TENTAMEN KERNENERGIE *NUCLEAR ENERGY*

29-10-2013 9.00-12.00 16.0116

- this exam consists of 4 questions
- value of the questions 1-4: 1 point, 2 points, 3 points, 3 points
- the weight of the subquestions is the same
- please use a separate paper for each question
- please write your name and studentnumber on each paper you hand in
- you may answer in English or Dutch
- **motivate your answers and give the formulas on which your numerical answers are based**

1.

a) What are the 2 most abundant isotopes of uranium; what are their natural abundances ?

Which of these is fissile by neutrons with practically no energy ? Explain why.

b) Which 3 isotopes are fissile (in the practice of nuclear energy) ?

c) Which of these isotopes (question b) occur in nature ?

d) How do we obtain the other ones (i.e. those not available in nature) ? Give the reactions.

fuel and H_2O

e) Which reactors can use natural U as moderator/cooling medium ? Explain why.

f) If we want to use water (H_2O) as moderator, what is required as fuel ? Explain why.

g) What is the main reason the natural reactor in Africa possible could work almost 2 billion years ago?

2.

The so-called reactivity is defined as: $\rho = \dfrac{k-1}{k}$

Consider the increase of the number of neutrons *dn* produced by the fission process during a certain timeperiod *dt*.

a) Derive an expression for dn/dt after a disturbance at t=0.

b) Solve this equation for the number of neutrons n

Assume now (for questions c and d) a typical neutron lifetime in a reactor of 100 μs, and a disturbance $\rho = 0.001$.

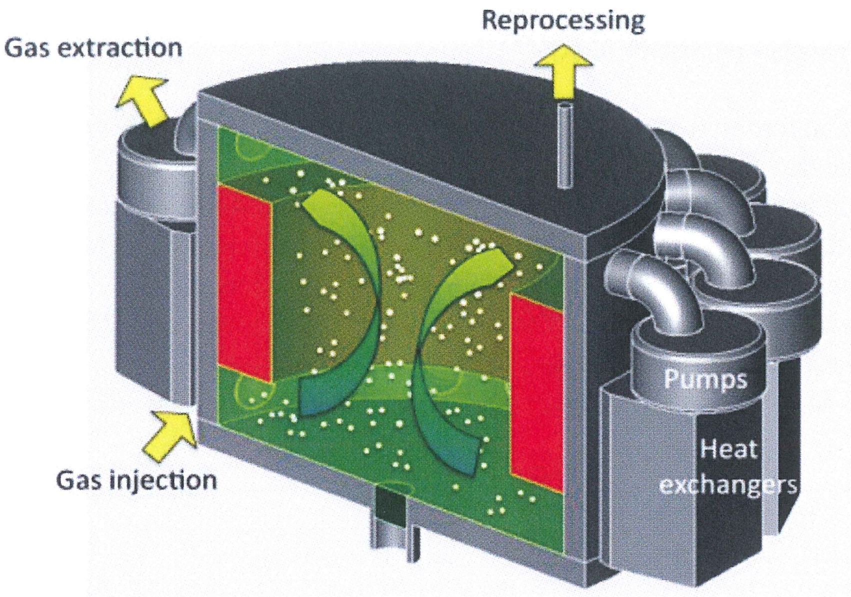
c) By what factor is the number of neutrons increased after 1 ms ?

d) By what factor is the number of neutrons increased after 1 s ?

e) Based on the previous question, what do you conclude for operation of the reactor ?

3.

The molten salt fast breeder reactor



In the framework of the GEN-IV-programme a demonstrator for a fast breeder reactor for the Th/U fuel cycle is under design. The characteristics of the reactor are the following:

- fuel composition 22.5 % LiF and 77.5 % ($^{232}ThF_4$ + $^{233}UF_4$) by weight
- ^{233}U content 654 kg
- fuel volume 1.8 m^3: 1.08 m^{3}in core and 0.72 m^3 in external circuits
- fuel density 4100 kg/m^3
- fuel thermal capacity 2.5 kJ/kg K
- thermal power 100 MW

When passing through the heat exchanger on the outside of the reactor vessel the temperature decrease of the fuel is ΔT = 30 K.

a. Calculate the flowrate [m^{3}s^{-1}] of the fuel through the heat exchangers and the circulation time [s] of the fuel through the system.

The delayed neutron fraction in the fission of ^{233}U amounts to 0.26 %. The delayed neutron emission from the fission of ^{233}U has an effective half life of 13.8 s.

b. Which fraction of the delayed neutrons is emitted in the core on the basis of the volumes of fuel in the core and the external circuits under two assumptions:
   - The circulation time of the fuel through the system is very short compared to the effective half life of the delayed neutron emission.
   - The circulation time of the fuel through the system is very long compared to the effective half life of the delayed neutron emission.

Estimate the fraction of delayed neutrons emitted in the core under the actual operating conditions. If you did not find a numerical answer for question a. assume the circulation time to be 7 s.

c. How does emission of delayed neutrons outside the core affect the prompt criticality margin and the response time of the reactor to reactivity changes? What is the influence of both these changes on reactor safety?

The cross section for fast neutron induced fission of ^{233}U is 1.9 barn, the cross section for fast neutron capture on ^{232}Th is 0.15 barn.

d. What should the ratio between the amounts of ^{232}Th and ^{233}U in the core of the reactor be in order to have a conversion ratio CR = 1? Assume neutron leakage and losses due to neutron reactions on Li and F to be negligible. Explain your answer.
e. What is the actual conversion ratio CR on the basis of the amounts of ^{232}Th and ^{233}U in the reactor? The atomic mass of fluorine is 19.
f. How could neutron leakage from the core be used to increase the conversion ratio.

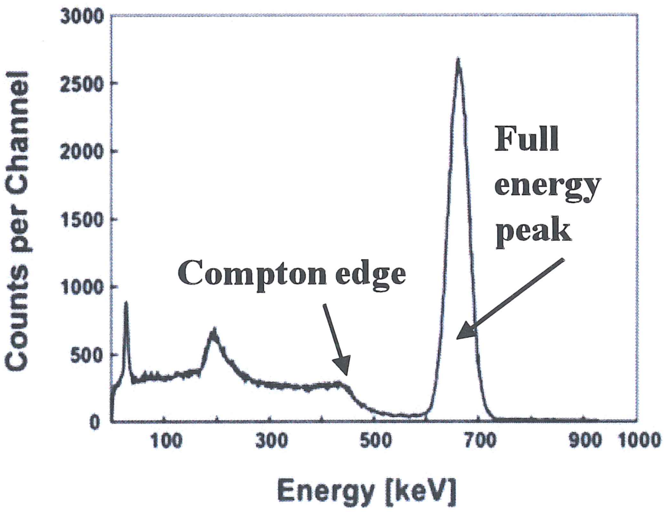
4.

Fukushima

Ishinomaki is a Japanese city north of Fukushima. At the fish market of Ishinomaki the fish from the waters along the coast of the Fukushima Prefecture is measured for radioactivity (see photo). The Japanese Government's safety level for ^{137}Cs in fish is 100 Bq kg^{-1}.

a) Calculate the committed effective dose *E* (50) of a person that eats 2 kg of salmon that contains exactly this safety level concentration of ^{137}Cs.

For an accurate measurement of the ^{137}Cs concentration a whole salmon of 2950 g is minced and homogenized. From the homogenized mass a sample of 100 g is taken and transferred into a cylindrical container with a diameter and height of 5 cm. This container is placed on a NaI gamma detector and a spectrum (see figure below) is measured for 10000 s.



b) Describe the interaction processes that are involved in producing the structures in the spectrum that are labelled 'full energy peak' and 'Compton edge'. Also quantitatively explain the position of these structures along the energy axis.

c) In this measurement geometry (cylindrical container on detector) the ‘full energy peak’ efficiency is 0.05. Calculate the net number of events (counts) in the ‘full energy peak’ if the activity concentration in the salmon was 50 Bq kg^{-1}.

A Japanese salmon fisher while repairing his nets gets exposed by radiation from small particles of nuclear fuel clinging to the nets. He is exposed to the following absorbed doses,

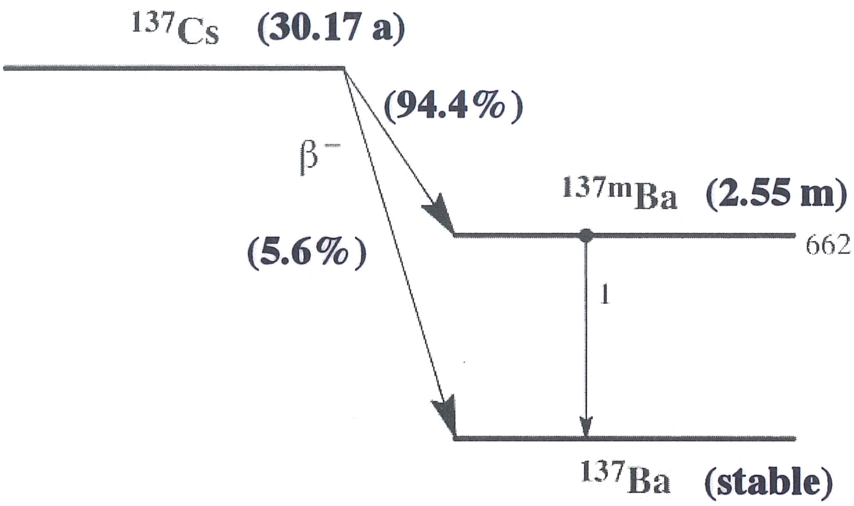
100 mGy of alpha radiation to the lung;
1.5 Gy of beta radiation to the skin and
500 mGy of gamma radiation whole body.

d) Calculate the effective dose that this fisher received.

Data that can be used:

1) Simplified decay scheme of ^{137}Cs
2) Effective dose coefficients of Cs isotopes
3) Tissue weighting factors
4) Radiation weighting factors

Simplified decay scheme of ^{137}Cs



Effective dose coefficients of Cs isotopes

Table B.1.—(*continued*)

		Effective dose coefficients (Sv Bq^{-1})					
		Inhalation, $e_{inh}(50)$				Ingestion	
Nuclide	$t_{1/2}$	Type	f_1	1 µm AMAD	5 µm AMAD	f_1	$e_{ing}(50)$
Caesium							
Cs-125	0.750h	F	1.000	1.3E-11	2.3E-11	1.000	3.5E-11
Cs-127	6.25h	F	1.000	2.2E-11	4.0E-11	1.000	2.4E-11
Cs-129	1.34d	F	1.000	4.5E-11	8.1E-11	1.000	6.0E-11
Cs-130	0.498h	F	1.000	8.4E-12	1.5E-11	1.000	2.8E-11
Cs-131	9.69d	F	1.000	2.8E-11	4.5E-11	1.000	5.8E-11
Cs-132	6.48d	F	1.000	2.4E-10	3.8E-10	1.000	5.0E-10
Cs-134	2.06y	F	1.000	6.8E-09	9.6E-09	1.000	1.9E-08
Cs-134m	2.90h	F	1.000	1.5E-11	2.6E-11	1.000	2.0E-11
Cs-135	2.30E+06y	F	1.000	7.1E-10	9.9E-10	1.000	2.0E-09
Cs-135m	0.883h	F	1.000	1.3E-11	2.4E-11	1.000	1.9E-11
Cs-136	13.1d	F	1.000	1.3E-09	1.9E-09	1.000	3.0E-09
Cs-137	30.0y	F	1.000	4.8E-09	6.7E-09	1.000	1.3E-08
Cs-138	0.536h	F	1.000	2.6E-11	4.6E-11	1.000	9.2E-11

Tissue weighting factors

Tissue/Organ	Weighting factor (2007)
Bone marrow	0.12
Breast	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Esophagus	0.04
Gonads	0.08
Liver	0.04
Thyroid	0.04
Bone surface	0.01
Brain	0.01
Kidney	Remainder
Salivary glands	0.01
Skin	0.01
Remainder tissues	0.12 †

Radiation weighting factors

TABLE 17.1 **Radiation Weighting Factors**[a]

Radiation Type	Radiation Weighting Factors
Photons	1
Electrons and muons	1
Protons and charged pions	2
α-particles, fission fragments, heavy ions	20
Neutrons	A continuous curve as a function of neutron energy