Version JHG/3

EGT3
ENGINEERING TRIPOS PART IIB

Thursday 1 May 2014 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

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) Outline the roles of the following components of a nuclear reactor:

(i) cladding;

(ii) moderator;

(iii) coolant;

(iv) shielding. [20%]

(b) What is the role of the control rods in a nuclear reactor? Describe the two types of control rod that are usually present. What are the requirements of control rod materials, and what are the most commonly chosen materials for this application? [40%]

(c) Zirconium alloys are often used for the fuel cladding in nuclear reactors. Why are they particularly suitable for this application? What main factor limits the temperature range of use? What problems arising during use can be attributed to the hexagonal crystal structure of zirconium? [40%]

2 (a) Describe the sequence of events that occurs during a displacement cascade in a material subjected to neutron irradiation. Why does this usually result in a large excess vacancy concentration? [30%]

(b) The major defects arising in a neutron-irradiated material differ below and above approximately $0.2T_m$, where T_m is the melting temperature. What are the main defects formed and how do they arise? Describe and explain the changes in mechanical properties and other problems caused by the defects. [55%]

(c) Define *creep*. Distinguish between radiation-induced creep and radiation-enhanced creep. [15%]

3 (a) Describe the impact that a typical heavy daughter nucleus of an actinide alpha-decay event has in a solid material. What energy does it have? Why does it cause structural damage? Compare this to the damage caused by the alpha-particle itself by including a discussion of nuclear and electronic stopping. [30%]

(b) Radiation damage caused by alpha-recoils may accumulate by a direct mechanism in which the amorphous volume fraction (f_a) is described by:

$$f_a = 1 - \exp\left(-V_i D_\alpha\right)$$

Explain the meaning of the terms V_i and D_α and the origin of the above expression. [20%]

(c) If the damage accumulation is not direct, and a *single overlap* mechanism is operating, f_a is given by:

$$f_a = 1 - \left[1 + V_i D_\alpha\right]\exp(-V_i D_\alpha)$$

If $V_i = 4.7 \times 10^{-25}$ m^3, determine the total cumulative alpha dose (α m^{-3}) that is required to amorphise 50% of a tailored nuclear waste form made from $ZrSiO_4$ (zircon) containing 10 wt% of excess weapons grade ^{239}Pu, if it follows a direct radiation damage accumulation mechanism. If a second tailored nuclear waste form made from ZrO_2 (zirconia) follows a single overlap damage accumulation mechanism, what fraction of the ZrO_2 would be damaged for the same α dose as $ZrSiO_4$? [30%]

(d) For repository storage conditions below 90 ˚C, explain the differences in the underlying processes occuring during the radiation damage of $ZrSiO_4$ and ZrO_2 that cause them to follow different accumulation mechanisms. [20%]

END OF PAPER

Engineering Tripos Part IIB
Module 4I5: Nuclear Materials
1 May 2014

List of numerical answers

Q3 (c)

$D_\alpha = 1.475 \times 10^{24}\ \alpha\ m^{-3}$

$f_a = 0.154$