Version ES/4

EGT3
ENGINEERING TRIPOS PART IIB

Friday 5 May 2017 2 to 3.30

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
NE Data Book
Engineering Data Book

10 minutes reading time is allowed for this paper.

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

1 (a) Describe the unique features of the power conversion cycles in Advanced Gas-cooled Reactors (AGR). Contrast these features against those of a Light Water Reactor cycle. [20%]

An AGR operates on a simple steam cycle with superheat, a single stage steam expansion to the condenser pressure and no feed water heaters. The cycle has the following parameters:

Boiler pressure	150 bar
Condenser pressure	0.1 bar
Superheated steam temperature	500 °C

(b) Sketch the *T*-*s* diagram of the power cycle, labelling all important state points. [5%]

(c) Calculate the thermal efficiency of the cycle. [25%]

(d) It is proposed to replace the CO_2 coolant in an AGR by a molten salt in order to increase the core power. Explain what characteristics of molten salts may allow such a power uprate. [20%]

(e) With CO_2 coolant, the AGR core inlet temperature is 350 °C and the core outlet temperature is 650 °C. After switching to molten salt, the coolant temperature rise across the core can be significantly reduced, with the inlet temperature increasing to 450 °C, while the outlet temperature remains fixed at 650 °C. Assuming that the boiler and condenser pressure remain fixed, what are the factors that would affect the thermal efficiency of the power conversion cycle as a result of this change of coolant? [30%]

2 Following a Loss Of Coolant Accident (LOCA) in a Pressurised Water Reactor, the primary water coolant is discharged into the containment and flashed into steam pressurising the containment.

(a) Describe the means used to keep the pressure inside the containment within the design limits. [20%]

(b) Prior to the LOCA, the containment air pressure was 1 bar, temperature 25 °C and zero humidity. Calculate the gas mixture pressure inside the containment after the LOCA, if the final temperature is 150 °C. [25%]

(c) Calculate the containment volume needed to keep the steam pressure below 4 bar if the mass of steam is 500,000 kg. [20%]

(d) The containment has 25 mm thick carbon steel walls with a total surface area of 20,000 m^2. The containment is cooled by natural convection of air flowing along the outside surface of the walls. The containment wall to outside air heat transfer coefficient is 5 W m^{-2} $°C^{-1}$ and the air temperature is 30 °C. Calculate the maximum possible heat removal rate from the containment if the maximum temperature of the containment wall is limited to 150 °C. Clearly state any assumptions you are making. [35%]

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3 (a) A plate-type fuel element (Fig. 1) consists of a fuel region of thickness $2a$ with thermal conductivity k_f sandwiched between two cladding plates of thickness t with thermal conductivity k_c. The fuel region is generating q''' of power per unit of fuel volume. The power is generated uniformly throughout the fuel region. Thermal contact between the fuel and the cladding can be considered perfect (i.e. infinitely high gap conductance). The coolant temperature on the outside of the cladding is T_f and the heat transfer coefficient to the coolant is h. Show that an expression for the temperature distribution $T(x)$ inside the fuel element as a function of distance x from the centre of the fuel has the following form

$$T(x) = T_f + q'''\left(\frac{a}{h} + \frac{a\,t}{k_c} + \frac{x^2}{2k_f}\right)$$ [30%]

(b) The entrance to the coolant channel on the left side of the fuel element is partially blocked such that the heat transfer coefficient on that side is reduced by a factor of two. Estimate the factor by which the coolant flow rate in the channel will change. Assume the coolant is light water and the flow is turbulent. [30%]

(c) For the partially blocked channel condition described in (b) and uniform distribution of power inside the fuel, assume that the fuel temperatures at the left (blocked) and right surfaces are T_{foL} and T_{foR} respectively, and $T_{foL} > T_{foR}$. Show that an expression for the maximum fuel temperature and its location in terms of T_{foL}, T_{foR} and q''' has the following form

$$T_{\max} = T(x_{\max}) = -q'''\frac{(a^2 - x_{\max}^2)}{2k_f} + \left(\frac{T_{foR} + T_{foL}}{2a}\right)x_{\max} + \frac{T_{foR} + T_{foL}}{2}$$

where

$$x_{\max} = \frac{k_f\,(T_{foR} + T_{foL})}{2a\,q'''}$$ [40%]

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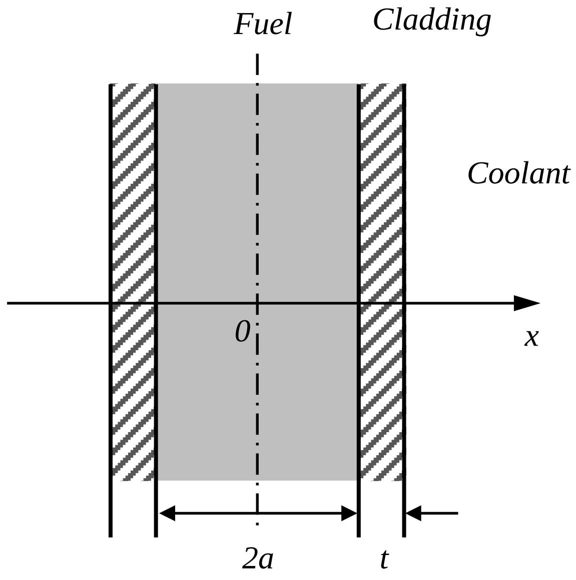

Fig. 1

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4 (a) List three passive safety systems in modern Light Water Reactors (LWR). State the basic principle of their operation. [25%]

(b) In-containment Refuelling Water Storage Tanks (IRWST) are commonly found in modern LWR designs. Apart from storing water for refuelling (as the name suggests), what other important safety functions can the IRWST perform? [25%]

Many Boiling Water Reactor designs use the Isolation Condenser (IC) system (Fig. 2). If an accident occurs, the main steam line is automatically closed and the decay heat is removed by the IC system that connects the reactor pressure vessel steam dome with a heat exchanger located in a large tank of water at atmospheric pressure and 100 °C. The steam generated inside the pressure vessel condenses on the tube side of the heat exchanger and the condensate is directed back into the pressure vessel. The vessel pressure is maintained at a safe level by controlling the flow rate through the steam line leading to the IC. The reactor power during normal operation is 3000 MW_{th}.

(c) Estimate the pressure inside the vessel 3 hours after an emergency shutdown. Assume infinite reactor operation time prior to the shutdown, the heat transfer coefficient in the IC heat exchanger is 8100 W m^{-2} K^{-1} and the heat transfer area is 20 m^2. [30%]

(d) Estimate the steam flow rate three hours after the emergency shutdown described in (c). Clearly state any assumptions you are making. [20%]

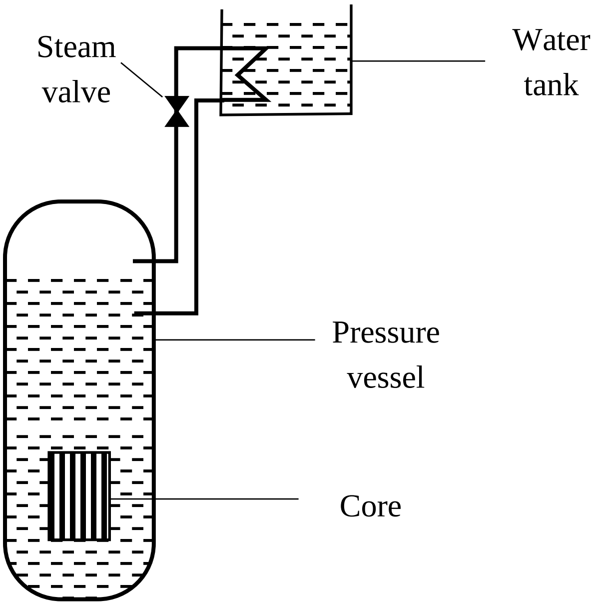

Fig. 2

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