The method of calculating tritium content in various technological media of BN-type reactors

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Abstact. During the reactor operation continuous generation of the radioactive isotope of hydrogen – tritium – takes place. Tritium is formed in nuclear reactions: fission reaction of the fuel and interaction of neutrons with nuclei of some elements contained in the fuel, structural materials and coolant. Tritium has a great penetrating ability and migrates through the technological media. Thus, it also gets into the environment. Peculiarities of its transfer essentially depend on the reactor facility type.
Experience in operating domestic BN reactors as well as international experience suggests that only a small portion of tritium getting into the sodium coolant is released to the environment.

Data on the amount of tritium getting into the environment, along with the data on the content of tritium in technological environments, can be used in practical calculations of the staff and population exposure to tritium at NPPs with the BN reactor. This is required for the various operating modes of BN, including decommissioning.

As it has been shown in several studies, tritium transfer and distribution in sodium loops of BN reactors are directly connected with the content of protium (hereinafter referred to as hydrogen - H) in sodium. Therefore, simultaneous determination of the mass transfer of hydrogen and tritium is needed. Tritium mass transfer model applied to the three-loop reactor is based on the considered hydrogen-tritium balance in the loops.

The preliminary calculation results show that neutron reactions on ^{10}B and ^{11}B nuclei and triple fission provide the main contribution both to the rate of tritium production at the reactor facility and to the rate of tritium release to the primary sodium loop. These data are important for determining the effects of tritium on the personnel, population and the environment.

Key words: tritium**,** technological environments, main sources, production rate

Special attention is paid to T because it is one of those radionuclides which have radiation effect on the personnel of reactor plants and the population. The behavior of the radionuclide and its part that goes out to the environment depend on the reactor type essentially. Depending on various reactor types, the processes of tritium production and migration differ due to use of various fuel types, structural materials of fuel cladding, temperature modes of operation, types of the coolant and the systems that ensure radiation safety.

First of all, it is necessary to determine the main sources of tritium production in fast reactors. It is shown in a number of works [1,2,3] that tritium transfer and distribution in sodium loops of fast reactors are directly connected with the content of hydrogen in sodium and, therefore, it is necessary to consider them together. The main sources of tritium and hydrogen production are nuclear reactions of fuel material fission and neutron reactions on some isotopes which are contained in the fuel, constructional materials and coolant:

- triple fission of ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu fuel nuclei in the fuel assemblies - only for T;
- neutron reactions on the nuclei of B_4C in the control rods, boron shielding assemblies, upper axial blanket of the fuel subassembly: for T -^{10}B (n, 2α)T and ^{11}B(n, T)^{9}Be, for hydrogen - (*n*,*p*) ;
- neutron reactions on the nuclei of basic and impurity elements contained in:
  - fuel and reproducing assemblies - $^{17}O(n,T)^{15}N$, $^{18}O(n,T)^{16}N$ for oxide fuel;

- steel construction elements of control rods, fertile blankets, SS-shielding and B_4C - shielding assemblies - (*n*, T) and (*n,p*)-reactions on different isotopes of Fe, Cr, Ni, Mo, Nb, Mn mainly;
- primary sodium coolant: (*n*,T) and (*n,p*)-reactions on different isotopes of Na, Li, B, N, K.

It is very important what nuclear and neutron-physical data are used in calculating the production rates of T and hydrogen: T yields produced by triple fission on fissioning nuclei, neutron sections on various nuclei. The analysis and comparison of these data in various evaluated nuclear data libraries such as ENDF/B-7, JEFF3.2, EAF-2010, RUSFOND has shown that the evaluations generally agree, though not in all cases [4]. When the main reactions are defined and neutron fields in the corresponding environments are calculated, it is possible to determine the value of produced T. Nuclear data from the RUSFOND[5] library were used in our calculation.

The production rate of T by any isotope of the element which is part of material (or its impurity) in the zones of reactor assemblies is calculated by the formula (1)

$$W_{i,k}^{n,l,m} = \sum_i \sum_j (\phi_{i,k}^j \cdot \sigma_{i,k}^{j,n,l}) \cdot \rho_{i,k}^{n,l,m} \cdot V_{i,k} \tag{1}$$

where $W_{i,k}^{n,l,m}$ is the production rate of T by *n*-isotope of *l*-element in *m*-material in *i*-calculation zone of *k*-assembly, nuclei/sec; $\phi_{i,k}^j$ is the neutron flux in *j*-group in *i*-calculation zone of *k*-assembly, n/cm^2·sec; $\sigma_{i,k}^{j,n,l}$ is the shelfshieled microsection in *j*-group of production reaction of T , barn; $\sum_j (\phi_{i,k}^j \cdot \sigma_{i,k}^{j,n,l})$ is the integral of T production, nuclei/sec; $\rho_{i,k}^{n,l,m}$ is the nuclear concentration, nuclei/cm^3 (*l*-element of *m*-materal may be an isotope, if material is a mix of concentrations of elements and isotopes or only isotopes); $V_{i,k}$ is the volume of *i*-calculation zone in *k*-assembly , cm^3.

Isotope concentrations in the main materials of assemblies (coolant, fuel, steel, B_4C) are calculated by standard formula (2)

$$\rho_{i,k}^{n,l,m} = \varepsilon^{n,l,m} \cdot \rho o_{i,k}^{l,m} \tag{2}$$

where: $\varepsilon^{n,l,m}$ is the weight fraction of *n*-isotope in *l*-element of *m*-material; $\rho o_{i,k}^{l,m}$ is the nuclear concentration , nuclei/cm^3.

To estimate isotope concentrations of the impurities in the main materials is a more difficult task. Isotope concentrations of impurities dissolved in sodium are also determined by formula 2, but estimation of the concentrations of the impurity elements themselves is added to the formula. Isotope concentrations of the impurity elements in sodium are estimated by formula (3)

$$\rho_{i,k}^{n,pr,Na} \cdot = \varepsilon^{n,pr,Na} \cdot (\frac{A_{Na}}{A_{pr}}) \cdot W_{pr} \cdot \rho o_{i,k}^{Na} \tag{3}$$

where: $\varepsilon^{n,pr,Na}$ is the weight fraction of *n*- isotope in *pr*-impurity element in sodium; $\frac{A_{Na}}{A_{pr}}$ is the atomic weight of sodium and atomic weight of *pr*-impurity element in sodium ; W_{pr} is the content of *pr*-impurity element in sodium in weight fractions; $\rho o_{i,k}^{Na}$ is the sodium concentration in *i*-calculation zone in *k*-assembly, nuclei/cm^3.

Isotope concentrations of the impurity elements in the fuel, constructional steel, boron shielding assemblies are estimated by using formula (4) where data on the specific weights and volume fractions of materials in the zones of assemblies are used, besides the content of the impurity elements in materials

$$\rho_{i,k}^{n,l,m} = \gamma^m \cdot W_{pr} \cdot \frac{A_V}{A_{pr}} \cdot \varepsilon^{n,pr,m} \cdot do_{i,k}^{m} \tag{4}$$

where: γ^m is the specific weight of *m*-material, g/cm^3; W_{pr} is the content of *pr*- impurity element in *m*-material in weight fractions; A_V is the Avogadro number (=0,6023); A_{pr} is the atomic weight of *pr*-impurity element ; $\varepsilon^{n,pr,m}$ is the weight fraction of *n*-isotope in *n*-element in *m*-material; $do_{i,k}^{m}$ is the volume fraction of *m*-material in *i*-calculation zone of *k*-assembly.

The next step in the calculation algorithm is to solve the problem of estimating the T yield from the irradiated materials to the primary sodium coolant. The problem is quite complicated due to the lack of information for giving a precise definition. Moreover, the available data are widely dispersed [1,2,6]. However, the following expert estimation of the T yield from the irradiated materials to sodium was made: 99% from the fuel pins; 50% from the control rods and B_4C-based shielding assemblies; 100% from the steel constructional materials. Also, it is proposed to make a conservative assumption that the H yield from various irradiated materials to sodium in the specified nuclear reactions is 100%. Table 1 shows calculation results of T production rate in a high-power reactor with MOX-fuel and T-yields to the primary sodium coolant in atom/MW(e) [7].

The model of the T subsequent mass transfer in a three-loop reactor is based on the considered T-H balance in the first, second and third loops and is written in the form of a system of differential equations. For the BN-reactor these tasks are a little simpler because it can be taken with sufficient accuracy for practical calculations that the gas phase doesn't influence mass transfer of hydrogen isotopes (H, T) in sodium loops since their larger mass is in the coolant. Some assumptions are made: hydrogen isotopes are perfectly mixed in sodium loops; the power of the T source is determined by reactor power, etc., specific concentrations of H, T in sodium loops and in SEHR are the solution of the system of differential equations.

Table 1: CALCULATION RESULTS

Nuclear reaction	**The rate of tritium production at the reactor facility, atom/MW(e)·s**		**The rate of tritium release to sodium in the primary circuit, atom/MW(e)·s**	
In the entire reactor facility	$1{,}71\cdot10^{14}$		$9{,}53\cdot10^{13}$	
On ^{10}B and ^{11}B nuclei	$1{,}5\cdot10^{14}$	(88%)	$7{,}5\cdot10^{13}$	(79%)
Triple fission	$2{,}05\cdot10^{13}$	(12%)	$2{,}03\cdot10^{13}$	(21%)
On nonfissile nuclei in the fuel	$3{,}27\cdot10^{10}$	(< 0,1%)	$3{,}23\cdot10^{10}$	(< 0,4%)
On the impurities in steel construction	$7{,}64\cdot10^{8}$	(<< 0,1%)	$7{,}56\cdot10^{8}$	(<< 0,1%)
On the impurities in the primary coolant	$1{,}74\cdot10^{10}$	(< 0,1%)	$1{,}74\cdot10^{10}$	(< 0,1%)

The preliminary results from Table 1 show that neutron reactions on ^{10}B and ^{11}B nuclei and triple fission provide the main contribution both to the rate of tritium production at the reactor facility and to the rate of tritium release to the sodium in the primary loop.
The received values of H and T content in various technological environments of BN reactors are the basis for defining the effects of tritium on the personnel, population and the environment.

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