Write your name and student number. This exam comprises 4 problems. The total number of points is 36. The final grade is obtained by dividing the number of points by 3,6.

Problem 1 (10 pts)

A reactor has the shape of a parallelepiped with a square base of side 5.2 m and a height of 6.8 m. The reactor is filled uniformly with a fuel with the properties
$\nu\Sigma_f = 0.0072\ cm^{-1}, \nu = 2.45$ and $\Sigma_a = 0.0070\ cm^{-1}$.
The reactor operates steadily at a fission power of 15 MW. The average energy released by fission is $E_f = 200\ MeV$.

a. Calculate the value of the diffusion coefficient D. (2 pts)
b. What are the average and maximum values of the neutron flux? (4 pts)
c. At what rate is the fuel consumed in the entire reactor (in nuclides/s) and at the centre of the reactor (in nuclides/cm^3.s)? (4 pts)

Problem 2 (6 pts)

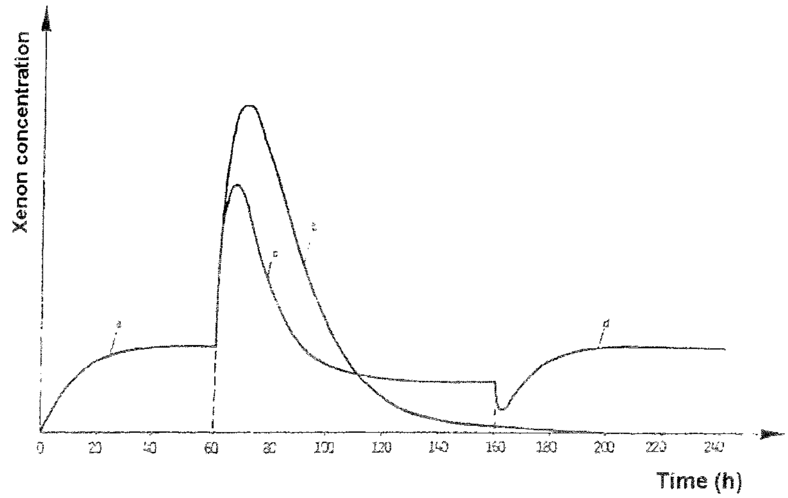
In a nuclear accident, a reactor output increases suddenly in about $\Delta t = 4\ s$ from $P_1 = 0.20P_0$ to $P_2 = 100P_0$ with P_0 the nominal power of the reactor. As a result of the accident, I-131 (half-life 8.02 days) is released in the environment.

a. Assuming a constant reactivity excess during this time, calculate the average reactor period τ. (2 pts)
b. Calculate the time needed for the activity of I-131 to reduce by a factor 256 (expected to be a safe level). (4 pts)

Problem 3: Xenon concentration (12 pts)

The figure below shows the response of xenon-135 concentration as a function of time to changes in the power level of a reactor. The reactor is started at $t = 0$. At $t = 60\ h$, the power is decreased and then restored to its original value at $t = 160\ h$.
Assume that Iodine is produced only by fissions, that its microscopic absorption cross section is negligible and that Xenon is produced by fissions and the decay of Iodine.

a. Give the expression of the xenon concentration corresponding to $t = 50\ h$ in curve a. (4 pts)
b. Explain the reason of the rise in concentration in curve c. (4 pts)
c. Curve d shows a dip between $t = 160\ h$ and $t \sim 190\ h$. Explain how this dip in concentration occurs. (4 pts)



Problem 4 (8 pts)
Consider a Pressurized Water Reactor.

a. What is the state of criticality of the reactor at the start and at shutdown? (2 pts)
b. Explain why it is necessary to use enriched fuel in such a reactor? (4 pts)
c. What is the purpose of the pressurizer? (2 pts)

Radioactive decay law:

$$N = N_0 e^{-\lambda t}$$

Geometric buckling $B^2(cm^{-2})$:

$$B^2 = \frac{1}{D}\left(\frac{\nu}{k}\Sigma_f - \Sigma_a\right)$$

Total average power of a reactor:

$$P[W] = E_f \times R_f \times V$$

$1\ MeV = 1.602\ 10^{-13}\ J$ and $1\ W = 1\ J/s$

Reactor period

$$P(t) = P_0 \exp[t/\tau]$$

$$\tau = \frac{\ell}{\rho} + \frac{\beta_{\text{eff}} - \rho}{\lambda_{\text{eff}} \cdot \rho + \dot{\rho}}$$

Buckling and neutron flux for different reactor geometries

Geometry	Dimensions	Buckling B^2	Flux	A
Infinite slab	Thickness a	$\left(\frac{\pi}{a}\right)^2$	$A\cos\left(\frac{\pi}{a}x\right)$	$1.57 \times \frac{P}{a\ E_f\ \Sigma_f}$
Rectangular parallepiped	a x b x c	$\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{c}\right)^2$	$A\cos\left(\frac{\pi}{a}x\right)\cos\left(\frac{\pi}{b}y\right)\cos\left(\frac{\pi}{c}z\right)$	$3.87 \times \frac{P}{V\ E_f\ \Sigma_f}$
Infinite cylinder	Radius R	$\left(\frac{2.405}{R}\right)^2$	$AJ_0\left(\frac{2.405\ r}{R}\right)$	$0.738 \times \frac{P}{R^2 E_f \Sigma_f}$
Finite cylinder	Radius R, height H	$\left(\frac{2.405}{R}\right)^2 + \left(\frac{\pi}{H}\right)^2$	$AJ_0\left(\frac{2.405\ r}{R}\right)\cos\left(\frac{\pi\ z}{H}\right)$	$3.63 \times \frac{P}{V\ E_f\ \Sigma_f}$
Sphere	Radius R	$\left(\frac{\pi}{R}\right)^2$	$A\ \frac{1}{r}\sin\left(\frac{\pi\ r}{R}\right)$	$\frac{P}{4R^2\ E_f\ \Sigma_f}$

Neutron poisons concentrations in reactors

$$\frac{dN_I}{dt} = \gamma_I \Sigma_f^{Fuel}\phi - \lambda_I N_I - \sigma_a^I N_I \phi$$

$$\frac{dN_{Xe}}{dt} = \gamma_{Xe}\Sigma_f^{Fuel}\phi + \lambda_I N_I - \lambda_{Xe} N_{Xe} - \sigma_a^{Xe} N_{Xe}\phi$$