EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 29 April 2025 2 to 3.40

Module 4I10

NUCLEAR REACTOR ENGINEERING

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Nuclear Energy Data Book (21 pages)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

1 A water-cooled reactor is producing 300 MW of heat. The reactor coolant flows through the core increasing in temperature by 50 K. The flow is turbulent and most of the pressure losses are frictional.

(a) If the water coolant is replaced by liquid sodium, estimate the sodium temperature rise across the core. Assume the core geometry and pumping power remain the same. Relevant coolant properties are summarised in Table 1 below. [40%]

(b) Helium gas is now considered as a coolant. Discuss the potential effects of such a coolant choice on the reactor's safety and economics. [30%]

(c) List all the desirable reactor coolant properties, explaining their significance. [30%]

Table 1

Water density, kg m^{-3}	700
Water specific heat capacity, J kg^{-1} K^{-1}	5800
Water dynamic viscosity, Pa s	9×10^{-5}
Sodium density, kg m^{-3}	800
Sodium specific heat capacity, J kg^{-1} K^{-1}	1300
Sodium dynamic viscosity, Pa s	23×10^{-5}

2 A plate-type fuel element can be approximated by a one-dimensional slab of thickness $2a$ (see Fig. 1 below). The temperatures at the left and right boundaries of the slab are T_L and T_R, respectively. The thermal conductivity of the slab is k and can be assumed constant. Power density in the slab is spatially uniform and equal to q'''.

(a) Show that, in order to transfer twice as much heat through the left boundary as through the right boundary, the difference between the right and left boundary temperatures is given by:

$$\Delta T = (T_R - T_L) = \frac{2}{3}\frac{q''' a^2}{k}$$ [40%]

(b) Is it possible to transfer all the heat generated in the slab through the left boundary? If so, under what conditions? If not, why not? [25%]

(c) Compare the plate and cylindrical pin-type fuel configurations with respect to their ability to support high core power density operation. Assume that the pin radius R is equal to the half thickness of the plate a and the fuel to coolant volume ratio (and, thus, H/HM) is the same in both configurations. [35%]

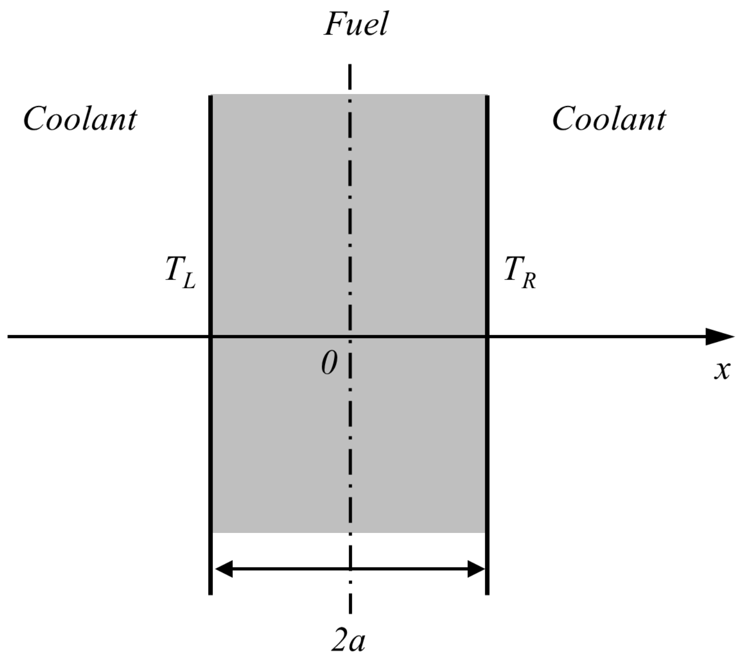

Fig. 1

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3 (a) A cylindrical reactor core, 150 cm tall and 150 cm in diameter, has the following neutron flux distribution:

$$\Phi(r,z) = \Phi_0 \left[1 - \left(\frac{r}{75}\right)^2\right] \cos\left(\frac{\pi z}{150}\right)$$

The core produces 200 MW of thermal power and contains 2000 kg of ^{235}U with a fission cross section of 35 barns. ^{235}U is the only fissile material in the core. Assuming that the core is approximately homogeneous and energy per fission is 200 MeV, estimate the power density at the location with coordinates $r = 20$ cm, $z = 20$ cm. [40%]

(b) The core uses 3-batch fuel management. However, each batch has two types of fuel assemblies, type a and type b, with the following reactivity characteristics:

$$\rho_a = 0.18 - 0.009B$$

$$\rho_b = 0.24 - 0.01B$$

where B is the burnup in MWd kg^{-1}.
The desired equilibrium cycle burnup $B_c = 11$ MWd kg^{-1}.

(i) Calculate the fraction of fuel assemblies of each type within each batch. [15%]

(ii) Calculate the core reactivity at the beginning of the equilibrium cycle. [15%]

The Linear Reactivity Model assumptions apply and the core leakage can be neglected.

(c) List the fuel design parameters that affect the core initial reactivity and the rate of reactivity loss with burnup. Explain the reasons behind each of the effects. [30%]

4 A PWR operates in steady state producing 3000 MW_{th}. The reactor has a Moderator Temperature Coefficient of -20 pcm K^{-1} and a Fuel Temperature Coefficient of -2 pcm K^{-1}. The coolant mass flow rate is 20×10^3 kg s^{-1}. The core power distribution is uniform and the effect of xenon poisoning can be neglected. The fuel is in the form of cylindrical pins, and the fuel thermal conductivity, k, is independent of temperature. The coolant's specific heat capacity is 5800 J kg^{-1} K^{-1}. The coolant core inlet temperature is 570 K. The core average fuel temperature is 900 K. Thermal resistance to heat transfer across the cladding, gap and the coolant boundary layer can be neglected.

Clearly state any other assumptions you make.

(a) Verify that the volume weighted average fuel temperature for a cylindrical fuel pin is given by:

$$T_{av} = \frac{T_{CL} + T_{fo}}{2}$$

where T_{CL} is the fuel centreline temperature and T_{fo} is the fuel outer surface temperature. [30%]

(b) The core inlet temperature of the coolant is decreased by 5 K, while the reactor power remains at 3000 MW_{th}. Estimate the change in the core reactivity. [15%]

(c) The coolant mass flow rate is decreased to 15×10^3 kg s^{-1}, while the core power and core inlet temperature of the coolant remain at their nominal values. Estimate the change in the core reactivity. [20%]

(d) The reactor core power is increased to 3500 MW_{th}, while the core inlet temperature of the coolant and mass flow rate remain at their nominal values. Estimate the change in the core reactivity. [35%]

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