EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 24 April 2024 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 cube shaped PWR core is to produce 100 MW_{th} for 10 years using a single batch of fuel. The core contains cylindrical UO_2 fuel pins and has a uniform power distribution. The coolant temperature rise across the core and the temperature rise across the cladding and gap are negligible.

(a) Using the data from Table 1 below, determine the minimum core size, the number of fuel pins and the pin radius. [50%]

(b) Would the design parameters found in (a) meet the additional constraint of 50 MWd/kg imposed on fuel burnup? What would be the implications of your finding? [30%]

(c) Consider a case in which the core configuration found in (a) is subcritical. Suggest how the core reactivity can be increased, including pros and cons of each option. List all the considerations for selecting the value for the initial reactivity of the core. [20%]

Table 1

UO_2 density, g cm^{-3}	10.4
UO_2 thermal conductivity, W $m^{-1}K^{-1}$	3
Maximum fuel temperature, K	1500
Critical heat flux, MW m^{-2}	1.5
Minimum departure from nucleate boiling ratio (MDNBR)	1.7
Average coolant temperature, K	600
Fuel pin lattice pitch, cm	1.5

2 A natural circulation flow of cooling water needs to be established between a reactor vessel and a residual heat removal system heat exchanger as schematically shown in Fig. 1 below. The heat exchanger is submerged in an open pool of secondary water at 1 bar saturated conditions.

(a) If the nominal thermal reactor power is 200 MW, estimate the secondary water inventory in the pool above the heat exchanger needed to sustain 72-hour operation of the system after reactor shutdown. Make conservative assumptions if necessary. [30%]

(b) Using the data provided in Table 2, estimate the height separation, Z, between the core and the heat exchanger, if the reactor decay heat is 10 MW and boiling of the primary water is to be avoided. Neglect acceleration and shock losses. Note that water density depends much more strongly on temperature than on pressure. It is also known that the flow in the loop is turbulent. The tempertaure drop, that drives the heat transfer across the heat exchanger, is negligible. Therefore, the primary coolant cold leg temperature can be assumed to be the same as the secondary water temperature in the tank. [50%]

(c) Provide as many examples as you can of the use of natural convection heat removal in accident conditions of modern LWR designs. [20%]

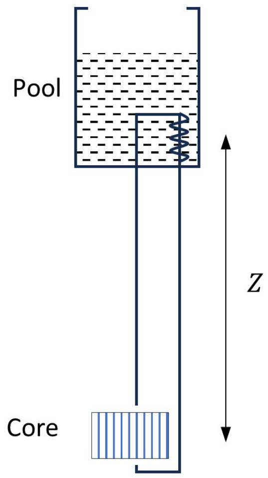

Fig. 1

Table 2

Primary pressure, bar	100
Primary water specific heat capacity c_p, J kg^{-1}K^{-1}	5200
Cold leg primary water dynamic viscosity μ_C, Pa s	0.00028
Hot leg primary water dynamic viscosity μ_H, Pa s	0.00008
Connecting pipe diameter, cm	8
Core pressure loss, kPa	3
Heat exchanger pressure loss, kPa	3

3 A reactor core has a positive coolant reactivity coefficient. The core designer wants to make the reactivity coefficient negative by doubling the number of the fuel assemblies while halving their height.

(a) If the coolant mass flow rate is to remain the same and the flow to remain turbulent, estimate the pumping power required to overcome the new core pressure loss relative to that of the original one. [50%]

(b) Why would such a design change make the coolant temperature coefficient negative (or less positive)? What are the disadvantages of such a strategy? [20%]

(c) Suggest other strategies for making the coolant temperature coefficient negative. Provide the physical reasoning behind each strategy. [30%]

4 A PWR operates in steady state with a core-average power density of 100 W cm^{-3}. The fuel is in the form of cylindrical pins.

(a) The power peaking factor at the core location with the maximum expected fuel temperature is 2.5. Heat transfer from the fuel pellet to the coolant can be characterised by an overall heat transfer coefficient h = 5 kW m^{-2} K^{-1}. The coolant temperature is 300 °C, the average thermal conductivity of the fuel pellet is 3 W m^{-1} K^{-1}, the fuel pellet radius is 0.48 cm and the fuel pin lattice pitch is 1.25 cm. Calculate the maximum fuel temperature in this location. [30%]

(b) A control rod is ejected from the core, resulting in the core-average power evolution shown in Fig. 2 below. Assume the core spatial power shape did not change during the transient. Make a conservative estimate of whether the maximum fuel temperature exceeded the fuel melting point of 2800 °C. The fuel specific heat capacity is 350 J kg^{-1} K^{-1} and the fuel density is 10^4 kg m^{-3}. [40%]

(c) Sketch qualitatively on the same graph the evolution of the core reactivity and of the relevant positive and negative core reactivity components as functions of time. On a different graph, sketch the evolution of the fuel and coolant temperatures. State the reasons for the observed trends. [30%]

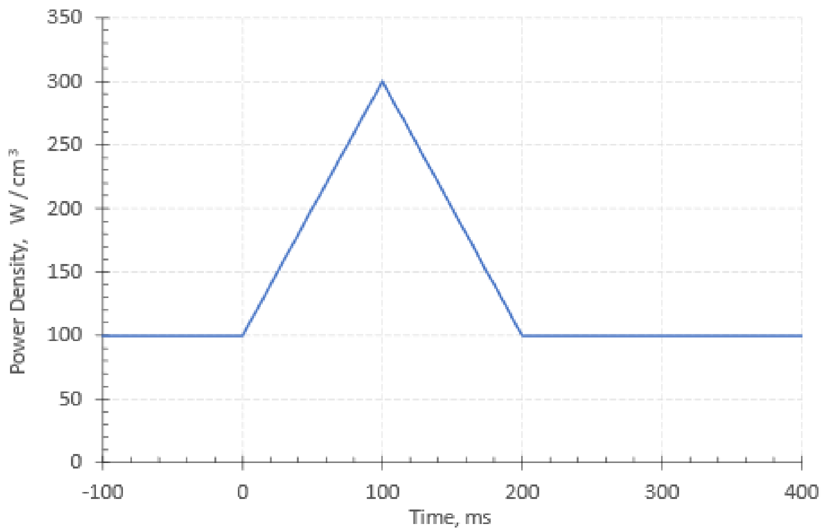

Fig. 2

END OF PAPER

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