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PHYS-E0460 Introduction to Reactor Physics, 2nd mid-term exam 1 Dec 2023

You may use an unprogrammed calculator and the document "Mathematical Tools for Reactor Physics". You are welcome to answer in English, Finnish or Swedish.

1. Give a concise explanation of the following:
   a) stable period b) prompt criticality ($) c) reactivity feedback coefficient α_T
   d) pressurizer e) convective heat transfer f) ALARA principle.

2. a) Derive a thermal reactor's reactivity equation taking delayed neutrons into account. Assume just one delayed neutron precursor group. Hint: in the diffusion equation, the thermal neutron source is $s_T = (1-\beta)k_\infty \overline{\Sigma}_a \phi_T + p\lambda C$. The precursor concentration C is also time-dependent with the source term $\beta k_\infty \overline{\Sigma}_a \phi_T / p$.

   b) How large (in $) is the reactivity inserted into a thermal ^{235}U water pool reactor (TRIGA) with power growing at a stable period of $T = 0.015$ s? The effective half-life of the precursor is 7 seconds, the share of delayed neutrons of all neutrons is $\beta = 0.0065$, and the prompt neutron lifetime is $l_p = 1 \cdot 10^{-4}$ s.

   c) Explain briefly what happens to the reactor described in b) and why.

3. The thermal absorption cross section of the reactor poison ^{157}Gd is $\overline{\sigma}_{aG} = 2.5 \times 10^5$ barn. ^{157}Gd is stable and born in the β^- decay chain: $\cdots \xrightarrow{\beta^-} {}^{157}\text{Sm} \xrightarrow{\beta^-} {}^{157}\text{Eu} \xrightarrow{\beta^-} {}^{157}\text{Gd(stable)}$. ^{157}Sm has a half-life of 8 min and its yield is 6×10^{-5} atoms per ^{235}U fission. ^{157}Eu has a half-life of 15.2 h and its yield directly from fission is very small. Let's assume a pure ^{235}U fuel so that $p = \epsilon = 1$, $\nu = 2.42$ and $\beta = 0.0065$.
   a) Derive the expression for the reactivity effect of a reactor poison (hint: only fuel utilization f is affected in the multiplication factor k).
   b) What is the reactivity effect of ^{157}Gd in equilibrium, if the average thermal flux of the reactor is $\Phi_T = 2.5 \times 10^{14}$ cm^{-2}s^{-1}?
   c) If the reactor has been running for a long time at the mentioned average flux, what is the maximum reactivity effect of ^{157}Gd after shutdown?

4. A small PWR operates at a thermal power $q = 485$ MW. The diameter of the reactor core is 1920 mm and the height H is 2330 mm. There are 23142 fuel rods in a square lattice with a pitch of 11 mm. The cladding tubes are 0.5 mm thick and their inner diameter is 7.5 mm. The core is cooled by water that enters the core at temperature $T_{in} = 258$°C with mass flow $w = 4300$ kg/s and has the following properties: pressure $p = 13.9$ MPa, specific heat $c_p = 4970$ J/(kg°C), density $\rho = 778$ kg/m^3 and viscosity $\mu = 1.03 \cdot 10^{-4}$ kg/(ms).
   a) What is the average power density q''' of the core?

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b) The core's linear power q' in the axial (z) direction is of cosine form. What are the maximum and average linear power (MW/m)?

c) What is the average coolant outlet temperature T_{out} (°C)?

d) What is the average coolant flow velocity v (m/s)?

e) What is the average Reynolds number $Re = (D_e v \rho)/\mu$? D_e is the equivalent diameter of the coolant channel $D_e = 4A_c/p_{wet}$, where A_c is the cross-sectional area and p_{wet} is the wetted perimeter.

f) What can be concluded from the Reynolds number?

5. Describe the main differences between PWR and BWR power plants.