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ANSWER BOOK

Nuclear reactors and safety

Nuclear physics · Year 13

AQA 3.8.1.7, 3.8.1.8 · OCR A 6.4.4

10 questions · 30 marks

NAVY EDITION

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SECTION A · Warm-up

A1 The moderator slows the fast neutrons released by fission down to thermal speeds, so that they are much more likely to be absorbed and cause further fission of uranium-235. [2]

A2 The control rods absorb neutrons, and can be raised or lowered to adjust the number of neutrons available, controlling the rate of the chain reaction (or shutting it down). [2]

A3 The coolant carries thermal energy away from the reactor core to a heat exchanger, where it is used to raise steam to drive turbines (and it stops the core overheating). [2]

SECTION B · Standard

B1 A neutron transfers the most kinetic energy in a collision when it hits a particle of similar mass. Light nuclei (such as those in water or carbon) have a mass close to that of a neutron, so each collision removes a large fraction of the neutron's energy, slowing it efficiently over few collisions. [3]

B2 They are adjusted so that, on average, exactly one neutron from each fission goes on to cause another fission. Lowering them absorbs more neutrons and slows the reaction; raising them allows more fissions, so the reaction rate is held steady. [3]

B3 Fission in the fuel releases fast neutrons and energy. The moderator slows the neutrons so they sustain the chain reaction; the control rods absorb surplus neutrons to keep the rate steady; and the coolant removes the thermal energy from the core to raise steam, while preventing overheating. [4]

B4 Critical mass is the amount of fuel for which, on average, exactly one neutron per fission goes on to cause a further fission, so the chain reaction is just self-sustaining. Below it the reaction dies out; a reactor is run at or just above this point under control. [3]

SECTION C · Stretch

C1 In an elastic head-on collision, a neutron gives up the greatest share of its energy to a target of equal mass and very little to a much heavier one. Light nuclei (hydrogen in water, carbon in graphite) are close in mass to a neutron, so they slow neutrons quickly; a heavy nucleus would barely slow them, needing far more collisions. [4]

C2 Safety features include thick concrete-and-steel shielding to absorb radiation, a sealed containment building, and emergency systems that drop all control rods to shut the reactor down. High-level waste is highly radioactive and hot, so it is stored underwater to cool and shield it for years, then may be encased (for example in glass) and stored securely in stable deep repositories. [4]

C3 Spent fuel contains highly radioactive fission products that emit intense, harmful radiation and generate heat. It must be handled remotely behind shielding to protect workers, and stored for a long time because many of the isotopes have long half-lives and take a great while for their activity to fall to safe levels. [3]