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WORKSHEETS
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Fission, fusion and reactor control

A power-system study for a polar research station

35–40 minutes independent work + 15–20 minutes review

OCR A H556 | A-level physics | Module 6 | 44 marks

Specification points covered

6.4.4(g): induced nuclear fission and chain reactions.

6.4.4(h): functions of the components of a nuclear fission reactor.

6.4.4(i): environmental effects associated with nuclear waste.

6.4.4(j): nuclear fusion, fusion reactions and temperature.

6.4.4(k): balancing nuclear transformation equations.

Supporting 6.4.4(a), (b), (d), (e): mass–energy and binding-energy reasoning; earlier power and efficiency skills.

Use $c = 2.998 \times 10^{8}$ m s^{-1}, 1 MeV = 1.602×10^{-13} J and $k = 1.38 \times 10^{-23}$ J K^{-1}. One day = 86 400 s. All power and fuel figures describe supplied models, not current commercial reactor specifications.

Use a calculator and your OCR A data booklet. Show working, units and directions where relevant.

1 Identify the nuclear process

A polar research station compares a controlled-fission power model with a future fusion concept. Use only the stated physical and engineering information to judge the proposals.

Figure 1 shows component roles in a simplified thermal-neutron reactor model. The external heat exchanger and generator are not drawn; the coolant transfers heat to that external system.

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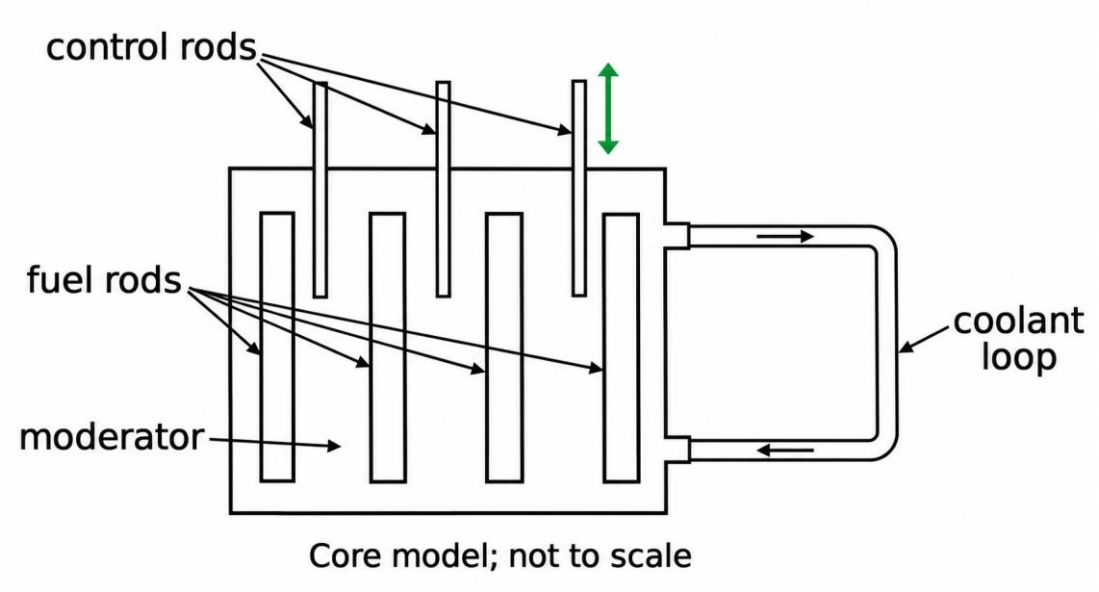


Figure 1 Simplified core and coolant loop

1(a) Explain what induced fission means, distinguishing it from fusion. **[1 mark]**

1(b) In the model, uranium-235 absorbs a neutron, then forms barium-141, krypton-92 and free neutrons. Use Z(U) = 92, Z(Ba) = 56 and Z(Kr) = 36 to write the complete balanced equation. **[2 marks]**

2 Control a chain reaction

2(a) Explain how emitted neutrons can make the fission process a chain reaction. **[2 marks]**

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2(b) For steady reactor power, what must happen on average to the number of further fissions caused by each fission? Explain why “all three emitted neutrons must cause fission” is wrong. **[2 marks]**

2(c) The measured fission rate begins to rise. State how control rods should be moved and explain the neutron process that reduces the rate. **[2 marks]**

2(d) Explain the different roles of the moderator and coolant in this reactor model. Why is “the moderator absorbs all the neutrons” an unsuitable description? **[2 marks]**

3 Turn a mass difference into a reaction rate

3(a) For one complete model fission event, the total initial rest mass is 3.91810×10^{-25} kg and the total final rest mass is 3.91480×10^{-25} kg, including every product neutron. Calculate the rest-mass decrease. **[1 mark]**

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3(b) Calculate the energy release per event in joules and MeV. Retain the unrounded joule value for later calculations. **[2 marks]**

3(c) The station's model reactor supplies 45.0 MW of thermal power entirely from these fissions. Calculate the fission rate. **[2 marks]**

3(d) Calculate the number of fissions in one day and the mass of uranium-235 nuclei fissioned. Use 3.90×10^{-25} kg for the mass of one uranium-235 nucleus. **[2 marks]**

4 Keep the system boundary clear

4(a) The thermal-to-electrical efficiency is 32.0%. Calculate the electrical output and the rate at which energy must be transferred to the surroundings, for 45.0 MW thermal input. **[2 marks]**

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4(b) A pupil divides 45.0 MW by the fission energy and then multiplies that fission rate by 0.320, calling it the actual rate needed by the reactor. Explain the error. **[2 marks]**

4(c) A model fuel capsule contains 0.100 kg of uranium-235, but only 20.0% of those nuclei may fission before the capsule is replaced. Estimate how long it could support the 45.0 MW thermal model. Use the uranium nucleus mass above. **[3 marks]**

4(d) Explain why energy release in fission does not mean that the two separated fragments need no careful containment after the chain reaction is stopped. **[1 mark]**

5 Assess the fusion concept

5(a) The fusion concept uses deuterium and tritium to form helium-4 and one neutron. Write the balanced nuclear equation and explain the origin of its released energy in terms of binding. **[2 marks]**

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5(b) Explain why very high temperatures are needed for this fusion concept. Refer to both the electrical interaction and the range of the strong nuclear force. **[2 marks]**

5(c) In a simple ion-energy model, the mean kinetic energy is 3kT/2. Calculate the temperature corresponding to mean energy 10.0 keV. This is an energy-scale estimate, not a prediction of a practical ignition temperature. **[3 marks]**

5(d) The briefing states that fusion produces helium, but its energetic neutrons can make surrounding structural materials radioactive. Evaluate the claim “fusion would produce no radioactive material, so waste management is unnecessary”. **[2 marks]**

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6 Write a linked judgement, not a list of parts

6(a) A proposed waste store is near meltwater feeding a lake. Describe one possible environmental consequence of radioactive material leaking from the store. Explain why half-life alone cannot establish the activity of the leaked material, and identify the other quantity needed. **[2 marks]**

6(b) A research unit has fission rate $7.20 \times 10^{17}\ s^{-1}$ and releases 3.00×10^{-11} J per fission. Identify the relationship needed to find its thermal power, and state what further measurement is needed to find its thermal-to-electrical efficiency. **[1 mark]**

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6(c) The research unit in 6(b) supplies 7.00 MW electrical output. Explain how its chain reaction can be kept steady, distinguish the moderator, control rods and coolant, and test a claim that the thermal-to-electrical efficiency is 30.0%. Present a linked answer with calculation and a conclusion. **[6 marks]**

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