Ref. No.: Ex/PG/NuE/T/114A/2024

Jadavpur University

Master of Nuclear Engineering, 1st year 1st semester examination, 2024

Subject: Reactor Control Engineering

Time:3 Hours **Full marks:100**

All questions are compulsory

1. a) What are the limitations of conventional control theory that the state-space theory can address?
   b) Find the time domain solution of the state equation
   $$\dot{X}(t) = AX(t) + BU(t)$$
   where the terms bear their usual meaning.
   c) Given the system differential equation
   $$y^{(3)} + a_1 y^{(2)} + a_2 y^{(1)} + a_3 y = b_0 u^{(3)} + b_1 u^{(2)} + b_2 u^{(1)} + b_3 u$$
   where the terms bear their usual meaning,
   (i) derive the transfer function of the system,
   (ii) derive the state equation of the system. 3+10+3+4

2. a) Derive the one-speed neutron balance equation using Fick's law and Laplacian operator.
   b) What are the underlying assumptions made by you during the derivation in 2.a).
   c) Derive the approximate thermal power generated in a nuclear power reactor using thermal fission as the source of energy with a volume V and neutron flux ϕ? What is the unit of ϕ?
   12+3+5

3. a) What do you mean by poisoning effect in a nuclear reactor and in which type of nuclear reactor it is predominant and why?
   b) Derive an expression for poisoning effect near criticality in a homogeneous nuclear reactor.
   c) What is the most important fission product poison and why?
   d) Derive the expression for equilibrium concentration of this predominant element in an operating nuclear reactor? (2+1+2) + 7 + 2+6

4. a) What are the effects of control rod movement inside a reactor core? What do you mean by "worth" of a control rod?
   b) Draw a typical plot of neutron flux vs. radial distance from the surface of a fully-inserted control rod inside a reactor and explain qualitatively the nature of the curve.
   c) Explain the calibration process of control rod worth using the "gradual-withdrawal" method.
   (3+2) + (3+2) + 10

[Turn over

5. a) Derive the open-loop transfer function of a nuclear reactor.

b) Consider the following:

m_c : mass of coolant in reactor core (kg),
c_{pc} : specific heat of coolant at a constant pressure (J/kg-^{o}C),
w_c : mass flow rate of coolant (kg/s),
T_c : average coolant temperature = $\frac{T_i+T_e}{2}$,
T_i : inlet coolant temperature (^{o}C); considered constant,
T_e : exit coolant temperature,
T_f : average fuel temperature.

Derive the differential equation, using small perturbation approximation, that relates T_e and T_f (coolant temperature model). This differential equation can be used as one of the state equations in the state-space model of the reactor. 10+10