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Accumulation of Tritium in Beryllium Material under Neutron Irradiation

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ABSTRACT

In the present work the programming code is created on the basis of which the accumulation kinetics of tritium and isotope of He^4 in the Be^9 sample is analyzed depending on the time. The program is written in C++ programming language and for the calculations Monte Carlo method was applied. This program scoped on the calculation of concentration of helium and tritium in beryllium samples depending on the spectrum of the neutron flux in different experimental reactors such as JMTR, JOYO and IPEN/MB. The processes of accumulation of helium and tritium for each neutron energy spectrum of these reactors were analyzed.

Key Words: **JMTR, JOYO, IPEN/MB, neutron flux, neutron reflector, neutron spectrum.**

1. INTRODUCTION

Due to the large scattering cross section and low absorption cross section, the beryllium material widely used in the reactors as a neutron reflector [3]. Intensive irradiation of beryllium neutron flux results in a loss of performance and probability of failure. The mainly products of the reactions, going in interactions of fast neutrons with beryllium materials, are He^4 and tritium. It is known, that generated by nuclear reactions, tritium and helium significantly reduces efficiency units and structures of the cores of nuclear reactors. In particular, phenomena such as embrittlement, swelling, according to the majority of hypotheses related with the formation, accumulation and behavior of tritium and helium in materials under irradiation.

2. THEORETICAL PART

It is known that the interaction of neutrons with Be^9 isotopes in the thermal region are reactions only elastic scattering and radiative capture. Formation of helium and tritium in this area is not observed. The interaction of neutrons with higher energies above 1 MeV, there is more inelastic processes. Below are the main reactions leading to the formation of helium and tritium:

$$n + Be^9 \rightarrow He^6 + He^4 \quad (1)$$

$$He^6 \rightarrow Li^6 + \beta^- + \tilde{\nu}_e \quad (T_{1/2} \approx 0.85 \text{ s}) \quad (2)$$

$$n + Be^9 \rightarrow 2n + Be^8 \quad (3)$$

$$Be^8 \rightarrow He^4 + He^4 \quad (T_{1/2} \approx 6.7\times10^{-17}\ \text{s}) \tag{4}$$

$$n + Li^6 \rightarrow H^3 + He^4 \tag{5}$$

You can see that the major products of these reactions are helium and tritium. Reactions (1) and (3) have a threshold of 0.71 MeV and 2.7 MeV respectively. Of those listed above reaction can be seen that tritium is produced from recycled product, i.e. nuclei of Li^6. A very intense Li^6 reaction comes in thermal neutrons. Cross section of the reaction (5) about 5000 barn in the thermal region, and it rapidly decreases with increasing energy. From this we can conclude that the need to produce tritium in beryllium materials under neutron irradiation formed Li^6, and for this it is necessary that in the neutron flux were thermal and fast neutrons.

3. THE PROGRAM ALGORITHM

For the simulation of nuclear processes was applied Monte Carlo method. The program was written in C++ language. Feature of this program is that it can be considered a change of element concentrations with time for any energy spectrum of neutrons.
All cross sections of these reactions were taken from the evaluated nuclear data library ENDF/B and JENDL [3].
Reactions of neutrons with beryllium materials are taken into account in the program, this reaction: elastic scattering, inelastic scattering, radioactive capture, $n + Be^9 \rightarrow Li^6 + He^4$, $n + Be^9 \rightarrow 2n + He^4 + He^4$, $n + Li^6 \rightarrow H^3 + He^4$.
In the simulation, beryllium material is irradiated from all sides. The geometry of the object is shown in the figure-1.

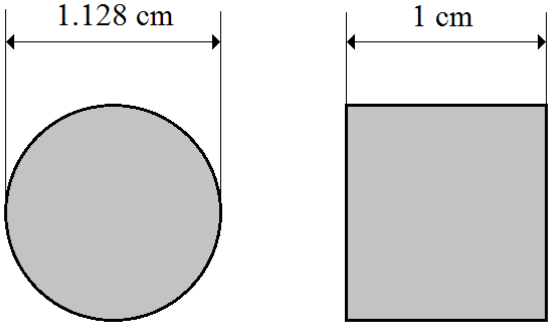


Figure 1. The geometry of the Be^9 slab and its parameters, the diameter and height. The view of the pictures is from the top and from the sidepiece concentration of tritium depending.

Initial coordinates of neutrons randomly selected one of the cylinder surfaces. The initial energy of the neutron is also randomly selected from the energy spectrum of the reactor. The non-dimensional energy spectrum function *f(E)* should be normalized for one, which means sum of probabilities *p(E)* of all neutron energy equals to one.

$$p(E_1)+ p(E_2)+ p(E_3)+\ldots+ p(E_n)=1 \tag{6}$$

After that from these probabilities the all two nearby probabilities should be added step by step, so that all probabilities increase from *1→N*. The figure-2 illustrates the scheme of selecting the initial energy of neutrons from neutron spectrum. The graphics *(a)* was modified to graphics *(b)*

in order to obtain stairs of probabilities. When program generates random number γ between [0,1), it gets the appropriate neutron energy.

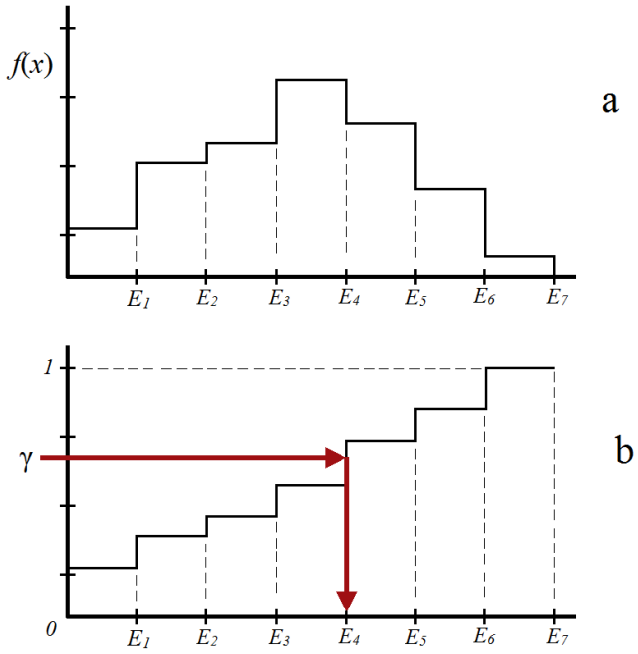


Figure 2. The scheme of selecting the initial energy of neutrons from neutron spectrum. The figure (a) shows neutron spectrum and figure (b) shows the stairs of probabilities.

It is considered that at the initial moment the neutron direction is normal to the surface. Further, according to this formula,

$$l = \frac{1}{\Sigma_t} \ln \gamma \tag{7}$$

the program calculates the mean free path. The number γ is a random number in the range [0,1), Σ_t – the total macroscopic cross section. Then randomly select the type of collision with kernel depending on the interaction cross section. The scattering angle and the energy after neutron scattering are calculated by this formula:

$$E` = E \frac{A^2+2A\mu_{c.m.}+1}{(A+1)^2} \tag{8}$$

$$\mu_{lab} = \frac{1+A\mu_{c.m}}{\sqrt{A^2+2A\mu_{c.m}+1}} \tag{9}$$

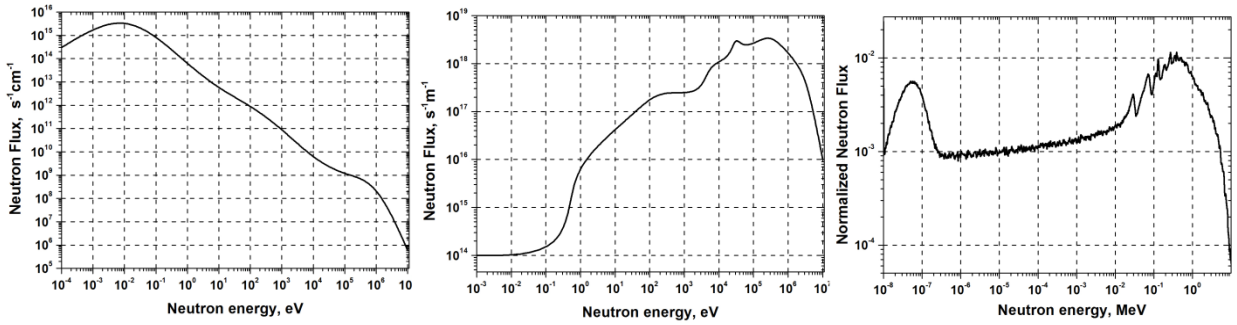
Here $E`$ – kinetic energy of the neutron after scattering, E – neutron energy before the collision, A – the ratio of nuclei mass to the mass of the neutron, $\mu_{c.m.}$ – the cosine of the scattering angle in the center of mass system, μ_{lab} – the cosine of the scattering angle in the laboratory system [2].
The cosine value of the scattering angle in the $\mu_{c.m.}$ was taken from the library JENDL-4.0 [3]. History neutron continues until absorption will happen or neutron energy becomes smaller than 10^{-4} eV. If there is a reaction with helium or tritium production the program will record the number of this process. After that the program generates new story. In each 100 sec time begins a new generation of neutrons. In each cycle, the program generates 5000 neutrons. The program, every 100 seconds, calculates concentration of He^4, H^3 and Li^6 according to this formula:

$$\Delta n = \frac{N}{N_{tot}} \frac{f}{V} \Delta t \tag{10}$$

Here Δn — difference in concentration of the element during Δt time, f – neutron flux, V – volume of the cylinder, N_{tot} – total number of neutrons which generated during Δt time, N – number of elements formed in the material under irradiation, N_{tot} – neutrons during Δt time.

4. SIMULATION RESULTS

Accumulation of tritium and helium in beryllium materials, depends on the spectrum of the neutron flux. Neutron spectrum is the basic characteristic of the reactor and the range can be different depending on the reactor. To understand the kinetics of helium and tritium, tasked to simulate the accumulation of helium and tritium at different neutron spectra.
For this purpose, program was developed and debugged, which helps to consider the concentration of helium and tritium depending on the time.
The neutron spectrums of the three experimental reactors such as JMTR, JOYO [4] and IPEN/MB [1] were taken to calculate. JMTR and JOYO are Japanese reactors and the reactor IPEN/MB is Brazilian. The figure-3 shows the spectra of the three reactors. As we can see they all have different spectra.
Neutron spectrum of the JMTR reactor was calculated in present work using MCNP5 and this neutron spectrum has thermal and fast neutrons.
Irradiation of beryllium by fast particles contributes to the formation and accumulation of radiation defects in it, and the nuclei of helium and tritium from nuclear reactions in the beryllium atoms. In certain irradiation parameters, these effects can cause significant changes in the physical and mechanical properties of the material, the main of which practical application is the density, thermal conductivity, strength and ductility.



(a) (b) (c)

Figure 3. The neutron spectrums of the reactors IPEN/MB-01 (a), JOYO (b) and JMTR (c).

Possible duration of the work in this case is determined by the neutron flux, at which the maximum permissible reduction in the quality of beryllium. The concentration of helium and tritium in Be^9 material depending on the time spectra for the three reactors JMTR, JOYO and IPEN/MB was calculated with developed program. The figure-4 and figure-5 show plots of the concentrations of tritium and He^4 from time to time for the three types spectra. The formation of tritium in reactor JMTR is more intensive and exceeds the formation of tritium in IPEN/MB and JOYO up to the 10^{10} times.

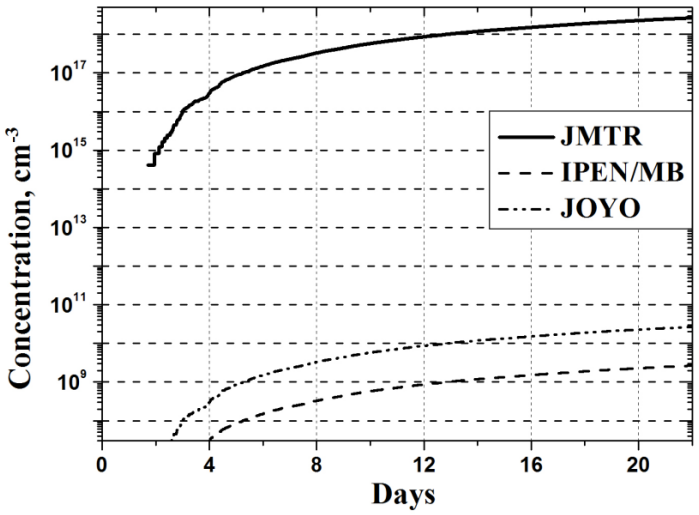


Figure 4. Here is shown the concentration of tritium in the Be^9 slab depending on time for spectrum of reactors JMTR, IPEN/MB and JOYO.

As for the He^4 accumulation in beryllium slabs will be the same in JOYO and JMTR reactors exceeding the correspondent formation in IPEN/MB reactor. The time exposition lasts up to the 22 days of continuous irradiation within the actives zone of the indicated nuclear reactors.

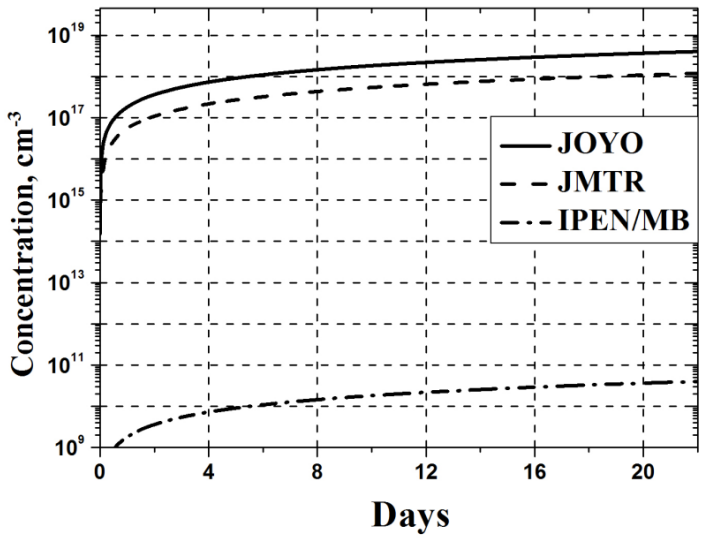


Figure 5. Here is shown the concentration of He^4 in the Be^9 slab depending on time for spectrum of reactors JMTR, IPEN/MB and JOYO.

5. CONCLUSIONS

It should be noted that the intense accumulation of tritium in the beryllium reflector at long exposure modes is possible only under conditions of simultaneous exposure to heat the sample and the high-energy neutron spectrum of the nuclear power plant. This fact is confirmed by our calculations for the experimental reactors JMTR, JOYO and IPEN/MB, see figure-3.

Simulation environment in this case is critical and research various structural materials of nuclear power facilities becomes clear meaning when determining formed in the operating zone of the reactor neutron energy spectrum. The intensity of accumulation of He^4 is determined only by the high-contrast part of the neutron spectrum that can be seen from figure-5.

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REFERENCES

[1] Ulysses d'Utra Bitelli, Fernando Prat Goncalves Martins, Rogerio Jerez, "Measurements of the neutron spectrum energy in the IPEN/MB-01 reactor core", *Brazilian Journal of Physics*, **volume(39)**, p. 41. URL http://www.scielo.br/pdf/bjp/v39n1/a07v39n1.pdf (2009)

[2] Forrest B. Brown, *Fundamentals of Monte Carlo Particle Transport*, Los Alamos National Laboratory, Los Alamos, USA, (2004)

[3] "Evaluated Nuclear Data File (ENDF)", available online. URL https://www-nds.iaea.org/exfor/endf.htm (2013)

[4] "Joyo User`s Guide", available online. URL http://www.jaea.go.jp/04/oarai/joyo_users_guide/joyomk3/spectrum/index.html/ (2014)