
Instructions:

- Answer in ENGLISH or FINNISH. Do not worry about spelling, but be understandable.
- Pen, eraser, ruler, calculator, and one ISO A4 cheat sheet (**handwritten**, back and front) are allowed.
- $N_A = 6.022\,140\,76 \times 10^{23} \text{ mol}^{-1}$, $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$, $c_{p,\text{H}_2\text{O}} = 4.2 \text{ kJ kg}^{-1} \text{ K}^{-1}$.

Good luck!

Professor Juhani Hyvärinen

Question 1: Thermal design of NPP

6 point(s)

It is known that at the surface temperature of a solid UO_2 fuel pellet is 530°C and power density in the pellet is 200 MW m^{-3} . What is temperature at the center of the pellet? The diameter of fuel pellet is 8.5 mm and its thermal conductivity constant $0.025 \text{ W cm}^{-1} \text{ K}^{-1}$. The fuel rod is long and thin, so you can neglect axial heat conduction.

Tip: If you do not remember the formulae by heart, solve the radial heat conduction equation

$$k\nabla^2 T = q'''$$

in the pellet.

Question 2: NPP Systems

6 point(s)

- (a) Sketch the ECCS for either PWR or BWR. (3 p)
- (b) The thermal power of the EPR is 4300 MW . Calculate the mass flow rate that the low-pressure ECCS must pump through the EPR reactor core one hour after a loss-of-coolant accident. Assume that the coolant in the core heats up from 60°C to 80°C and the pressure is 2 bar . (3 p)

$$h(2 \text{ bar}, 60^\circ\text{C}) = 251.3 \text{ kJ kg}^{-1}, \quad h(2 \text{ bar}, 80^\circ\text{C}) = 335.1 \text{ kJ kg}^{-1}$$

Question 3: Radiation & Operational Safety

6 point(s)

- (a) Calculate the absorbed dose of the radionuclide ^{131}I , when a man with a mass of 85 kg and a thyroid mass of 20 g drinks milk containing ^{131}I at a concentration of 1000 Bq . The radiological half-life of ^{131}I is 8 d and the biological half-life is 138 d . Iodine-131 emits β - and γ -rays, with an average energy release of 0.23 MeV per decay. Approximately 30% of the iodine accumulates to the thyroid. Quality and weighting factors can be found in Tables 1 and 2. (3 p)
- (b) A given layer of copper absorbs 90% of the γ rays. How much do you have to increase the thickness of the copper layer, to make it absorb 99% of the γ rays? (3 p)

Question 4: Accidents

6 point(s)

Since the first criticality of a man-made reactor, several accidents and incidents have occurred, not only at TMI-2, Chernobyl Unit 4, and Fukushima Units 1–5, but also elsewhere.

- Name two other nuclear power plants (NPPs) where incidents or accidents have happened. (2 p)
- Give the year and INES classification (incident or accident) of your choice in (a) (2 p)
- Provide a brief summary of what happened at the chosen NPP in task (a). (2 p)

Question 5: Fuel and Waste Management

6 point(s)

- Highly enriched uranium (HEU), with a concentration of ^{235}U is 93 %, is diluted for fuel of nuclear power reactor. Calculate the mass of nuclear fuel produced (concentration of ^{235}U is 4 %) if the dilution was made by depleted uranium, the concentration of which is 0.25 %. The mass of HEU is 1 t. (3 p)
- On 2026-08-04, STUK issued a positive safety assessment for Posiva's operating licence. The geological disposal of spent fuel using the KBS-3 concept implements the defence-in-depth principle. What are the main physical barriers to the release of radioactivity from spent fuel once it has been properly disposed of underground? (3 p)

Question 6: Bonus

1 bonus point(s)

What nuclear-powered cruiser had her commission 65 years ago to the day, on 1961-09-09? (1 p)

1. USS *Indianapolis* – USA
2. *Murmansk* – Soviet Union
3. *Scharnhorst* – Germany
4. USS *Long Beach* – USA

Table 1: Quality factors for radiation types

Radiation type	w_R
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	$2.5 + 18.2e^{-[\ln(E_n)]^2/6}, E_n < 1 \text{ MeV}$ $5.0 + 17.0e^{-[\ln(2E_n)]^2/6}, 1 \text{ MeV} \leq E_n \leq 50 \text{ MeV}$ $2.5 + 3.25e^{-[\ln(0.04E_n)]^2/6}, E_n > 50 \text{ MeV}$

Table 2: Tissue weighting factors according to ICRP 103 (ICRP 2007)

Tissue	w_T
Bone-marrow (red), colon, lung, stomach, breast, remaining tissues*	0.12
Gonads	0.08
Bladder, oesophagus, liver, thyroid	0.04
Bone surface, brain, salivary glands, skin	0.01

*Remaining tissues: Adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (σ), small intestine, spleen, thymus, uterus/cervix (φ).