frac{1}{\rho} = 0}$

4. $\nabla \times (\nu \nabla^2 \vec{u}) = \nu \nabla^2 (\nabla \times \vec{u}) = \nu \nabla^2 \vec{\omega}$

5. $\nabla \times \left(\frac{1}{\rho}\vec{j} \times \vec{B}\right) = \frac{1}{\rho}\nabla \times (\vec{j} \times \vec{B})$

$$\frac{\partial \vec{\omega}}{\partial t} = \nabla \times (\vec{u} \times \vec{\omega}) + \nu \nabla^2 \vec{\omega} + \frac{1}{\rho}\nabla \times (\vec{j} \times \vec{B})$$

But $\vec{j} = \sigma \vec{u} \times \vec{B}$ when $\vec{E} = 0$

$$\boxed{\frac{\partial \vec{\omega}}{\partial t} = \nabla \times (\vec{u} \times \vec{\omega}) + \nu \nabla^2 \vec{\omega} + \frac{\sigma}{\rho}\nabla \times (\vec{u} \times \vec{B} \times \vec{B})}$$

If $\vec{u} = u\hat{e}_x + v\hat{e}_y$ and $\vec{B} = B\hat{e}_z$, $\vec{\omega} = \omega \hat{e}_z$

$$\vec{u} \times \vec{\omega} = \begin{bmatrix} e_x & e_y & e_z \\ u & v & 0 \\ 0 & 0 & \omega \end{bmatrix} = v\omega \hat{e}_x - u\omega \hat{e}_y$$

$$\vec{U} \times \vec{\omega} = \begin{bmatrix} u & v & 0 \\ 0 & 0 & \omega \end{bmatrix} = v\omega\,\hat{e}_x - u\omega\,\hat{e}_y$$

$$\nabla \times (\vec{U} \times \vec{\omega}) = \begin{bmatrix} e_x & e_y & e_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ v\omega & -u\omega & 0 \end{bmatrix} = \frac{\partial}{\partial z}(u\omega)\hat{e}_x + \frac{\partial}{\partial z}(v\omega)\hat{e}_y - \left[\frac{\partial}{\partial x}(u\omega) + \frac{\partial}{\partial y}(v\omega)\right]\hat{e}_z$$

$$\vec{U} \times \vec{B} = vB\,\hat{e}_x - uB\,\hat{e}_y$$

$$\vec{U} \times \vec{B} \times \vec{B} = -uB^2\,\hat{e}_x - vB^2\,\hat{e}_y$$

$$\nabla \times (\vec{U} \times \vec{B} \times \vec{B}) = \begin{bmatrix} e_x & e_y & e_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ -uB^2 & -vB^2 & 0 \end{bmatrix} = \frac{\partial}{\partial z}(vB^2)\hat{e}_x - \frac{\partial}{\partial z}(uB^2)\hat{e}_y - \left[\frac{\partial}{\partial x}(vB^2) - \frac{\partial}{\partial y}(uB^2)\right]\hat{e}_z$$

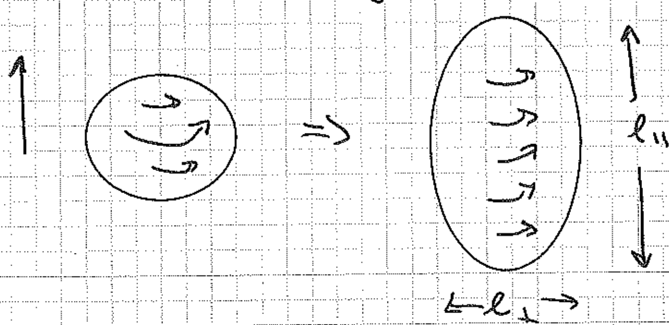
$\Rightarrow$ In the z-direction,

$$\frac{\partial \omega}{\partial t} = -\left[\frac{\partial}{\partial x}(u\omega) + \frac{\partial}{\partial y}(v\omega)\right] + \nu \nabla^2 \omega - \frac{\sigma}{\rho}\left[\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right]B^2$$

But $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$, $\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = -\omega$

$$\boxed{\frac{\partial \omega}{\partial t} + \underbrace{u\frac{\partial \omega}{\partial x} + v\frac{\partial \omega}{\partial y}}_{\sim \vec{U}\cdot\nabla\vec{\omega}} = \nu \nabla^2 \omega + \frac{\sigma}{\rho}\omega B^2}$$

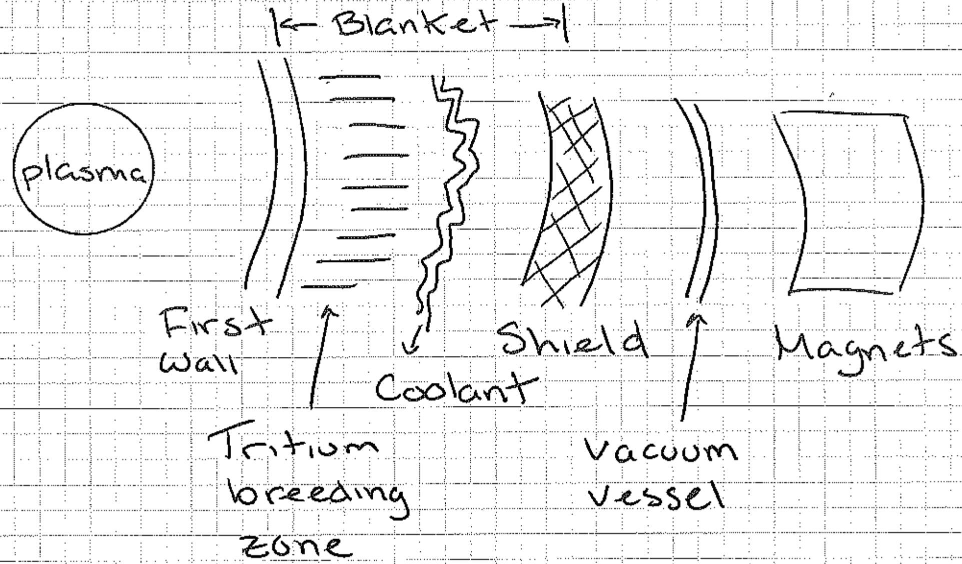
$$\underbrace{\frac{D\omega}{Dt} = \nu \nabla^2 \omega}_{\text{2D hydrodynamic vorticity equation}} + \underbrace{\frac{\sigma}{\rho}\omega B^2}_{\text{vortex damping by magnetic field}}$$



$\tau_j = \frac{\sigma}{\rho}B^2$

Problem 4

a)



b) The plasma makes D-T cycle possible so that energy is produced and carried out by energetic neutrons

The first wall (FW) removes most of the plasma heat load and minimizes sputtering to the plasma

The divertor removes impurities (e.g. α particles, sputterants) from the plasma

The blanket is responsible for energy extraction and tritium breeding.

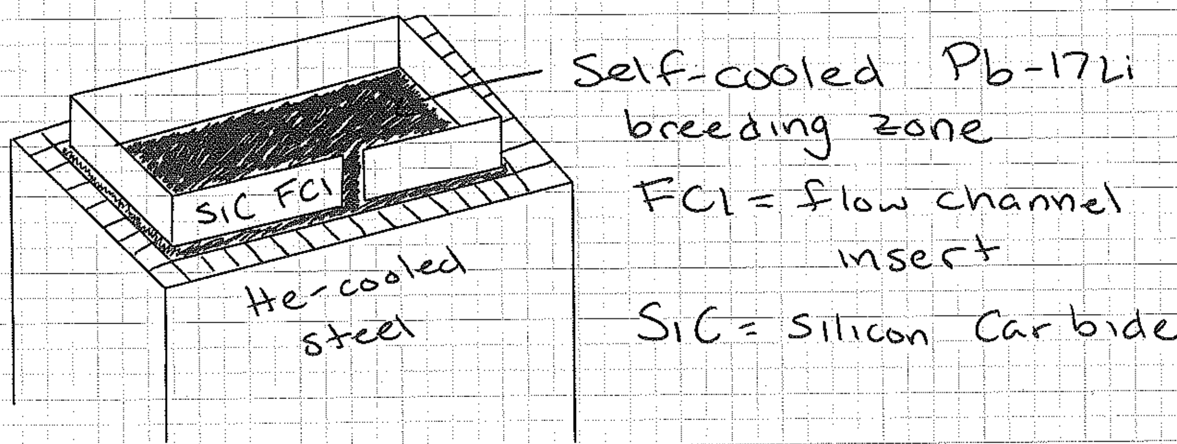
The shield protects the magnets from radiation damage

The vacuum vessel maintains low background pressures around the plasma

The magnets help confine the plasma away from the walls.

c) Tokamaks drive a current through the plasma, creating a transient poloidal field which twists the magnetic field lines and results in improved plasma confinement.

d)



e) The main distinction is the SiC flow channel insert, which allows the PbLi to be thermally and electrically insulated from the steel structure.

Advantages: higher thermal efficiency than self-cooled. Not subject to tritium permeation

Disadvantages: MHD pressure drop is still a consideration (not so in separately-cooled LM blankets)

f) Tritium is diffused from ceramic blanket (via He purge gas) as T_2, HT, T_2O, and HTO (and He is pumped back to TBM). Room temp.

and cryogenic molecular sieve beds extract the tritium, which then goes through the diffuser and into the getter, where it is stored via absorption in the tritide metal.

Problem 5

a) Assume plasma cross-section is circular and that the FW radius $\sim a$

$$a = \frac{R}{AR} = \frac{6.8\,m}{3} = 2.27\,m$$

$$A_w = \pi a^2 = 16.1\,m^2$$

$$P_n = P_{nw} A_w = (3.6\,MW/m^2)(16.1\,m^2) = 58.1\,MW$$

Assuming D-T

$$P_f = P_n \frac{17.58}{14.06} = \boxed{72.65\,MW}$$

b) Assume cryogenic system is right in front of superconducting magnets

Blanket attenuates neutron flux to 1%

$$\Rightarrow P_{shield} = P_n(0.01) = 0.581\,MW$$

For 85% Pb + 15% B_4C, $\mu_n = 0.0977$

$$\Rightarrow P_{cs} = P_s e^{-\mu\Delta_s^i} = (0.581\,MW)\,e^{-(0.0977)(0.9)}$$

$$= \boxed{0.5322\,MW}$$

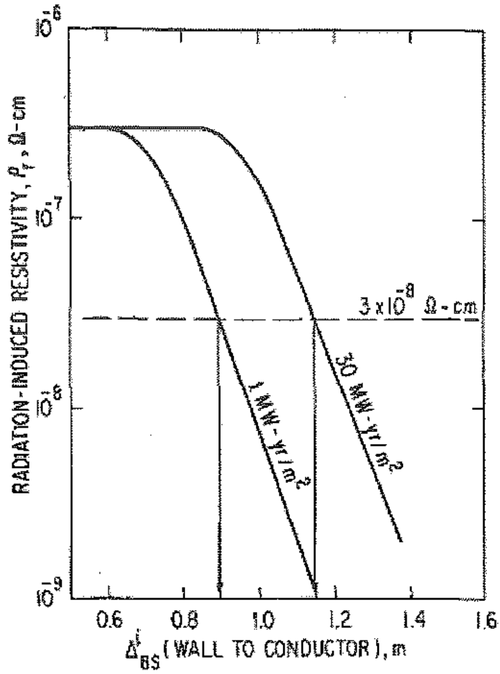
c) Assume heat is removed at 300 K and magnets are at 4 K

$$COP = \frac{1}{\frac{300}{4}-1} = 0.0135 = \frac{\dot{Q}_{out}}{\dot{W}_{in}}$$

$$\dot{W}_{in} = \frac{P_{sc}}{0.0135} = \boxed{39.4\,MW}$$

d) $A_{TF} = \pi R^2 = 145.27\ m^2$

$$P_{TF} = \frac{0.5322\ MW}{145.27\ m^2} \cdot 4\ yr = 14.65\ kW \cdot yr/m^2$$



Assume $P_{TF} \sim 1\ MW \cdot yr/m^2$

(conservative estimate)

For $\Delta^i_{BS} = 0.9$,

$\rho_r \sim 3 \times 10^{-8}\ \Omega \cdot cm$

e) Tritium consumption:

$$\dot{N}^- = \frac{P_n}{17.58\ MeV/reaction} (1\ T\ atom/reaction), \quad P_n = 58.1\ MW$$

$$= 2.06 \times 10^{19}\ T\ atoms/s\ (3.016\ g/mol)(1.66 \times 10^{-24}\ \tfrac{mol}{atoms})$$

$$= 1.03 \times 10^{-7}\ kg/s$$

$$\dot{N}^+ = (1.15)(1.03 \times 10^{-7}\ kg/s) = \boxed{1.19 \times 10^{-7}\ kg/s}$$

Problem 6

a) $\boxed{I^2 R \leq q P_{sc} \quad \text{or} \quad I^2 \rho \leq q A_{sc} P_{sc}}$

The cryogenic stabilization criterion states that the I^2R heat generated in the stabilizing material must be transfered out by the stabilized superconducting matrix.

b) High neutron fluences can change the critical temperature, T_c, and current density, J_c, of superconductors. This risks the superconductor behaving as a conventional conductor. In addition, the resistivity of the stabilizer can increase ($\rho = \rho_0 + \rho_m + \rho_r$) and break cryogenic stability.

c) Bulk shield: protects vacuum vessel and superconducting magnets

Penetration shield: protects against penetrations such as natural beams and vacuum ducts

Biological shields: building walls (typically concrete) to protect personnel inside and outside the power plant

d) The 3 leading structural materials for DEMO:

- Ferritic/martensitic steel
- V alloys
- SiC composites

These materials are promising due to safety, waste disposal and performance considerations. Ferritic/martensitic steel is considered reference material for DEMO However, it suffers at its operational temp. limits due to embrittlement and thermal creep. The most promising material is $\boxed{SiC_f/SiC}$ ceramic composites because of its low activation characteristics, engineerability, good lifetime performance even at high temps. (1000-1200°C) and high corrosion resistance to PbLi. These materials suffer from radiation stability concerns, high porosity/permeability and other fabrication concerns, however, so they represent a long-term consideration.

Problem 7

a) $Q = \Delta m c^2$

$^6Li + n \rightarrow \alpha + T + Q$

$m_6 = 9.98834 \times 10^{-27}$ kg
$m_n = 1.674927 \times 10^{-27}$ kg
$m_T = 5.008267 \times 10^{-27}$ kg
$m_\alpha = 6.646476 \times 10^{-27}$ kg

values from Wikipedia

$$Q = (m_6 + m_n - m_T - m_\alpha)c^2$$

$$= (9.98834 \times 10^{-27} + 1.6749 \times 10^{-27} - 5.008267 \times 10^{-27} - 6.646476 \times 10^{-27})(3 \times 10^8)^2 \text{ J}$$

$$= \boxed{7.67 \times 10^{-13} \text{ J} = 4.78 \text{ MeV}} \Rightarrow \underline{\text{exothermic}}$$

$^7Li + n \rightarrow n' + \alpha + T + Q$

$m_7 = 11.6503 \times 10^{-27}$ kg (from AMDC)

$$Q = (m_7 + \cancel{m_n} - \cancel{m_n} - m_T - m_\alpha)c^2$$

$$= (11.6503 \times 10^{-27} - 5.008267 \times 10^{-27} - 6.646476 \times 10^{-27})(3 \times 10^8)^2 \text{ J}$$

$$= \boxed{-3.96 \times 10^{-13} \text{ J} = -2.47 \text{ MeV}} \Rightarrow \text{endothermic}$$

b) $E_H = \overline{E_r} = \frac{2AE}{(A+1)^2}(1 - \overline{\cos\theta_{cm}})$, $A = 6$

Assume $\theta_{cm} = 45°$ (problem was vague)

$$E_H = \frac{12(1\text{ MeV})}{7^2}(1 - \cos 45°) = \boxed{71.7 \text{ keV}}$$

c) Assuming the nuclide remains at ground state,

$E_H = E + Q = 14\text{ MeV} - 5\text{ MeV} = 9\text{ MeV}$

No σ given, so microscopic kerma factor is

$$\boxed{k = 9\sigma \quad \text{MeV}\cdot\text{cm}^2}$$

d) $E_f = E_i e^{-\mu\Delta s}$

$$10^{-4} = e^{-\mu\Delta s}$$

$$\Delta s = \frac{-\ln(10^{-4})}{0.138\text{ cm}^{-1}} = \boxed{66.7\text{ cm}}$$

e) Neutron Transport Equation:

$$\boxed{\begin{aligned}\frac{\partial n}{\partial t} + v\hat{\Omega}\cdot\nabla n + v\Sigma_t n(\vec{r},E,\hat{\Omega},t) &= s(\vec{r},E,\hat{\Omega},t) \\ &+ \int_{4\pi} d\hat{\Omega}' \int_0^\infty dE' v' \Sigma_s(E'\to E, \hat{\Omega}'\to\hat{\Omega}) n(\vec{r},E,\hat{\Omega},t)\end{aligned}}$$

or in terms of neutron flux:

$$\boxed{\begin{aligned}\frac{1}{v}\frac{\partial \phi}{\partial t} + \hat{\Omega}\cdot\nabla\phi + \Sigma_t \phi(\vec{r},E,\hat{\Omega},t) &= s(\vec{r},E,\hat{\Omega},t) \\ &+ \int_{4\pi} d\hat{\Omega}' \int_0^\infty dE' \Sigma_s(E'\to E, \hat{\Omega}'\to\hat{\Omega}) \phi(\vec{r},E,\hat{\Omega},t)\end{aligned}}$$

The integral, also know as the inscattering term, is difficult to treat mathematically and is simplified, e.g., by group discretization.

f) i. ${}^{51}V + n \rightarrow {}^{50}V + 2n$

${}^{51}V + n \rightarrow {}^{52}V + \gamma$

${}^{6}Li + n \rightarrow \alpha + T$

${}^{7}Li + n \rightarrow {}^{8}Li + \gamma$

${}^{7}Li + n \rightarrow n' + \alpha + T$

$$TBR = \frac{\dot{N}^{+}}{\dot{N}^{-}} = \frac{(0.8+0.4)}{1} = \boxed{1.2}$$

2. Assuming D-T cycle

$$\epsilon = \frac{[(0.1)(13) + (0.05)(8) + (0.8)(4.8) + (0.02)(5) + (0.4)(24)]}{14.06}$$

$$\boxed{\epsilon = 0.4694}$$

3. $$P_E = \eta_{TC} P_f \left[\frac{3.52}{17.6} + \epsilon \frac{14.06}{17.6} \right]$$

$$= (0.35)(3000\,MW)\left[\frac{3.52}{17.6} + (0.4694)\frac{14.06}{17.6} \right]$$

$$= \boxed{603.7\ MW}$$