DOI 10.31489/2021PH4/78-84

UDC621.039

N.A. Suleimenov[1,2*], N.E. Mukhamedov[2], O.M. Zhanbolatov[2]

[1]*D. Serikbayev East Kazakhstan technical University, Ust-Kamenogorsk, Kazakhstan*
[2]*Branch "Institute of Atomic Energy" RSE NNC RK, Kurchatov, Kazakhstan*
*(*E-mail: sna@mail.ru)*

Using a user–defined function in Ansys Fluent to implement the energy release profile in model fuel elements taking into account radiation heating

The paper presents a model of an experimental device tested on the complex of impulse graphite reactor of the Branch IAE RSE NNC RK, designed to study the possibility of changing the neutron spectrum of the reactor from thermal to fast. At the stage of preparation for testing, a series of neutron-physical studies were carried out using the MCNP. The purpose of these studies is to determine the specific energy release both in the model fuel elements and in non-fuel structural elements of the experimental device during their radiation heating, taking into account the thermal state of the reactor core. After that, the obtained data are used as initial conditions for development of user-defined functions and conducting thermophysical calculations to determine the distribution of the temperature field in the tested device, the ANSYS Fluent software package. The method for calculating the specific energy release in non-fuel structural elements during their radiation heating in the impulse graphite reactor, considering its thermal state, has been used relatively recently. It requires a special approach to the implementation of the required energy release profile when carrying out thermophysical calculations in the Ansys software. The paper also illustrates the advantages of using a custom function in Ansys Fluent to define the profile of the energy release in model fuel elements and structural elements of an experimental device depending on time and height. In addition, the results of a thermophysical calculation of the experimental device for determining the distribution and maximum values of temperature in fuel and non-fuel structural elements are presented.

Keywords: user–defined function, Ansys Fluent, radiation heating, energy release, fuel elements, experimental device, impulse graphite reactor, thermophysical calculations.

Introduction

The object of research is model fuel rods and structural elements of an in-reactor experimental device [1]. Earlier, in [2], the results of computational studies to substantiate the technology of testing this experimental device were highlighted.

The aim of the work is to demonstrate the methodology for specifying complicated profiles of energy release in model fuel rods and structural elements in the Ansys Fluent software.

The tasks of the work are as follows:

– processing and preparation of the results of neutron-physical calculations;
– preparing a user-defined function for profiling the energy release in model fuel elements and structural elements;
– checking the function and initializing the thermophysical calculation.

Figure 1 shows a model of an experimental device created in the SolidWorks software. The device includes an ampoule, a test section and a trap. The ampoule consists of a body and a lid. The trap protects the ampoule from possible mechanical and thermal effects. The main elements of the test section are the upper and lower fuel rods, which are cooled with nitrogen. The center of the lower fuel rod coincides with the reactor core center (RCC), and the center of the upper fuel rod is at the level of +800 mm from the RCC.

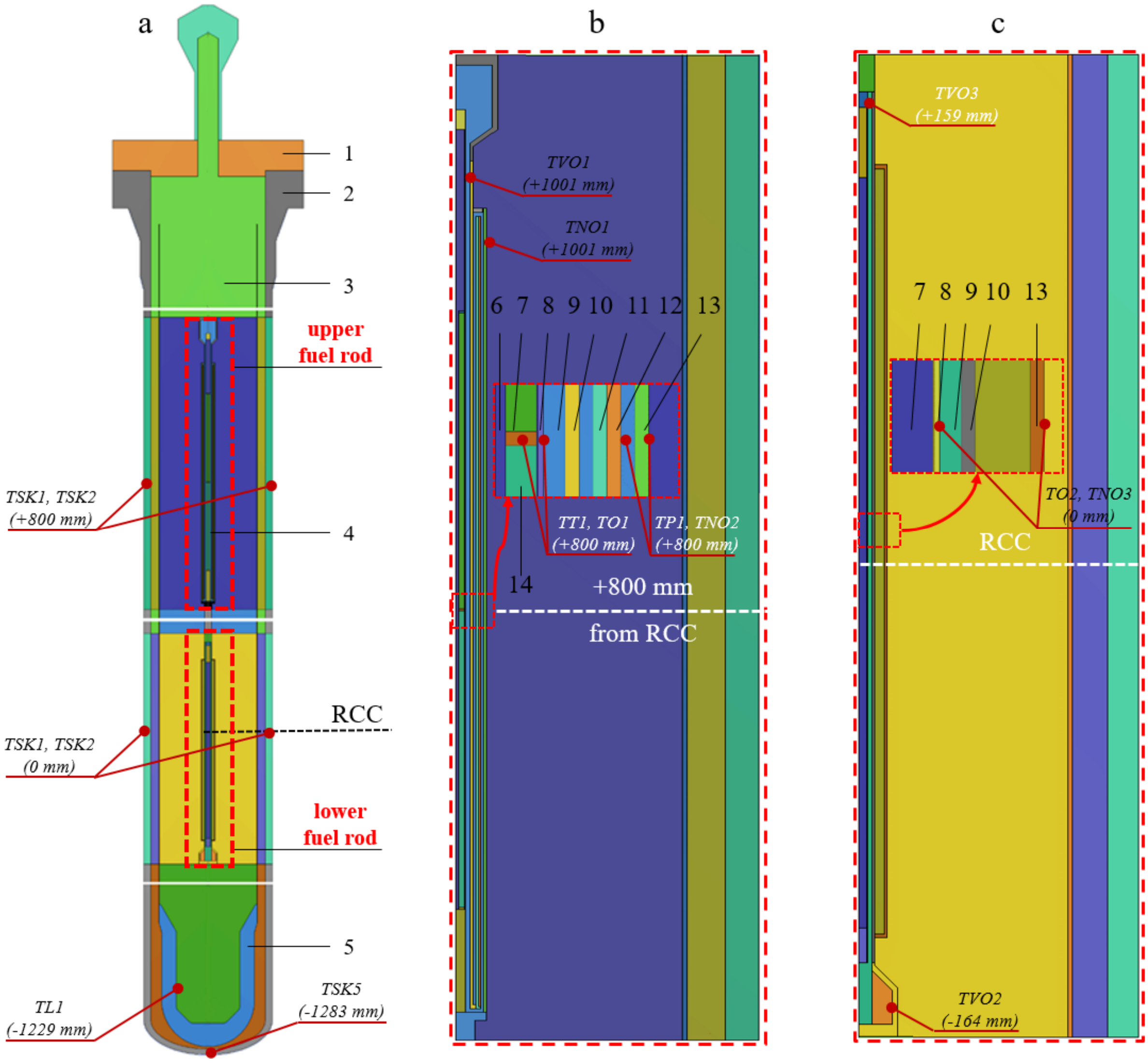

Figure 1. Model of the experimental device: a – general view, b – upper fuel rod, c – lower fuel rod, 1 – ampoule lid, 2 – ampoule body, 3 – ampoule cavity, 4 – test section, 6 – fuel, 7 – nickel indicator, 8 – fuel cladding, 9 – fuel rod cooling tract, 10 – inner shell, 11 – heat shield, 12 – cadmium absorber, 13 – outer shell

Results and Discussion

According to the conditions of the performed neutron–physical calculation, the reactor power is 5.2 MW, the diagram duration is ~ 1000 s, and the integral energy release in the reactor is ~ 5.2 GJ. Taking into account the limiting test mode and the absence of melting of nuclear fuel in the experiment tasks, obtaining accurate estimates of the temperature field is a priority goal of the calculations.

As a result of a neutron-physical calculation carried out in the MCNP program, a reactor power change diagram during the test was obtained, also, the values of the specific power of energy release in the elements — fuel, fuel cladding, inner and outer shells, heat shield and cadmium absorber when they are heated by radiation [3]. The calculations took into account the reactor core heating and the effect of the delayed power on the increase in energy release in the fuel and non-fuel structural elements. The markup, considering this effect, can reach 50 % in structural elements, which can lead to undesirable consequences, such as local overheating, especially in structural elements with a low melting point.

Each element of fuel rods is divided into 10 parts by height (numbered from top to bottom) and has its own specific per-second diagram of the specific power change in accordance with the reactor power diagram change. For example, Figure 2 illustrates a diagram for nuclear fuel.

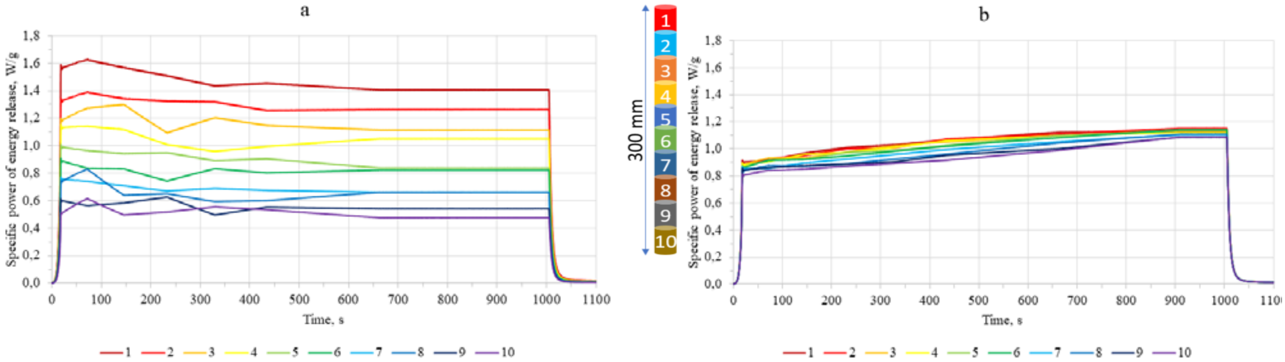

Figure 2. Diagram of the change in the power of energy release in the fuel:
a – upperfuelrod; b – lower fuel rod

The maximum specific power change of energy release in the structural elements of the fuel rods is indicated in Figure 3. The cadmium absorber is strongly exposed to radiation heating, and its specific power diagram change is shown on the auxiliary axis on the right. These values are in the range from 2.5 till 3.2 W/g.

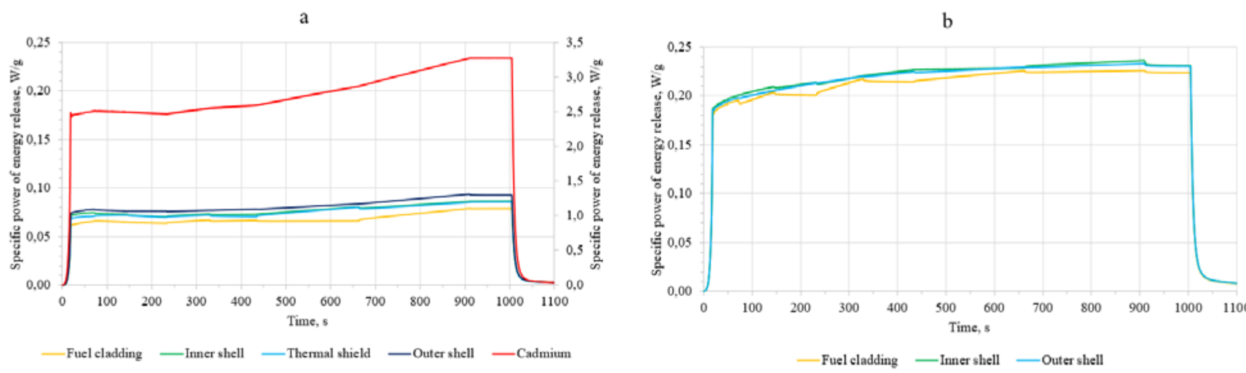

Figure 3. The specific power change of energy release in the structural elements:
a – elements of the upper fuel rod; b – elements of the lower fuel rod

To implement such a profile of energy release without using a custom function, it is necessary to divide the considered elements by height into a predetermined number of parts at the stage of developing a computational thermophysical model, and also, to take into account the distribution of energy release over time when performing calculations. This procedure makes thermophysical calculations a laborious process.

The application of a user-defined function in Ansys Fluent software consists in preparing it, using the C ++ programming language commands and compiling it in Ansys Fluent. Figure 4 shows the general structure of this function.

In the user-defined function, an array of element coordinates by height is set, dividing into the required number of parts, arrays of the energy release values of elements for these coordinates, which are read by the program at certain intervals, set in a separate array according to the reactor power change diagram.

The function also specifies arrays of energy release values in other structural elements of fuel rods — inner and outer shells, heat shield and cadmium absorber.

Next, in the Ansys Fluent software, one needs to import the mesh model, compile the user-defined function and specify the boundary conditions. In the elements where it is necessary to set the energy release, we select the corresponding function from the list (Figure 5). By default, the software allows to set a constant value for the volumetric energy release.

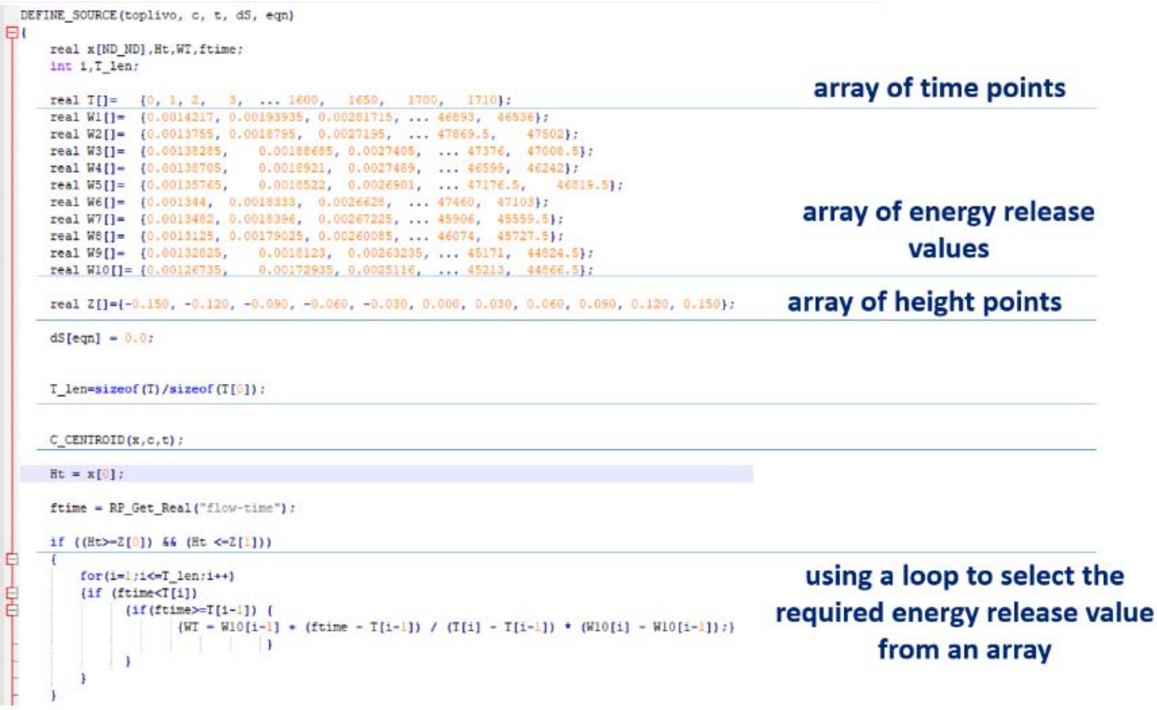

Figure 4. The general structure of function

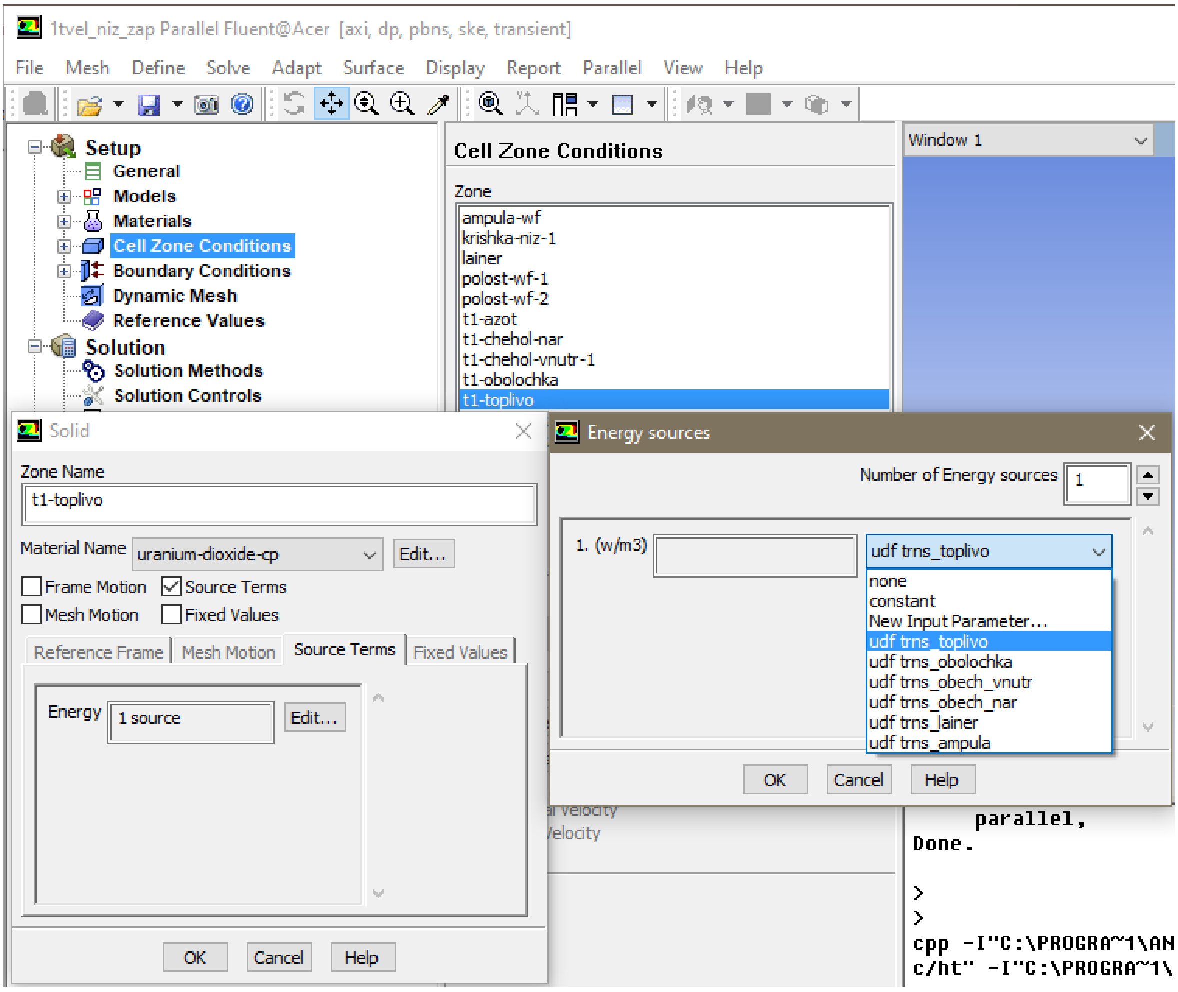

Figure 5. Window for selecting a user-defined function

After that, one needs to initialize the calculation. Considering the obtained calculation results, we can judge the final operability of the function. At the stage of performing a function, its operability can also be checked in a separate external compiler, for example, DevCpp.

As a result of the thermophysical calculation results, the maximum temperature diagram change of the fuel and structural elements during the experiment was obtained (Figure 6). The maximum temperature of the elements is observed at ~ 990 s, which corresponds to the moment of reactor “shutdown” according to the diagram of the experiment. The fuel temperature of the upper fuel element reaches 618 K, the lower one – 475 K. The dynamics of changes in the maximum value of the element temperature (Figure 6a) after 700 s from the beginning of the experiment diagram grows due to the heating of the reactor core, leading to an increase in the energy release in the experimental device elements. This property was taken into account when developing a user-defined function for a more accurate and closer to real conditions calculation, therefore, the energy release profile depending on time is set correctly. The temperature distribution of the elements relative to the reactor core center (RCC) at 990 s from the beginning of the experiment diagram is demonstrated in Figure 7. At this moment, the experimental device elements have different temperatures in height relative to the RCC, which indicates an uneven distribution of energy release along the height and the operability of the user-defined function. In the performed calculation, the mass flow rate of the cooling nitrogen was 2 g / s for each fuel rod.

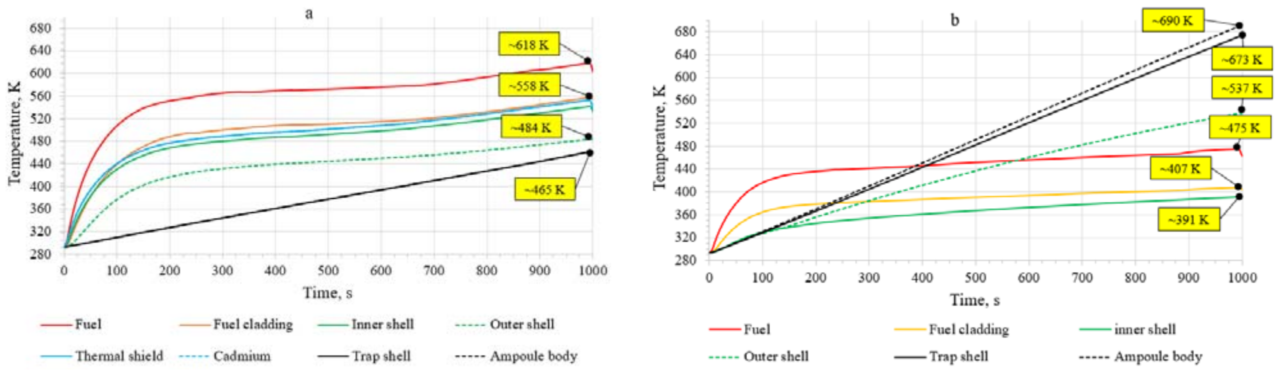

Figure 6. The maximum temperature changing of fuel and structural elements: a – upper fuel rod; b – lower fuel rod

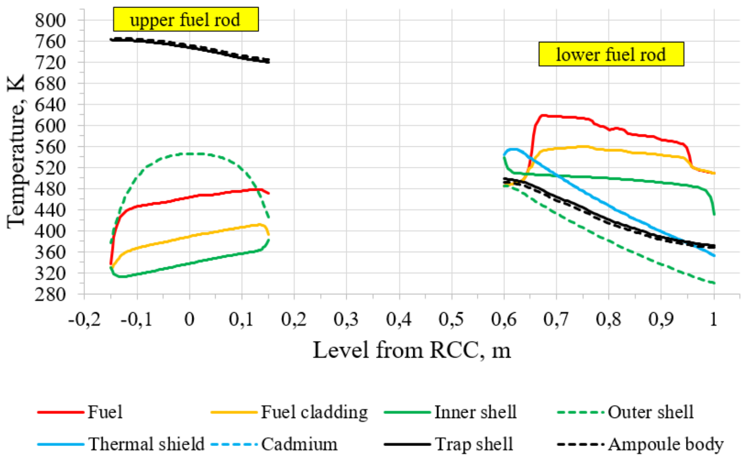

Figure 7. Temperature of fuel and structural elements relative
to the RCC at 990 s from the beginning of the experiment diagram

Conclusions

The paper considers a model of an experimental device designed to study the possibility of changing the neutron spectrum of the impulse graphite reactor from thermal to fast. To carry out a thermophysical calculation in the ANSYS Fluent software, closer to real conditions and taking into account the reactor core heating during the test, a user-defined function was developed. Based on the results of the thermophysical calculation, a diagram of the maximum temperature values change in the fuel and structural elements of the device was obtained. Changes in the maximum temperature of the elements have shown full operability and applicability of user-defined functions for modeling and setting complex profiles of energy release in model fuel elements with a distribution by time and height.

The developed user-defined functions will be used in subsequent computational studies to assess the thermal state of other experimental devices, and can also find their application in other engineering calculations, for example, in aerodynamic and electromagnetic [4–6].

References

1 Сулейменов Н.А. Влияние радиационного разогрева конструкционных материалов экспериментального устройства с конвертером нейтронов на их температурный режим / Н.А.Сулейменов, Н.Е.Мухамедов, В.М.Котов // Вестн. НЯЦ РК. — 2020. — Вып. 4. — № 84. — С. 61–68.

2 Котов В.М. Обоснование технологии экспериментальных исследований твэлов быстрых реакторов в ИГР / В.М. Котов, О.М. Жанболатов, Н.А. Сулейменов // Вестн. НЯЦ РК. — 2020. — Вып. 1. — № 81. — С. 62–67.

3 Жанболатов О.М. Расчет диаграммы мощности экспериментального устройства с конвертором нейтронов / О.М. Жанболатов, Р.А. Иркимбеков, Н.Е. Мухамедов // Вестн. НЯЦ РК. — 2020. — Вып. 4. — № 84. — С. 82–87.

4 Tanasheva N.K. Simulation of flow of the blade wind turbine / N.K. Tanasheva, E.R. Shrager, A.N. Dyusembaeva, A.K. Kussaiynova, D.A. Ospanova, A.R. Bakhtybekova // Bulletin of the university of Karaganda-Physics. — 2016. — No. 4 (84). — P. 20–23.

5 Tanasheva N.K. The study of the aerodynamic coefficients of rotating cylinders/ N.K. Tanasheva, A.N. Dyusembaeva, B.R. Nussupbekov, L.L. Minkov, Zh.G. Nurgalieva, K.K. Sadenova // Bulletin of the university of Karaganda-Physics. — 2019. — № 2 (94). — P. 108–113.

6 Айкеева А.А. ANSYS Maxwell бағдарламалық ортада скип қозғалысының имитациялық моделін жасау / А.А. Айкеева, К.С. Роговая, А.Р. Танскожанова, А.Е. Аюбекова, П.А. Мухтарова, А.Е. Оспанов // Қарағанд. унив. хаб. Физика сер. — 2017. — № 1(85). — Б. 82–88.

Н.А. Сулейменов, Н.Е. Мухамедов, О.М. Жанболатов

Модельдік жылушығарғыш элементтеріндегі энергия шығарылу кескінін іске асыру үшін радиациялық қызуын есепке ала отырып, AnsysFluent бағдарламасындағы пайдаланушы функциясын қолдану

Мақала импульстік графитреактордың нейтрондық спектрін жылулықтан шапшаңға өзгерту мүмкіндігін зерттеуге арналған және ҚР ҰЯО РМК «Атом энергиясы институты» филиалының импульстік графитреактор кешенінде сыналған эксперименттік құрылғының моделі көрсетілген. Сынауға дайындау барысында MCNP бағдарламалық кодын қолданып, көптеген нейтрон-физикалық зерттеулер мен есептер өткізілді. Зерттеулердің мақсаты жылушығарғыш элементтердің ядролық отындағы және отынсыз конструктивтік элементтердің радиациялық қызу кезінде импульстік графитреактордың жылулық күйін есепке алумен меншікті энергия шығарылуын анықтау болып табылады. Алынған мәліметтердің бастапқы шарттары пайдаланушы функциясын әзірлеу және сыналып жатқан эксперименттік құрылғының температура өрісін анықтау мақсатымен AnsysFluent бағдарламалық жасақтамасында өткізілетін жылуфизикалық есептерде қолданылады. Отынсыз конструктивтік элементтердің импульстік графитреакторында радиациялық қызу кезінде және де реактордың жылулық күйін есепке алатын, меншікті энергия шығарылуын санау әдістемесі кейінгі уақытта қолданыла басталған. Оған AnsysFluent бағдарламалық жасақтамасында өткізілетін жылуфизикалық есептерде керекті энергия шығарылу кескінін іске асыру үшін жеке тәсілдеме қажет. Сонымен қатар, мақалада эксперименттік құрылғының модельдік жылушығарғыш және конструктивтік элементтерінде уақытқа және биіктікке тәуелді меншікті энергия шығарылу кескінін Ansys Fluent бағдарламасында қою үшін пайдаланушы функциялардың артықшылықтары көрсетілген. Мұнан басқа эксперименттік құрылғының отынды және отынсыз конструктивтік элементтерінің температура үлестірімі және оның максимум мәнін анықтау үшін өткізілген жылуфизикалық есептеудің нәтижелері келтірілген.

Кілт сөздер: пайдаланушы функциясы, Ansys Fluent, радиациялық қызу, энергия шығарылуы, жылушығарғыш элемент, эксперименттік құрылғы, импульстік графит реакторы, жылуфизикалық есептеу.

Н.А. Сулейменов, Н.Е. Мухамедов, О.М. Жанболатов

Применение пользовательской функции в Ansys Fluent для реализации профиля энерговыделения в модельных твэлах с учетом радиационного разогрева

В статье представлена модель экспериментального устройства, испытанного на комплексе импульсного графитового реактора Филиала ИАЭ РГП НЯЦ РК и предназначенного для изучения возможности изменения спектра нейтронов реактора из теплового в быстрый. На этапе подготовки к испытаниям проведен ряд нейтронно-физических исследований и расчетов с использованием программного кода MCNP. Целью исследований — определение удельного энерговыделения как в топливе модельных твэлов, так и в нетопливных конструктивных элементах экспериментального устройства в процессе их радиационного разогрева с учетом теплового состояния активной зоны реактора. После чего полученные данные были использованы в качестве начальных условий для разработки пользовательской функции и проведения теплофизических расчетов по определению распределения температурного поля в испытываемом устройстве в программном пакете Ansys Fluent. Методика расчета удельного энерговыделения в нетопливных конструктивных элементах в процессе их радиационного разогрева в реакторе, с учетом его теплового состояния, применяется относительно недавно. Это требует особого подхода к реализации необходимого профиля энерговыделения при проведении теплофизических расчетов в Ansys Fluent. В работе показаны преимущества пользовательской функции в Ansys Fluent для задания профиля удельного энерговыделения в модельных твэлах и конструктивных элементах испытанного экспериментального устройства в зависимости от времени и высоты. Кроме этого, приведены результаты проведенного теплофизического расчета экспериментального устройства по определению распределения и максимальных значений температуры в топливе и нетопливных конструктивных элементах.

Ключевые слова: пользовательская функция, Ansys Fluent, радиационный разогрев, энерговыделение, твэл, экспериментальное устройство, импульсный графитовый реактор, теплофизические расчеты.

References

1 Suleimenov, N.A., Mukhamedov, N.E., & Kotov, V.M. (2020). Vliianie radiatsionnogo razogreva konstruktsionnykh materialov eksperimentalnogo ustroistva s konverterom neitronov na ikh temperaturnyi rezhim [Effect of radiation heating of construction materials of an experimental device with a neutron converter on their temperature regime]. *Vestnik NIaTs RK— NNC RK Bulletin, 4 (84)*, 61–68 [in Russian].

2 Kotov, V.M., Zhanbolatov, O.M., & Suleimenov, N.A. (2020). Obosnovanie tekhnologii eksperimentalnykh issledovanii tvelov bystrykh reaktorov v IGR [Substantiation of an experimental study technologyof fuel rods of fast reactors in the IGR]. *Vestnik NIaTs RK — NNC RK Bulletin, 1 (81)*, 62–67 [in Russian].

3 Zhanbolatov, O.M., Irkimbekov, R.A., & Mukhamedov, N.E. (2020). Raschet diagrammy moshchnosti eksperimentalnogo ustroistva s konvertorom neitronov [Calculation of the power diagram of an experimental device with a neutron converter]. *Vestnik NIaTs RK — NNC RK Bulletin, 4 (84)*, 82–87 [in Russian].

4 Tanasheva, N.K., Shrager, E.R., Dyusembaeva, A.N., Kussaiynova, A.K., Ospanova, D.A., & Bakhtybekova A.R. (2016). Simulation of flow of the blade wind turbine. *Bulletin of the Karaganda University-Physics, 4(84),* 20–23.

5 Tanasheva, N.K., Dyusembaeva, A.N., Nussupbekov, B.R, Minkov, L.L., Nurgalieva, Zh.G., & Sadenova,K.K. (2019). The study of the aerodynamic coefficients of rotating cylinders. *Vestnik Karagandinskogo universiteta. Seriia Fizika — Bulletin of the Karaganda University – Physics, 2(94),*108–113.

6 Aikeeva, A.A., Rogovaia, K.S., Tanskozhanova, A.R. Aiubekova, A.E., Mukhtarova, P.A., & Ospanov, A.E. (2017). ANSYS Maxwell bagdarlamalyq ortada skip qozgalysynyn imitatsiialyq modelin zhasau [Development of imitating model of skip motion in the programenvironment ANSYS Maxwell]. *Karagandy universitetinin khabarshysy. Fizika seriiasy — Bulletin of the Karaganda University – Physics, 1(85),*82–88 [in Kazakh].