REVIEW QUESTIONS

THE CRITICAL REACTOR AT STEADY POWER OUTPUT

1. List the particles and radiation produced by the fission process at the "moment" of fission and those produced by subsequent fission product decay.

2. Describe how the 200 MeV per fission deposited in the reactor is distributed over the complete list of prompt and delayed energy sources that result from fission.

3. Compare the terms "unit cell multiplication factor" and "effective neutron multiplication factor", distinguishing clearly between them.

4. Describe how characteristics of the CANDU reactor affect each of the following:
   (a) Fast fission factor
   (b) Resonance escape probability
   (c) Thermal utilization factor
   (d) Reproduction factor
   (e) Fast and thermal non-leakage probabilities

5. Why does the size of the lattice pitch affect reactivity?

6. Explain why H_2O is not suitable as a moderator for CANDU reactors but is quite satisfactory for reactors using enriched fuel.

7. Explain what is meant by each of the following:
   (a) Reactivity
   (b) Reactivity worth
   (c) Excess core reactivity (as used in CANDU stations)
   (d) Control reactivity

8. Define <u>macroscopic</u> cross-section, and explain what is meant by mean free path.

9. Write the expression for the reaction rate per unit volume of some material in a reactor with a flux = ϕ neutrons/(cm^2 s).

10. When a particular nuclear reaction takes place, the sum of the masses of the original reactants is "heavier" than the sum of the masses of the products by 0.0043 u. Use the formula $E = mc^2$ to calculate the energy release (in MeV).
    (1 u = 1.66×10^{-27} kg; 1 MeV = 1.6×10^{-13} J; speed of light = 3×10^8 m/s).

11. Write down the sequence of reactions that produce Pu-239 from U-238.

12. The table below gives the thermal neutron cross-sections of U-235 and U-238 for elastic scattering, radiative capture, and fission, (Cross-sections given in barns). The table also gives the average number of neutrons per fission (ν).

	σ_s	$\sigma_{n,\gamma}$	σ_f	ν
U-235	17.6	98.3	580.2	2.43
U-238	10.0	2.71	0	0

(a) If a thermal neutron interacts with a nucleus of U-235, what is the probability that fission occurs?

(b) What is the probability that a thermal neutron moving through an infinite medium of natural uranium will eventually produce a fission (atomic abundance of U-235 in natural uranium = 0.72%).

(c) Calculate the value of k_∞ for natural uranium, assuming that all the neutrons involved (both those causing fission and those produced in fission) are thermal neutrons.

REVIEW QUESTIONS

RESPONSE OF THE CRITICAL REACTOR TO A REACTIVITY CHANGE

1. Define log rate and reactor period and state their relationship.

2. Explain how delayed neutrons affect reactor control.

3. Define the following and explain how they arise:
    a) Prompt jump,
    b) Prompt drop

4. For a reactor at low power, compare the change in reactor power following a very small positive reactivity insertion with a much larger insertion (but one that is too small to cause prompt criticality).

5. State why reactor power first drops rapidly following a large negative reactivity insertion and then continues to decrease more slowly.

6. State what the term "prompt criticality" means and give the approximate reactivity insertion that causes it.

7. The effect of delayed neutrons on the ease of control of an equilibrium-fuelled CANDU becomes insignificant as a reactor becomes supercritical by about 5 mk. Explain why.

8. At time t = 0, a positive step change of reactivity of magnitude $\Delta k \ll \beta$ is added to a reactor running at a low power, P_0. Write down the expression for the power at time t after the step.

9. An equilibrium fuelled reactor ($\beta \approx 0.005$) is critical at 40% Full Power when it receives an insertion of + 0.1 mk of reactivity. Ignore feedback effects.
    (a) Calculate the size of the prompt jump.
    (b) Calculate the stable period.
    (c) Calculate the reactor power after 30 seconds.

REVIEW QUESTIONS

RESPONSIVENESS OF THE SUBCRITICAL REACTOR

1. Define the subcritical multiplication factor.

2. Explain how subcritical multiplication of a neutron source causes:
    a) An observable, steady power level that is larger than the source.
    b) A change in power level following a reactivity change that leaves the core subcritical.

3. Select the phrase (a) to (d) that correctly completes the following statement, and then justify your choice using knowledge of fundamental reactor theory.

    The change in neutron power resulting from a step insertion of 1 mk of positive reactivity in a reactor when k = 0.998 differs from the change resulting from *the same* insertion of 1 mk when k = 0.900 in that for k = 0.998 the change is:
    a) larger and it takes longer to achieve equilibrium power;
    b) smaller and it takes less time to achieve equilibrium power;
    c) larger and it takes less time to achieve equilibrium power;
    d) smaller and it takes longer to achieve equilibrium power;

4. Describe the response to a reactivity change in a subcritical core and explain why the dynamic response is different for a deeply subcritical reactor and one that is almost critical. (The reactor remains subcritical following each reactivity addition).

5. Consider a subcritical equilibrium fuelled reactor ($\beta \approx 0.005$) that has been shut down for 3 weeks. The source strength is $P_{source} = 10^{-7}$ of F.P. and k = 0.9995.
    a) What percent of all neutrons are source neutrons?
    b) What percent of all neutrons are fission neutrons?
    c) What percent of all neutrons are delayed?

REVIEW QUESTIONS

EFFECTS OF TEMPERATURE AND VOIDING ON CORE REACTIVITY

Describe what is meant by the term “temperature coefficient of reactivity”

1. Give typical approximate operating temperatures for the fuel, moderator, and coolant in a CANDU reactor for the following operating states:
   (a) shut down and cooled down
   (b) hot shutdown (zero power hot)
   (c) full power
2. Describe the effect of an increase in the thermal neutron temperature on absorption in the fissile isotopes U-235 and Pu-239.
3. Name and explain the main effect that makes the fuel Temperature Coefficient of Reactivity negative.
4. Explain the effect on reactivity caused by a change in temperature of the:
   a) Fuel
   b) Moderator
   c) Coolant
5. Use the graphs of reactivity vs. temperature in the chapter (for fuel, moderator and coolant) to determine the reactivity change for:
   (a) HT system warm up from cold to zero power hot
   (b) Decrease in unit power from full power to zero power hot
6. Compare the times for the reactivity changes due to changes in the moderator, coolant, and fuel temperatures following a power increase.
7. Explain what the terms “Power Coefficient” and “Void Reactivity” mean.
8. Explain how the CANDU power coefficient affects:
   (a) Normal regulation
   (b) A power transient following an upset
9. Explain how voiding of the coolant simultaneously increases fast fission and decreases resonance capture.
10. Describe how the thermal neutron temperature changes on coolant voiding and state the effects on thermal neutron absorption rate.

11. Explain why loss of coolant from a fuel channel in a CANDU increases reactivity.

12. Name the major upsets that set the lower and upper limits on heat transport isotopic and for each describe how the limit arises.

REVIEW QUESTIONS

EFFECTS OF FISSION PRODUCTS ON CORE REACTIVITY

1. Name the two most operationally significant saturating fission products and for each list the properties that make it a significant fission product.

2. Write the equations for the nuclear processes that produce and remove I-135 and Xe-135 from the fuel.

3. On the same graph, sketch the buildup curves for iodine load vs. time and xenon load vs. time following restart with no xenon or iodine in the core.

4. On the same graph, sketch the variation of iodine load vs. time and xenon load vs. time following a trip from full power equilibrium steady-state conditions. On the graph, mark the approximate time of the xenon peak, the approximate size of the peak, and the approximate time until the reactor can be restarted.

5. State the meaning of each of the following terms:
   a) Poison out
   b) Poison prevent operation
   c) Poison override capability
   d) Poison override time
   e) Decision and action time

6. Write down the equations describing the rate of change of iodine and xenon in a CANDU reactor. Calculate the equilibrium iodine concentration and put in the percentage (at full power) contributed by each of the xenon terms.

7. Sketch the reactivity transient that follows a power increase and a power decrease for a reactor operating at a steady high power level. State the operational problems that could occur in these two situations.

8. What are the two conditions that determine whether a reactor can develop xenon oscillations?

9. Describe a xenon oscillation.

10. State how oscillations are controlled in a CANDU reactor and indicate how an uncontrolled oscillation could nevertheless develop.

11. Compare the operational effects of samarium with those of xenon with respect to:
    a) Initial build up,
    b) Dependence of equilibrium level on flux,
    c) Transient following a trip or shutdown,
    d) Return to equilibrium following a restart,
    e) Transients on power changes

REVIEW QUESTIONS

EFFECTS OF FUEL IRRADIATION AND ON-POWER FUELLING ON CORE REACTIVITY

1. List the chief characteristics associated with using on-power fuelling for maintaining core reactivity.

2. State what the following terms mean:
   (a) fresh fuel
   (b) fuel burnup, and
   (c) equilibrium-fuelled reactor

3. Explain why the following expressions used to describe fuel "burnup" are not exactly proportional to each other.
   (a) Heat energy extracted per unit mass of Uranium in units MWh/kgU;
   (b) Total neutron exposure of the fuel (flux × time) in units n/kb.

4. Explain the operational distinction between "saturating fission products" and "non-saturating fission products"

5. For the graph in the text showing the reactivity change of a fuel bundle with irradiation, explain the shape of the graph in terms of:
   a) U-235 burnup and Pu-239 growth
   b) Buildup of Pu-240 and Pu-241
   c) Increasing fission products

The complete fission of 1 g of U-235 produces 1 MW-day of thermal energy. Since natural uranium contains only 0.72% U235, it follows that approximately 140 g of natural uranium is required to produce 1 MW-day. Give the two main reasons why calculation of the refuelling rate in an operating CANDU reactor using only this data is not correct.

REVIEW QUESTIONS

REACTOR OPERATIONS AT LOW POWER

1. List the three main reasons for non-linearity between neutron and thermal power.

2. When a CANDU reactor is shutdown after running for a long period, the power rundown can be divided into three phases. These are 0 to 0.1 second; 0.1 second to 10 minutes; 10 minutes onwards.
   (a) Show why the duration of the first phase is so short
   (b) Estimate the size of the initial drop in power (the prompt drop) for an equilibrium fuelled reactor
   (c) Discuss the composition of the neutron density (in terms of prompt neutrons, delayed neutrons, photo neutrons, and spontaneous fission neutrons) during each of these phases

3. State the approximate value of decay heat at full power, and at 3 minutes, and 60 minutes after a trip from full power.

4. Compare the thermal power rundown with the neutron power rundown following a trip in terms of:
   a) Initial rate of drop
   b) Duration

5. Identify the reactivity changes that occur in a reactor after it is shutdown from extended operation at power and, for each change give the:
   a) sign
   b) approximate size
   c) time scale

6. When bringing a reactor critical following a long shutdown, it is customary to maintain a plot that allows one to predict the critical poison concentration.
   (a) What is plotted and why does it produce a linear plot?
   (b) Explain why start-up procedures require monitoring of neutron flux during start-up and do not depend solely on criticality predictions made in advance.

7. When a reactor is held in a low power critical state for an extended period, there may be some uncertainty as to whether the reactor remains critical. State what the term “critical” means in this situation and explain the uncertainty.

8. Describe the power response of a slightly supercritical reactor at low power and explain why the response changes as power approaches the last decade of reactor power.

REVIEW QUESTIONS

REACTOR OPERATIONS AT HIGH POWER

1. Describe the possible safety concerns with inadequately flattened flux.

2. List four ways of producing overall (global) flux flattening in a CANDU reactor and state why flux flattening is important.

3. State how CANDU reactors achieve relative zone-to-zone flux balance and how localized “hot spots” are avoided. Indicate how local peaks could nevertheless occur.

4. Describe the response of the liquid zones while the adjusters are driving from full in to full out. State why a limit on bulk power is imposed with adjusters out of core.

5. State the meanings of the terms “fuelling ripple” and “CPPF”.

6. State the approximate power levels above which reactor operation is affected by:
   a) Transient xenon
   b) Xenon oscillations