# Examination in the Reactor Physics Course

# SH 2600, HT 2007

## *I. Grading system*

The grading standard is based on the European Credit Transfer and Accumulation System abbreviated as ECTS. The grading marks and their description are summarized in the following table.

| **ECTS** | **N** | **Verbal** | **Description** |
|---|---|---|---|
| A | 7 | Excellent | (90 – 100)% |
| B | 6 | Very Good | (80 – 90)% |
| C | 5 | Good | (70 – 80)% |
| D | 4 | Satisfactory | (60 – 70)% |
| E | 3 | Sufficient | (50 – 60)% |
| Fx | 2 | Insufficient | (40 – 50)% |
| F | 1 | Insufficient | < 40% |

## *II. Mid-term written examination*

The mid-term written exam is elective but bonus giving if passed with the mark C or greater with the bonus being an extra point in the final examination. It comprises 6 problems and runs for 2 hours. The topics for the mid-term written exam are as follows:

- Nuclear reactions
- Geometric cross section of nuclei
- Radioactive decay, half-life, radioactivity
- Relationship between mass density and number density
- Reaction rates
- Neutron flux
- Neutron micro and macro cross sections

## *III. Final written examination*

The final written exam is compulsory. It comprises two theoretical questions and two problems and runs for 2 hours. The topics for the final exam are as follows:

1) Fission
2) Radioactivity
3) Neutron physics
4) Neutron slowing-down
5) Thermal neutrons
6) Neutron diffusion
7) Neutron multiplication factor
8) Space distribution of neutron flux
9) Reactor kinetics
10) Reactor dynamics
11) Reactor safety
12) Reactor fuel and waste
13) Energy and environment

## *IV. List of questions included in the topics*

**1) Fission**

1. Explain why energy liberates during fission and fusion processes.
2. Explain why neutrons liberate and why radioactive nuclei emerge during fission processes.
3. Explain why $^{235}U$ fissions with thermal neutrons while $^{238}U$ does not.

**2) Radioactivity**

1. Specify the relation between decay constant, half-life and mean life time for radioactive isotopes.
2. Natural radioactivity. Radioactive decay chains.
3. Explain the origin of decay heat in a nuclear reactor and show approximately how it looks like after the reactor shut-down (e.g. after scram).

**3) Neutron physics**

1. Show a diagram of an energy spectrum of fission neutrons.
2. Show a diagram of energy dependence of the $^{235}U$ and $^{238}U$ neutron fission cross sections.
3. Specify an equation which gives the reaction rate between neutrons and nuclei.
4. Formulate en equation which gives probability that a neutron passes a distance (path) of $x$ cm in medium without interacting with a nucleus (equation for a neutron free flight or free path).

4) **Neutron slowing-down**
   1. Specify how much energy a neutron can loose in a single collision with a nucleus.
   2. Specify an expression which gives a number of collisions needed to slowdown a neutron from a high energy $E_0$ to a low energy $E_{th}$.
   3. Explain why a slow-down process should be accomplished with a lowest possible number of collisions.
   4. Explain the meaning of the concept “neutron age” or “Fermi’s age.”
   5. Show a neutron spectrum in a slowing-down energy interval.

5) **Thermal neutrons**
   1. Show the neutron spectrum in a thermal energy interval, i.e. spectrum of thermal neutrons.
   2. Show the neutron absorption cross section of thermal neutrons for major LWR isotopes ($^{235}U$, $^{238}U$, $H_2O$).

6) **Neutron diffusion**
   1. Propound a neutron diffusion equation and explain meaning of different terms of this equation.
   2. Specify what kind of simplifications and/or approximations are necessary to derive the diffusion constant and how it may be corrected with more detail theory (i.e. transport approximation).
   3. Describe a neutron diffusion process and explain the meaning of a “diffusion length.”
   4. Specify the source term in a case of a single-energy-group theory and for a combined slowing-down and one-group approach.
   5. Specify the boundary conditions to be observed while solving neutron diffusion equation.

7) **Neutron multiplication factor**
   1. Propound the four factor formula and explain meaning of the parameters in this formula.
   2. Specify an expression to determine the non-leakage factor.
   3. Specify the equation for buckling in cylindrical geometry. Explain its meaning.

8) **Space distribution of neutron flux**
   1. Specify the equation for a neutron flux in a cylindrical reactor with a fixed material composition without a reflector.
   2. Show the axial power distribution of BWR at start-up conditions (initial enrichment).

9) **Reactor kinetics**
   1. Propound the reactor kinetic equations taking into account delayed neutrons.
   2. Present the neutron density variation with a fast, respectively slow change of reactivity.
   3. Present a simplified formula for the neutron density time dependence involving the multiplication factor.
   4. Present an expression for determination of the prompt neutron life-time. Compare these values for fast and thermal neutrons.
   5. Quantify margins against prompt criticality.

**10) Reactor dynamics**

1. Which physical processes determine reactor dynamics?
2. Which factors are affected by reactor poisoning?
3. Derive the equation for $^{135}Xe$ concentration and show how Xe-poisoning varies after:
   - A fast start-up of an non-poisoned reactor.
   - A fast power increase respectively power decrease.

**11) Reactor safety**

1. Safety aspects of different reactor types.
2. Describe safety barriers in LWRs.
3. Your scenario for a reactor accident.

**12) Reactor fuel and waste**

1. Describe uranium and thorium nuclear fuel cycles.
2. Describe the main problems related to nuclear wastes.
3. Actinides in nuclear wastes.
4. Advanced reactors and actinide burners.

**13) Energy and environment**

1. Assess the options for the future energy supply. Environmental and economical aspects of the future energy sources.
2. Has nuclear energy any future?