Version JHG/4

EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 29 April 2015 9.30 to 11

Module 4I5

NUCLEAR MATERIALS

Answer not more than ***two*** *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
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) Compare the advantages and disadvantages of uranium metal and uranium dioxide as nuclear fuels. [25%]

(b) Define irradiation growth and describe the mechanism by which it occurs in α-U. [25%]

(c) An α-U single crystal is subjected to a neutron fluence that causes an increase in dislocation density of 5×10^{15} m^{-2}. Calculate the expansion along [010] caused by the irradiation, assuming this increase in dislocation density is due only to the formation of interstitial dislocation loops on planes parallel to (010).

[The spacing of the planes on which dislocation loops form can be taken to be $b/2$, where b refers to the b lattice parameter = 0.5865 nm. Assume that the diameter of the dislocation loops is 500 nm.] [30%]

(d) Why does γ-U not exhibit irradiation growth to the same extent as α-U, and how can this phase be stabilised? [5%]

(e) Outline why plutonium is not widely used as a nuclear fuel. [15%]

2 (a) Define stress-corrosion cracking and describe the mechanism by which it occurs. Why are metals with an intermediate repassivation rate particularly susceptible to stress-corrosion cracking, and why are alloys with a high stacking fault energy less susceptible than those with a low stacking fault energy? [30%]

(b) How can radiolysis of water enhance stress-corrosion cracking and why is it a particular problem in Boiling Water Reactors? [20%]

(c) Explain the function and desirable characteristics of a *moderator* in a thermal nuclear reactor. [20%]

(d) The Wigner energy can be a problem with the use of graphite as a moderator. What is the origin of this energy and how can the energy be released from graphite? Why is the Wigner energy not a problem with modern reactors? [20%]

(e) How does irradiation affect the thermal expansion behaviour of graphite? [10%]

3 (a) Describe the effects of a Pb ion accelerated to 10 MeV impinging on a ceramic material and eventually coming to rest. Comment on the validity of this model to simulate the effect of the recoil of the heavy daughters of uranium or plutonium on the structural integrity of a ceramic nuclear waste form. [25%]

(b) Describe how the radiation damage associated with permanently displaced atoms caused by the alpha decay of an actinide accumulates by (i) a direct process and (ii) a single overlap process. [25%]

(c) If a ceramic nuclear waste form of density 4700 kg m^{-3} is loaded with 10 wt% ^{239}Pu and the volume of displaced material per ^{239}Pu alpha decay (V_i) is 4.25×10^{-26} m^3, determine how long it will take for the waste form to become 50% amorphous given that the accumulation of amorphous material follows the equation below:

$$V_{amorph} = V_0\left[1 - \exp\left(-V_i\varphi\right)\right]$$

where V_{amorph} is the volume of amorphous material, V_0 is the original material volume and φ is the alpha radiation dose (in α m^{-3}).

[Half-life of ^{239}Pu = 24,100 years] [50%]

END OF PAPER

Numerical answers

Q1 (c) – 18.3%

Q3 (c) – 480 years

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