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R.E. Kelsingazina[1,2]
[1]Branch «Institute of Atomic Energy» NNC RK,
071100, Republic of Kazakhstan, Kurchatov, Beybit Atom street, 10
[2]Shakarim University of Semey,
071412, Republic of Kazakhstan, Semey, Glinka street, 20 A
e-mail: kelsingazina@nnc.kz

SAFETY JUSTIFICATION FOR TRANSPORTATION OF NUCLEAR MATERIALS

Abstract: *The Institute of Atomic Energy of the National Nuclear Center of the Republic of Kazakhstan conducts a large number of studies to justify the safety of designed reactors and already operating reactors. Experiments are carried out both at in-pile and out-of-pile research installations. To implement these studies, there is a need to transport nuclear materials to the place where they are performed. Thus, it is necessary to justify the safety of nuclear material transportation. This paper presents neutronic calculations of the effective neutron multiplication factor to justify the safety of nuclear material transportation in accordance with the legislation of the Republic of Kazakhstan. The calculations used the most commonly transported type of nuclear materials – uranium dioxide (UO_2) fuel pellets of various enrichments. Transportation was conducted using a transport packaging set IP-1, in accordance with the rules for the transportation of nuclear materials. Both normal and emergency conditions for the transportation of nuclear materials were modeled, taking into account the possibility of water leaking into the packaging and water getting into canisters with uranium dioxide fuel pellets. To determine the effective neutron multiplication factor (k_{eff}) of the transport and packaging set, the Monte Carlo calculation method was used in the MCNP5 program, with the ENDF/B-VII nuclear data library.*

Key words: *nuclear materials, transportation, Monte Carlo method, transport and packaging container, effective neutron multiplication factor.*

Introduction

The Institute of Atomic Energy of the National Nuclear Center of the Republic of Kazakhstan (IAE NNC RK) is engaged in research of processes accompanying the development of a severe core melt accidents at nuclear power plants. For this purpose, experiments are carried out both in reactor and non-reactor installations. For example, thanks to the design features of the research impulse graphite reactor IGR [1], it is possible to conduct large-scale experiments with a model fuel assembly containing up to 10 kg of uranium dioxide [2]. There is a need to transport nuclear materials to the assembly site of model fuel assemblies to conduct experiments on time. At each nuclear energy facility there is a system for transporting and storing fresh nuclear fuel; operations of reception, storage, preparation for loading and loading are carried out.

The International Atomic Energy Agency (IAEA) establishes standards of safe transport of radioactive materials [3]. Their basic concept is that during transportation of radioactive materials the safety and protection of people, property, and the environment from the harmful effects of ionizing radiation is mainly ensured by packaging [4]. According to the Law of the Republic of Kazakhstan “On the Use of Atomic Energy” [5], transportation of nuclear materials, radioactive substances and radioactive waste must be carried out in transport packaging sets (TPS).

There are different types of transport packaging sets (Fig. 1) depending on the radioactive material being transported, classified into the following types: excepted packaging; industrial packaging types 1 (IP-1), 2 (IP-2), 3 (IP-3); packaging types A, B, C [6].

In accordance with the rules for the transportation of nuclear materials, radioactive substances and radioactive waste [7], one of the requirements is to exclude the achievement of a critical mass under normal, routine and accident transportation conditions.

Nuclear safety during the transportation of radioactive materials in containers will be achieved under the conditions that the effective multiplication factor k_{eff} of an individual package does not exceed 0.95 under normal, routine and accident transportation conditions.

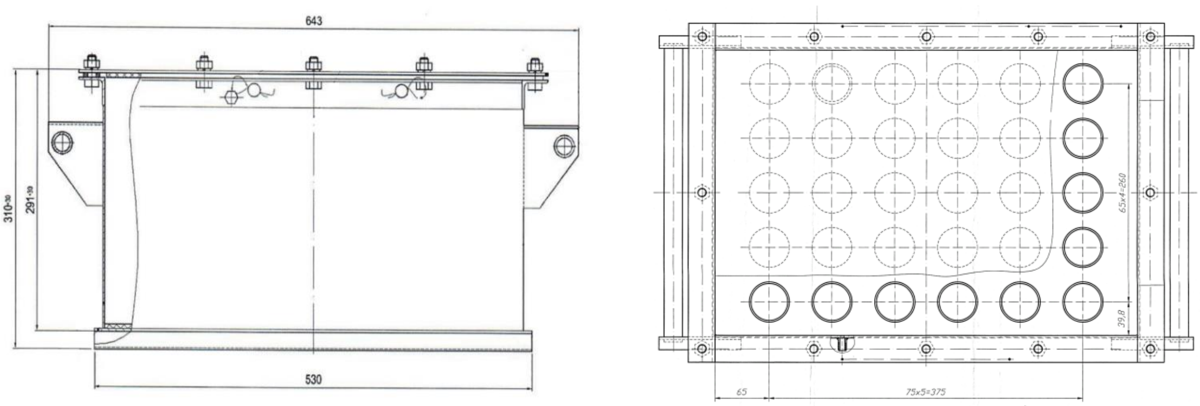
TPS-39M1 TPS-115 TPS-19

Fig. 1 – Transport packaging set

Problem formulation

The most frequently transported nuclear materials are fuel pellets made of uranium dioxide of various enrichments, intended for experimental devices with model fuel assemblies, when conducting research at reactor and non-reactor installations of the Institute of Nuclear Energy of the National Nuclear Center of the Republic of Kazakhstan in support of scientific and technical programs for the development of nuclear energy in the Republic of Kazakhstan. To assemble one fuel assembly of a model fuel assembly, more than 1 kg of fuel pellets is required. According to [7], transportation of fuel pellets must be carried out in industrial packaging type 1 (IP-1).

TPS IP-1 (Fig. 2) is a container consisting of a welded body of rectangular cross-section with a wall thickness of 2 mm, with a removable lid whose thickness is 3 mm. The material of the body and lid is St3 steel. The container contains a tray with 30 holes designed to accommodate cylindrical cases. The canisters are used for loading fuel pellets, they are made of stainless steel 12X18H10T.



Container IP-1 (side view) Tray for canisters (top view, TPS lid not shown)

Fig. 2 – Components of the TPS IP-1

The purpose of this work is to calculate the effective neutron multiplication factor (k_{eff}) to justify the safety of transportation of uranium dioxide fuel pellets. The main characteristics of the transported material are presented in Table 1.

Table 1 – Characteristics of transported fuel pellets

№	Name	Enrichment, %	Mass, g
1	Pellets UO_2	16	1756
2	Pellets UO_2	12	1171

It is accepted that transportation of pellets will be carried out inside canisters as part of the transport packaging set. According to the requirements [7], there are should be not more than 5 grams of fissile nuclides of uranium 235 in each individual package.

Neutronic calculations and their results

Among the methods for calculating the effective neutron multiplication factor, the most widely used is the Monte Carlo method, which allows calculations of any materials with a complex geometric configuration.

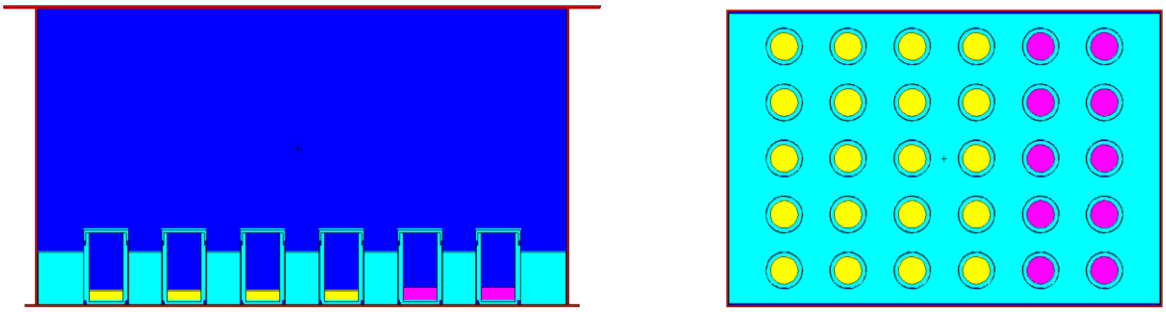
In this work, to determine the effective neutron multiplication factor (k_{eff}), a neutronic model of the TPS was developed, containing canisters with uranium dioxide pellets (Fig. 3), in the MCNP5 program [8] with the ENDF/B-VII nuclear data library. The physical properties of the materials were borrowed from reference literature [9, 10].

In order to take a conservative approach to calculating k_{eff}, uranium dioxide fuel pellets are modeled in the form of monolithic cylinders and distributed evenly among all canisters, and the possible redistribution of fuel pellets with maximum proximity to each other is also taken into account.

Two emergency situations were considered in calculations, taking into account the possibility of the packaging being flooded with water and the packaging getting into water or snow:

– flooding of TPS IP-1 with water, while there is no water in the canisters;

– complete flooding of the canisters and TPS IP-1 with water.



longitudinal section cross section

– Fuel enriched 16%
– Fuel enriched 12%
– Container
– Tray and canisters
– Air

Fig. 3 – Calculation model of the TPS IP-1

As a result of neutronics calculations under normal and ordinary transportation conditions, the effective neutron multiplication factor is 0.0152. In case of partial flooding of the TPS, when water did not enter the canister, k_{eff} = 0.0179. When the transport packaging is completely flooded, the coefficient k_{eff} does not exceed 0.0314.

Conclusions

To establish the safety of transportation of nuclear materials to the research site with model fuel assemblies, a computational model of the TPS IP-1 transport and packaging container with a canister containing uranium dioxide fuel pellets was developed. A number of neutronics calculations have been performed to justify nuclear safety during the transportation of uranium dioxide fuel pellets inside of a transport packaging set under conditions of normal movement and in the event of a number of accident situations. In none of the considered accident situations the value of the effective neutron multiplication coefficient exceeds the limit k_{eff} =0.95. Thus, we can assume that in the case considered, the transportation of nuclear materials is safe and complies with the rules for the transportation of nuclear materials, radioactive substances and radioactive waste [7]

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Р.Е. Келсинғазина[1,2]
[1]ҚР ҰЯО «Атом энергиясы институты» филиалы,
071100, Қазақстан Республикасы, Курчатов қ., Бейбіт Атом көшесі, 10
[2] Семей қаласының Шәкәрім атындағы университеті,
071412, Қазақстан Республикасы, Семей қ., Глинка көшесі, 20 А
e-mail: kelsingazina@nnc.kz

ЯДРОЛЫҚ МАТЕРИАЛДАРДЫ ТАСЫМАЛДАУ КЕЗІНДЕГІ ҚАУІПСІЗДІК НЕГІЗДЕМЕСІ

«Қазақстан Республикасының Ұлттық ядролық орталығы» РМК «Атом энергиясы институты» филиалында жобаланатын және іске қосылған реакторлардың қауіпсіздігін негіздеу үшін көптеген зерттеулер жүргізіледі. Эксперименттер реакторлық және реактордан тыс зерттеу қондырғыларында жүргізіледі. Осы зерттеулерді жүзеге асыру үшін ядролық материалдарды олар жүргізілетін жерге дейін тасымалдау қажет болады. Осылайша ядролық материалдарды тасымалдау қауіпсіздігін негіздеу қажеттілігі туындайды. Бұл жұмыста Қазақстан Республикасының заңнамасына сәйкес ядролық материалдарды тасымалдау қауіпсіздігін негіздеу үшін нейтрондардың тиімді көбею коэффициентінің нейтрондық-физикалық есептеулері ұсынылған. Есептеулерде ядролық материалдардың ең көп тасымалданатын түрі – әртүрлі байытылған уран диоксиді (UO_2) отын таблеткалары пайдаланылды. Тасымалдау кезінде ядролық материалдарды тасымалдау ережелеріне сәйкес ПУ-1 типті көліктік-қаптама комплектісі пайдаланылды. Ядролық материалдарды тасымалдаудың қалыпты, сондай-ақ авариялық жағдайлары уран диоксиді отын таблеткалары салынған қаптамаға судың ағып кету және пеналдарға су кіру мүмкіндігі ескеріліп модельденді. Көліктік-қаптама комплектің тиімді нейтронды көбейту коэффициентін ($k_{эф}$) анықтау үшін ENDF/B-VII ядролық деректер кітапханасымен MCNP5 бағдарламасында Монте-Карло есептеу әдісі қолданылды.

***Түйін сөздер**: ядролық материалдар, тасымалдау, Монте Карло әдісі, көліктік-қаптама контейнері, нейтрондардың тиімді көбею коэффициенті.*

Р.Е. Келсингазина[1,2]
[1]Филиал «Институт атомной энергии» НЯЦ РК,
071100, Республика Казахстан, г. Курчатов, улица Бейбит атом, 10
[2]Университет имени Шакарима города Семей,
071412, Республика Казахстан, г. Семей, улица Глинки, 20 А
e-mail: kelsingazina@nnc.kz

ОБОСНОВАНИЕ БЕЗОПАСНОСТИ ПРИ ТРАНСПОРТИРОВКЕ ЯДЕРНЫХ МАТЕРИАЛОВ

В Филиале «Институт атомной энергии» Национального ядерного центра Республики Казахстан проводится большое количество исследований в обоснование *безопасности проектируемых и уже введенных в эксплуатацию реакторов. Эксперименты проводятся как на реакторных, так и внереакторных исследовательских установках. Для осуществления данных исследований возникает необходимость транспортировки ядерных материалов до места их проведения. Таким образом, возникает необходимость обоснования безопасности перевозки ядерных материалов. В данной работе представлены нейтронно-физические расчеты эффективного коэффициента размножения нейтронов в обоснование безопасности транспортировки ядерных материалов, согласно законодательству Республики Казахстан. В расчетах использовался наиболее часто перевозимый вид ядерных материалов – топливные таблетки диоксида урана (UO_2) разных обогащений. Транспортировка производилась с использованием транспортно-упаковочного комплекта типа ПУ-1, в соответствие с правилами транспортировки ядерных материалов. Моделировались нормальные и аварийные условия перевозки ядерных материалов, учитывающие возможности протечки воды в упаковку и попадание воды в пеналы с топливными таблетками диоксида урана. Для определения эффективного коэффициента размножения нейтронов ($k_{эф}$) транспортно-упаковочного комплекта использовался метод расчета Монте Карло в программе MCNP5, с библиотекой ядерных данных ENDF/B-VII.*

Ключевые слова: *ядерные материалы, транспортировка, метод Монте Карло, транспортно-упаковочный контейнер, коэффициент эффективного размножения нейтронов.*

Сведения об авторах

Рузия Ерлановна Келсингазина – инженер лаборатории испытаний реакторного топлива; Филиал «Институт атомной энергии» Национального ядерного центра Республики Казахстан, Курчатов, Казахстан; e-mail: kelsingazina@nnc.kz.

Авторлар туралы мәліметтер

Рузия Ерлановна Келсингазина – реакторлық отын сынақтары зертханасының инженері; Қазақстан Республикасының Ұлттық Ядролық орталығы, Курчатов, Қазақстан; e-mail: kelsingazina@nnc.kz.

Information about the authors

Ruziya Erlanovna Kelsingazina – engineer of the Reactor Fuel Test Laboratory; National Nuclear Center of the Republic of Kazakhstan, Kurchatov, Kazakhstan; e-mail: kelsingazina@nnc.kz.

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О.В. Кофтанюк*, А.К. Кинжибекова
Торайгыров университет,
140008, Республика Казахстан, г. Павлодар, ул. Ломова, 64
*e-mail: oksana.koftanyuk@mail.ru

АНАЛИЗ ПОТРЕБЛЕНИЯ ОСНОВНЫХ ЭНЕРГЕТИЧЕСКИХ РЕСУРСОВ ПРИ ПРОИЗВОДСТВЕ ЭЛЕКТРИЧЕСКОЙ И ТЕПЛОВОЙ ЭНЕРГИИ НА ТЭЦ

Аннотация: *В данном исследовании были изучены показатели энергорезультативности работы ТЭЦ-3 АО «Павлодарэнерго», которые дают возможность отслеживать изменения в энергоэффективности технологического процесса. Это позволяет наблюдать, как повышение энергоэффективности, влияет на энергетические характеристики оборудования. Такой анализ позволяет тепловой энергоцентрали оптимизировать свои энергетические ресурсы и снизить негативное воздействие на окружающую среду.*