TRACT COMPUTER CODE APPLICATION IN THE ASSESSMENT OF SNF AND RW CLASS 1 RADIONUCLIDE COMPOSITIONS AND RADIATION CHARACTERISTICS

Blokhin A. I., Blokhin P. A., Kazieva S. T.

Nuclear Safety Institute of the Russian Academy of Sciences, Moscow, Russia

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The article presents the results of computational studies addressing radionuclide compositions and radiation characteristics of spent nuclear fuel from WWER-440 and BN-600 reactor units performed using new computer code TRACT. These studies were performed to acquire basic information enabling further forecasts of RW Class 1 characteristics generated from the reprocessing of these fuel types. The calculations allowed to identify the characteristics of WWER-440 and BN-600 SNF considering various irradiation and storage conditions, including different burnup levels and pre-reprocessing cooling times. Such data will enable further evaluation of possible ranges describing the characteristics of RW Class 1.

Keywords: *computer code, nuclide kinetics, spent nuclear fuel, radiation characteristics, energy release, pressurized water power reactor, sodium-cooled fast neutron reactor, radioactive waste, aluminum-phosphate glass.*

Introduction

The safety of personnel and population is ensured by Russian radioactive waste management practices to the fullest extent possible at various stages of the NFC, including RW disposal [1—3]. At the same time, standards established for the production impacts according to the radiation factor are unprecedentedly strict in case of certain nuclear technologies basically corresponding to the payback balance level, although safety margins of several orders of magnitude have been attained [4]. In case of nuclear legacy facilities with their uncertain characteristics, including those relevant for the safety demonstration purposes, assessment conservatism can be reduced and adequate long-term forecasting can be approached by refining the characteristics of the accumulated waste inventory. As practice shows, this is considered as a non-trivial and urgent task not only for obsolete repositories or abandoned buildings and structures for which no design documentation is available, but also as regards storage facilities for vitrified RW being considered quite modern as compared to the legacy structures [5—7].

By volume, the biggest inventory of RW Class 1 [8] in Russia accounts for aluminophosphate glass (APG) resulted from the reprocessing of spent nuclear fuel from WWER-440, BN-600, research, transport-ship and power reactor units. The biggest inventory of reprocessed SNF accounts for spent fuel assemblies from WWER-440 and BN-600 reactors. APG composition stands for the initial information allowing to predict APG compositions and its characteristics. At the same time, some other important characteristics that should be evaluated involve: the content of radionuclides considered important for the long-term safety assessment (the key ones are ^{14}C, ^{79}Se, ^{99}Tc, ^{129}I, ^{135}Cs, etc.), the amount of remaining fissile material, energy release, intensity and gamma spectra of neutron sources.

The article evaluates and presents the results of computational studies focused on WWER-440 and BN-600 SNF compositions implemented using modern computational code TRACT serving a basis for further analysis of the APG characteristics. Calculation tools were used to evaluate SNF composition affected by several factors: requirements for the completeness of the composition and the timeframes in which the changing SNF characteristics should be evaluated, complete or partial absence of information in open sources on the content of a few significant SNF radionuclides.

Computational studies and forecasting the radionuclide compositions of SNF from various types of reactor units

The TRACT code [9] has been developed by the Nuclear Safety Institute (IBRAE RAS) since 2018 to support the calculations focused on radionuclide compositions and radiation characteristics of irradiated materials. It should be emphasized that the TRACT code has been partially verified based on experimental data to enable the assessment of WWER-440 SNF characteristics [10], is currently undergoing some additional verification/validation and will be shortly submitted for certification, which is planned for 2021 with all necessary preparation being done.

TRACT-based computational studies focused on the radionuclide compositions and radiation characteristics of irradiated materials provide data on the number of atoms, their mass, activity, energy release through alpha-, beta-, gamma- decay and their sum, half-lives, the number of emitted gamma quanta which can be obtained for given exposure and cooling times considering almost unlimited timespan for each isotope and element.

Radiation characteristics calculated for WWER-440 SNF

Data on radiation characteristics of spent nuclear fuel, including its heat release, are commonly taken from a handbook [8] (hereinafter referred to as Handbook) and safety guidelines [12]. The Handbook contains information on radiation characteristics (activity, alpha, beta, gamma heat release, etc.) of spent nuclear fuel considering a cooling time of up to 20 years. To provide comparative calculations according to the Handbook, stationary WWER-440 reactor operating mode (Figure 1) was selected under this study being considered as a most representative one involving fuel (fuel assemblies) with an 3.6 % enrichment in ^{235}U and a burnup of about 30 GW·days/tU.

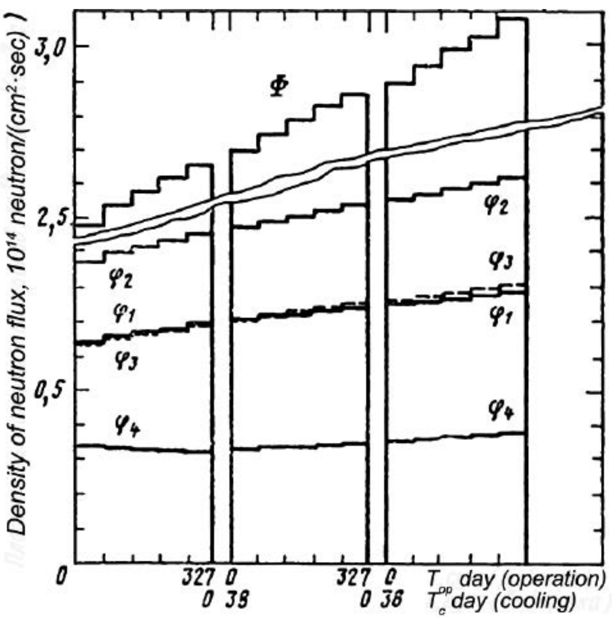

Figure 1. Irradiation mode for fuel (assemblies) with 3.6 % enrichment at WWER-440 reactor unit

As described in the Handbook, stationary WWER-440 reactor operation mode involves 18 steps:

- Steps 1—5 — reactor operation at a nominal power capacity during the first "annual" fuel life-time;
- Step 6 — first shutdown of the reactor for 38 days;
- Steps 7—11 — continued reactor operation at a nominal power during the second "annual" fuel life-time;
- Step 12 — second shutdown of the reactor for 38 days;
- Steps 13—17 — continued reactor operation at a nominal power during the third "annual" fuel life-time;
- step 18 — fuel (FA) unloading and cooling. In a somewhat simplified interpretation, this mode can be represented as follows: irradiation for 327 days (5 × 65.4 days) + shutdown for 38 days + irradiation for 327 days + shutdown for 38 days + irradiation for 327 days + cooling, i. e., the entire fuel lifetime would account for 3 years (plus cooling).

Table 1 (cooling times correspond to the data given in the Handbook) shows the calculation results obtained using the TRACT code and provided in the Handbook for a fuel with 3.6 % enrichment in ^{235}U providing for a burnup of about 30 GW·day/tU.

Figures 2—6 show the changes in the specific activity and heat release of WWER-440 SNF according to the data presented in the Handbook and calculated using the TRACT code.

Table 1. Changes in SNF specific activity and heat release

Cooling *t*	Activity, Bq/tU		Energy release, kW/tU					
			α-emitters		β-emitters		γ-quanta	
	[11]	TRACT	[11]	TRACT	[11]	TRACT	[11]	TRACT
1 s	6.42E+18	8.82E+18	1.25E+00	3.22E+00	8.70E+02	8.51E+02	7.90E+02	7.47E+02
10 s	5.75E+18	8.50E+18	1.25E+00	3.22E+00	6.62E+02	7.63E+02	6.57E+02	6.87E+02
1 min	4.98E+18	7.91E+18	1.25E+00	3.22E+00	4.73E+02	6.36E+02	5.19E+02	5.96E+02
5 min	4.22E+18	7.09E+18	1.25E+00	3.22E+00	3.38E+02	5.09E+02	3.88E+02	4.99E+02
10 min	3.87E+18	6.58E+18	1.25E+00	3.22E+00	2.88E+02	4.49E+02	3.41E+02	4.56E+02
30 min	3.20E+18	5.44E+18	1.25E+00	3.22E+00	2.05E+02	3.30E+02	2.64E+02	3.70E+02
1 h	2.78E+18	4.65E+18	1.22E+00	3.22E+00	1.60E+02	2.56E+02	2.15E+02	3.10E+02
3 h	2.32E+18	3.88E+18	1.25E+00	3.22E+00	1.15E+02	1.88E+02	1.53E+02	2.28E+02
6 h	2.11E+18	3.60E+18	1.25E+00	3.22E+00	9.48E+01	1.67E+02	1.26E+02	1.96E+02
12 h	1.88E+18	3.27E+18	1.25E+00	3.22E+00	7.67E+01	1.47E+02	1.06E+02	1.70E+02
1 day	1.61E+18	2.80E+18	1.25E+00	3.22E+00	6.12E+01	1.23E+02	8.88E+01	1.43E+02
5 days	8.89E+17	1.24E+18	1.24E+00	3.18E+00	3.57E+01	5.30E+01	5.19E+01	7.31E+01
10 days	6.29E+17	6.93E+17	1.21E+00	3.12E+00	2.77E+01	3.01E+01	3.78E+01	4.75E+01
15 days	5.24E+17	5.19E+17	1.19E+00	3.06E+00	2.40E+01	2.27E+01	3.08E+01	3.73E+01
30 days	3.91E+17	3.65E+17	1.13E+00	2.89E+00	1.89E+01	1.61E+01	2.07E+01	2.54E+01
60 days	2.79E+17	2.59E+17	1.01E+00	2.58E+00	1.47E+01	1.20E+01	1.29E+01	1.67E+01
90 days	2.20E+17	2.05E+17	9.04E-01	2.31E+00	1.26E+01	1.02E+01	9.52E+00	1.26E+01
120 days	1.82E+17	1.69E+17	8.12E-01	2.07E+00	1.12E+01	9.08E+00	7.39E+00	9.94E+00
180 days	1.34E+17	1.24E+17	6.60E-01	1.68E+00	9.28E+00	7.55E+00	4.76E+00	6.57E+00
1 year	7.78E+16	7.18E+16	3.78E-01	9.41E-01	5.94E+00	4.96E+00	2.00E+00	2.92E+00
2.3 years	3.86E+16	3.79E+16	1.75E-01	4.05E-01	2.42E+00	2.12E+00	1.05E+00	1.57E+00
3 years	3.02E+16	3.01E+16	1.57E-01	3.50E-01	1.65E+00	1.42E+00	8.72E-01	1.29E+00
10 years	1.36E+16	1.31E+16	1.67E-01	3.10E-01	4.73E-01	3.03E-01	3.20E-01	4.20E-01

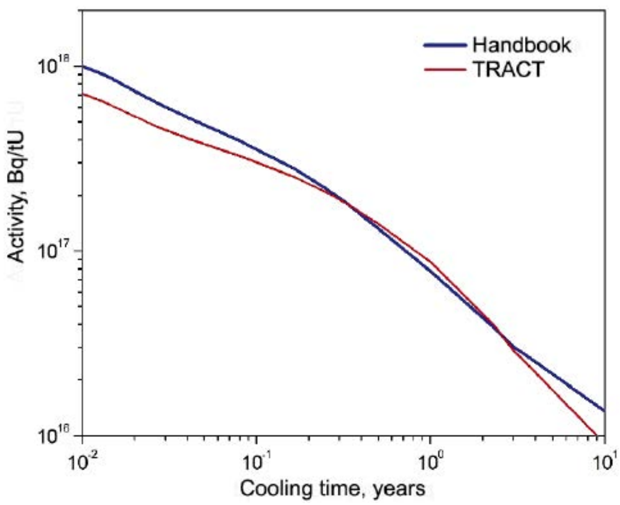

Figure 2. Changes in the specific activity of WWER-440 SNF

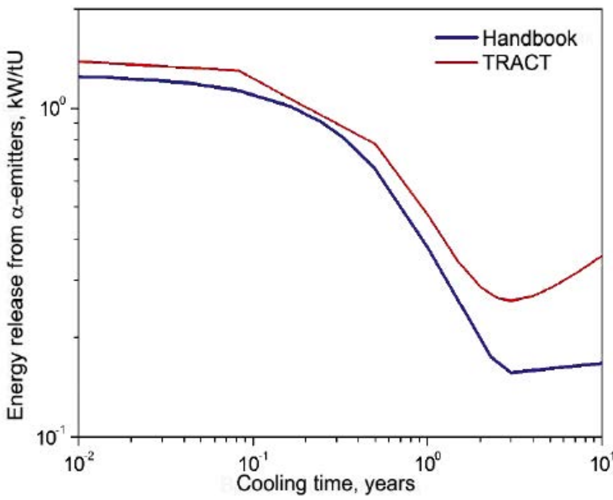

Figure 3. Changes in the energy release of alpha-emitters from WWER-440 SNF

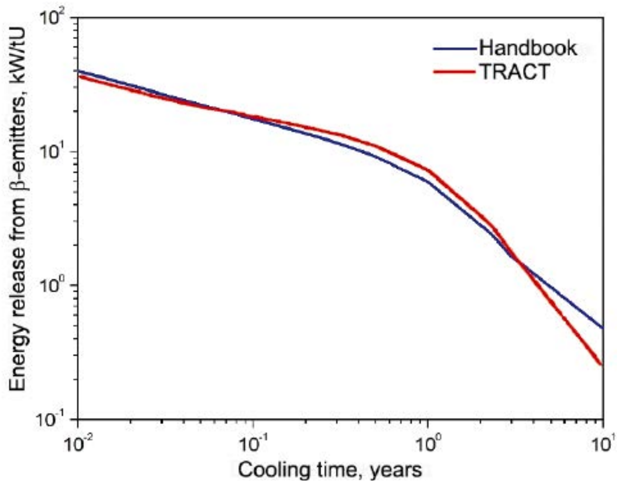

Figure 4. Changes in the energy release of beta-emitters from WWER-440 SNF

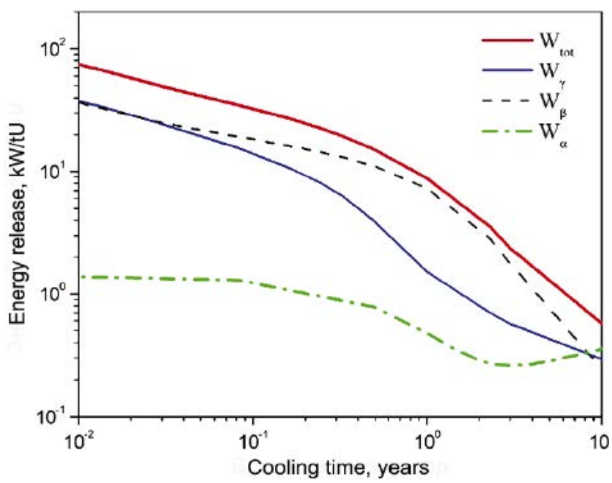

Figure 7. Total energy release from WWER-440 SNF and its constituent components

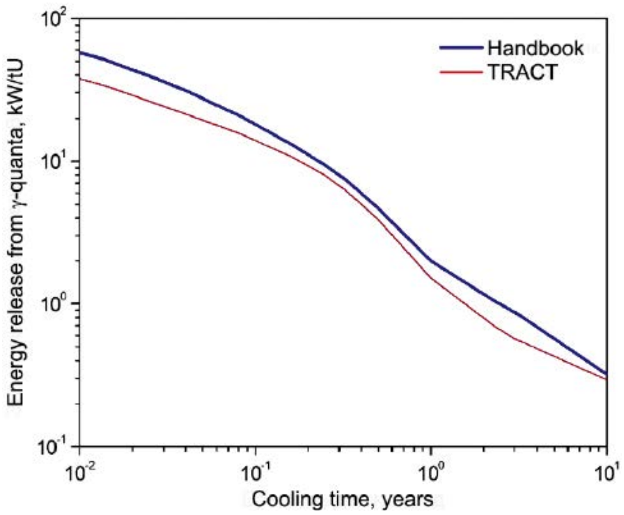

Figure 5. Changes in the energy release of gamma quanta from WWER-440 SNF

Figure 7 presents the total energy release and its components accounting for gamma, beta and alpha radiation calculated using the TRACT code.

Safety Guideline RB-093-20 [12] provides information on the radionuclide composition (for a limited radionuclide inventory) and SNF energy release considering different initial enrichment and burnup depth, in particular the one for WWER-440 reactor units (Table 2).

Table 2. WWER-440 fuel inventory

Average initial enrichment in ^{235}U, %	Design-based burnup, GW·day/tU
3.6	36
3.82	46
4.25	58
4.38	66

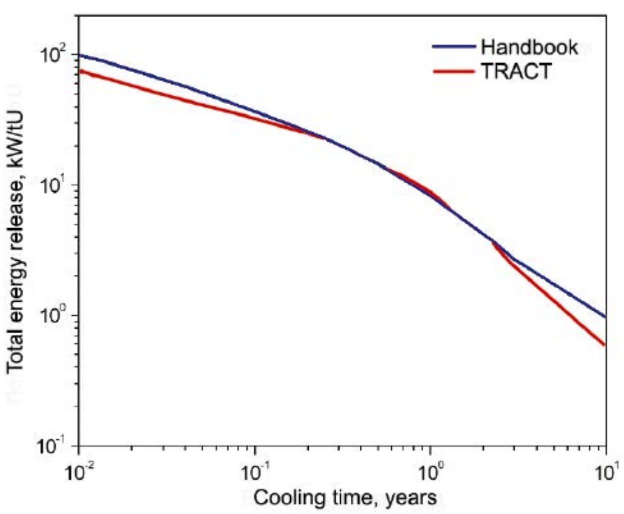

Figure 6. Total energy release from WWER-440 SNF

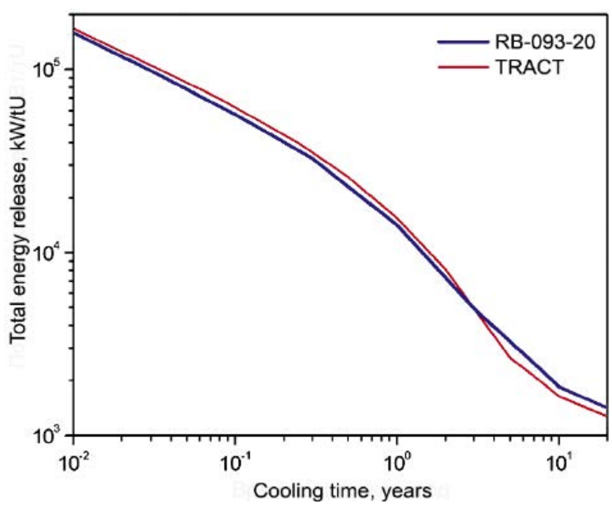

Figure 8. Change in the energy release of WWER-440 SNF with a fuel enrichment of 4.38% in ^{235}U and a burnup of 36 GW·day/tU

Energy release from WWER-440 SNF calculated using the TRACT code was compared against relevant data on the energy release presented in the RB-093-20 Safety Guideline accounting for a burnup of 36 GW·day/tU, exposure time of 1—20 years and average initial enrichments from Table 2. The comparison revealed an error in the energy release levels amounting to up to 10 %. Figure 8 presents an example showing the fluctuations of SNF energy release at 4.38 % fuel enrichment in ^{235}U.

The integral characteristics of WWER-440 SNF evaluated using the TRACT code considering various initial conditions have shown good agreement with the recommended data from the Handbook and RB-093-20.

Radiation characteristics calculated for BN-600 SNF

These full-scale computational studies of BN-600 SNF compositions were prompted by the fact that the data required for the analysis of radiation characteristics was almost completely missing in open publications.

Staged changes in the reactor core configuration are viewed as a particular feature of BN-600 reactor operation. Therefore, to have a comprehensive picture of BN-600 SNF characteristics, all the configurations involved had to be evaluated. Table 3 shows the main design parameters of all types of cores implemented in the BN 600 reactor during 30 years of its operation [13].

SNF compositions were evaluated considering each option of BN-600 reactor design upgrading accounting for the specified fuel burnups. BN-600 SNF compositions were calculated using the TRACT code considering different enrichment zones presented above. Figures 9—16 present specific activity and heat release fluctuations depending on fuel cooling time with the fuel enrichment in ^{235}U varying in different zones.

The data obtained will provide a basis for further calculations evaluating the compositions of RW Class 1 resulted from BN-600 SNF reprocessing.

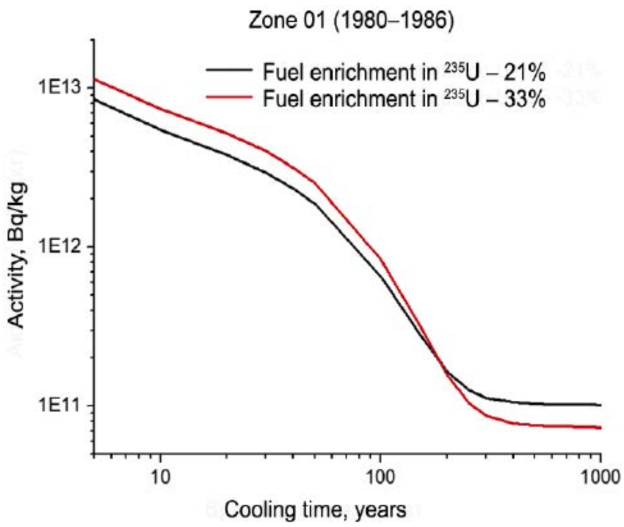

Figure 9. Changes in SNF activity for a fuel with various enrichment in ^{235}U in zone 01 (1980—1986)

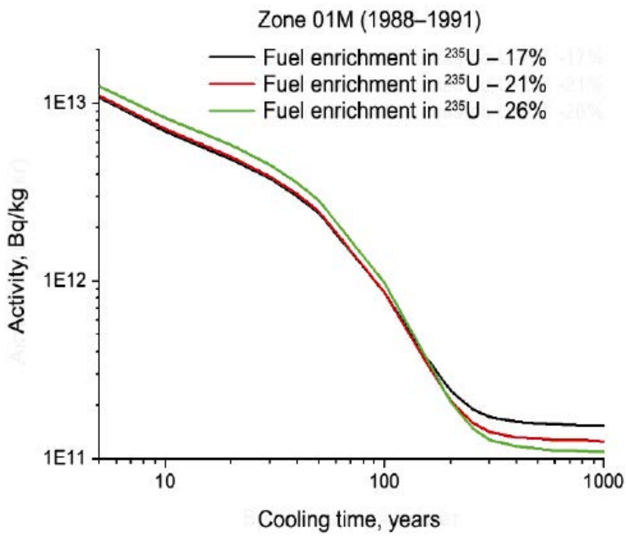

Figure 10. Change in SNF activity for a fuel with various enrichment in ^{235}U in zone 01M (1988—1991)

Table 3. Design characteristics of BN-600 reactor cores

Characteristic	Zone 01 (1980—1986)	Zone 01M (1988—1991)	Zone 01M1 (1993—2004)	Zone 01M2 (2006—till present)
Design-based FA life-time assuming reactor operation at N_{nom} (LEZ/IEZ/HEZ), eff. days	200/—/300	330/330/495	480/480/480	560/560/730
Fuel enrichment in ^{235}U (LEZ/IEZ/HEZ), %	21/—/33	17/21/26	17/21/26	17/21/26
Max. fuel burnup: (LEZ/IEZ/HEZ), % t.a.	5.1/-/7.2	6.5/6.9/8.3	9.0/9.5/10.0	10.1/10.6/11.2

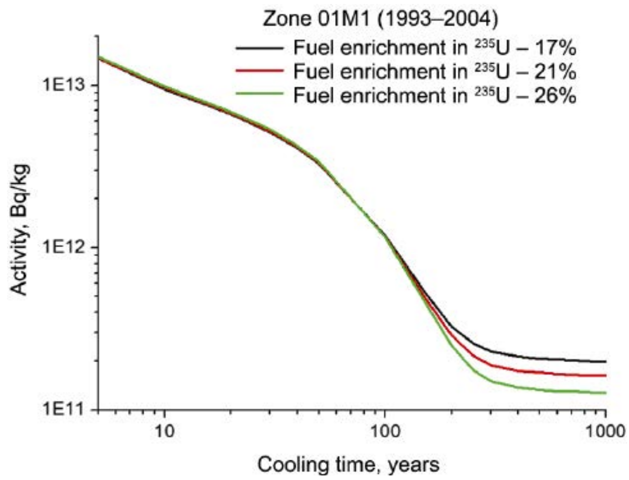

Figure 11. Changes in SNF activity for a fuel with different enrichment in ^{235}U in zone 01M1 (1993–2004)

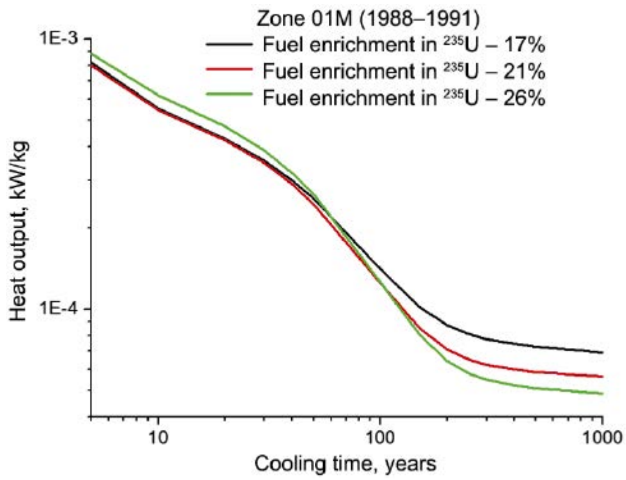

Figure 14. Changes in SNF heat release for a fuel with different enrichment in ^{235}U in zone 01M (1988–1991)

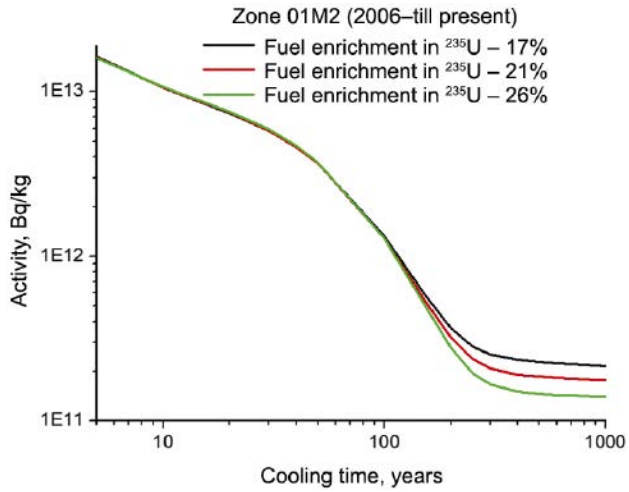

Figure 12. Change in SNF activity for a fuel with different enrichment in ^{235}U in zone 01M2 (2006–till present)

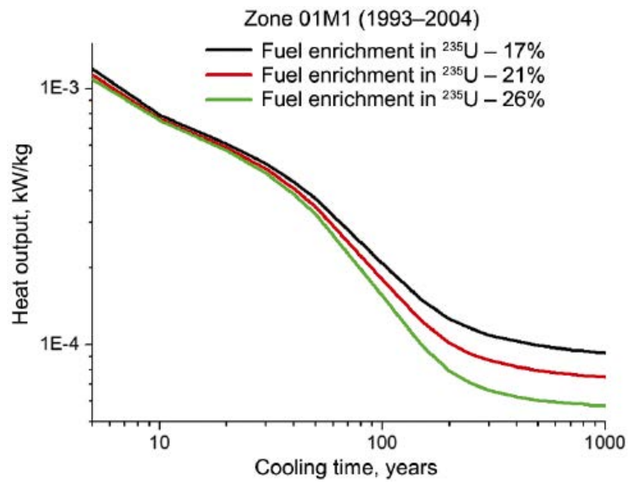

Figure 15. Change in SNF heat release for a fuel with different enrichment in ^{235}U in zone 01M1 (1993–2004)

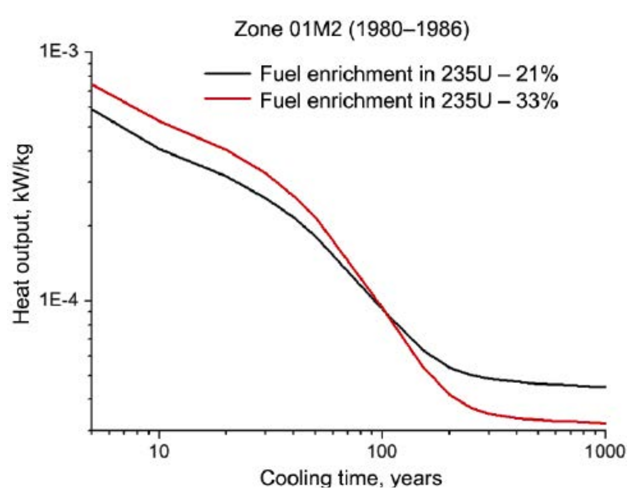

Figure 13. Change in SNF heat release for a fuel with different enrichment in ^{235}U in zone 01 (1980–1986)

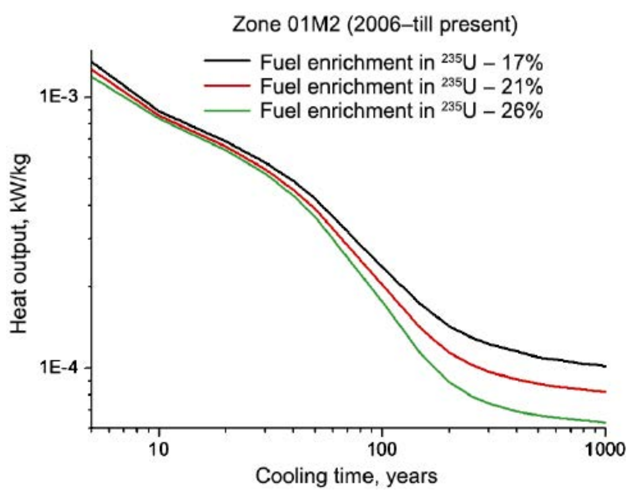

Figure 16. Change in SNF heat release for a fuel with different enrichment in ^{235}U in zone 01M2 (2006–till present)

Capabilities of the TRACT code demonstrated based on the evaluation of RW Class 1 radiation characteristics

As mentioned above, RW Class 1 inventory accumulated at PA Mayak site involves solidified LRW generated during SNF reprocessing. The process of SNF batch formation for reprocessing purposes suggests that different types of fuel are mixed in a certain way. By its volume, most part of fuel reprocessed at the plant accounts for SNF from WWER-440 and BN-600 reactor units. To calculate the radiation characteristics of mixed materials (as in case of SNF reprocessing), particular algorithm was implemented in TRACT code using the results of previous calculations as input data.

An example showing the possible way in which the characteristics of RW Class 1 can be evaluated is presented below:

1) calculation of SNF compositions for various types of reactor units (for example, for WWER-440 and BN-600);

2) summarizing the initial APG composition, which involves several stages, namely: the user specifies the cooling time for each SNF type, i.e. what kind of initial compositions will be used as a basis for the RW composition, sets the weight coefficients for each SNF type (during SNF reprocessing, fuel is mixed in various proportions, and the TRACT-based calculations are performed for a given mass, for example, 1 ton of fuel), sets the coefficients of process operations for each radionuclide (since during the reprocessing, some of the elements are extracted or lost from solutions), the conversion coefficient showing the SNF mass converted into the glass mass (i.e. the amount of glass resulting from the reprocessing of one SNF ton).

3) setting the exposure times for which the radiation characteristics should be calculated.

Let's take a closer look on how the radiation characteristics can be calculated for simulated RW Class 1 from the reprocessing of two SNF types: WWER-440 and BN-600. The initial SNF data were as follows:

- fuel type: uranium dioxide UO_2,
- fuel enrichment in ^{235}U — 4% in the WWER-440 reactor unit and 26% in the BN-600 reactor unit,
- burnup of fuel removed from the WWER-440 reactor — 40 GW·day/tU, SNF pre-reprocessing cooling time accounted for 7 years,
- burnup of fuel removed from the BN-600 reactor — 60 GW·day/tU (480 effective days of irradiation, approximate burnup of 10% ha), SNF pre-reprocessing cooling time accounted for 14 years.

Table 4 shows the isotopic compositions of fresh uranium oxide fuel for WWER-440 and BN-600 reactor units normalized to 1 ton of uranium.

Table 4. Compositions of fresh uranium oxide fuel for WWER-440 and BN-600 reactor units

WWER-440 (UO_2 with 4% enrichment in ^{235}U)		BN-600 (UO_2 with 26% enrichment in ^{235}U)	
Isotope	Number of isotope atoms, 1/tU	Isotope	Number of isotope atoms, 1/tU
^{235}U	1.02468E26	^{235}U	6.660E26
^{238}U	2.42823E27	^{238}U	1.871E27
^{16}O	5.04910E27	^{16}O	5.063E27
^{17}O	1.92323E24	^{17}O	1.928E24
^{18}O	1.01222E25	^{18}O	1.015E25

Figures 17 and 18 present changes in the specific activity and energy release for WWER-440 and BN-600 SNF, respectively, considering cooling times of up to 10^6 years. Figures 19 and 20 show the residual energy release from the SNF and its components accounting for beta, gamma and alpha radiation from the WWER-440 and BN-600 reactors, respectively. It should be noted that up to a cooling time of 150—200 years, it's the beta and gamma radiation that mainly contributes to the energy release. At exposure times of over 200 years, the main source of energy release accounts for the alpha decay of minor actinides.

Table 5 presents the data on the content of some radionuclides considered important in terms of RW disposal safety assessment. Analysis of these data shows that if BN-600 fuel is accounted for in the assessment of APG compositions, it may affect the specific activity of some long-lived radionuclides.

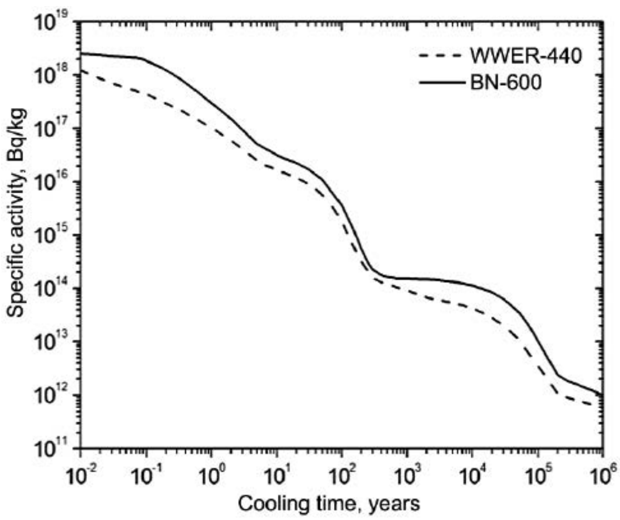

Figure 17. Specific activity of WWER-440 and BN-600 SNF

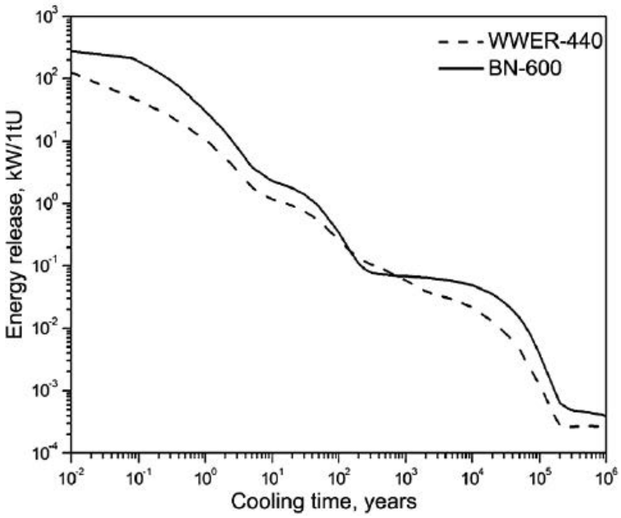

Figure 18. Energy release from WWER-440 and BN-600 SNF

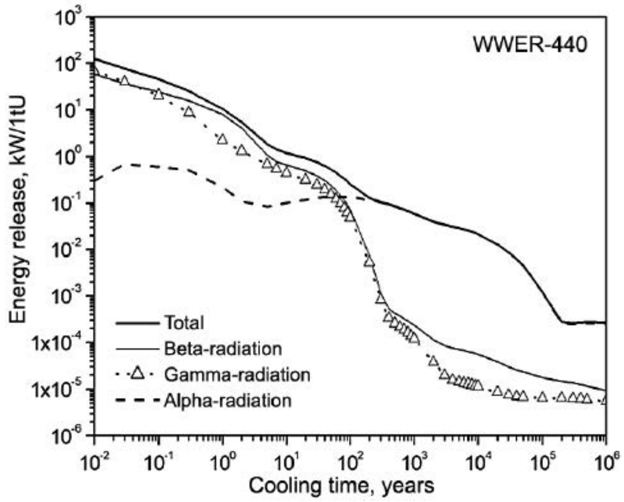

Figure 19. Energy release from WWER-440 SNF and its components associated with beta, gamma and alpha radiation from the WWER-440 reactor

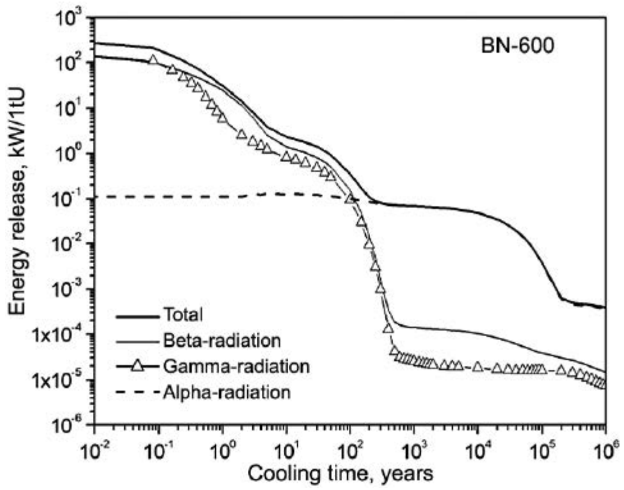

Figure 20. Energy release from SNF and its components associated with beta, gamma and alpha radiation from the BN-600 reactor

Table 5. Specific activity of some important radionuclides from WWER-440 and BN-600 SNF

Radionuclide	Specific activity, Bq/tU	
	WWER-440 (T=7 years)	BN-600 (T=14 years)
^{14}C	5.60E+09	5.24E+10
^{79}Se	8.58E+08	2.38E+09
^{99}Tc	7.50E+11	1.44E+12
^{129}I	1.03E+09	2.29E+09
^{135}Cs	1.85E+10	1.39E+11
^{234}U	3.23E+09	1.94E+10
^{235}U	3.62E+08	1.34E+10
^{237}Np	5.56E+09	2.87E+10
^{238}Pu	1.20E+13	5.75E+13
^{239}Pu	2.14E+13	7.19E+13
^{240}Pu	2.65E+13	1.15E+13
^{241}Pu	1.11E+14	7.60E+13
^{242}Pu	6.08E+10	1.52E+08
^{241}Am	9.83E+13	2.48E+12
^{243}Am	1.14E+11	1.24E+08
^{245}Cm	5.53E+07	7.15E+04

Initial APG compositions were developed assuming the following:

1) mixtures of SNF from WWER-440 and BN-600 reactors were sent for vitrification assuming the following ratios 70 and 30, 80 and 20, 90 and 10 percent, respectively (3 options);

2) 0.01 % U and 0.025 % Pu remains in the APG (from the initial SNF content);

3) according to the reprocessing flowchart, 1 ton of SNF mixture results in ~ 1.68 ton of APG.

The resulting RW options include both stable and radioactive isotopes. Table 6 shows the total amount of stable and radioactive isotopes.

Table 6. The number of stable and radioactive isotopes in RW

RW type	Total number of isotopes	Number of stable isotopes	Number of radioactive isotopes
WWER-440 (RW-1)	391	201	190
BN-600 (RW-2)	397	217	180
0.7*(RW-1) + 0.3*(RW-2)	411	207	204
0.8*(RW-1) + 0.2*(RW-2)	411	207	204
0.9*(RW-1) + 0.1*(RW-2)	411	207	204

For the obtained RW compositions, changes in their isotopic compositions and specific activities were calculated assuming a cooling time ranging from 0 to 10^6 years (Table 7). Relevant data on energy release are given in Table 8 (Figures 21 and 22). Figures 23 and 24 show the calculated yields of photons and neutrons reduced to a unit volume of an APG package — a 200 liter can.

Table 7. Specific activity of RW-1 (WWER-440, 7 years of cooling), RW-2 (BN-600, 14 years of cooling) and their mixtures

Cooling time, years	RW specific activity, Bq/kg				
	RW-1 (WWER-440)	RW-2 (BN-600)	0.7(RW-1) + 0.3(RW-2)	0.8(RW-1) + 0.2(RW-2)	0.9(RW-1) + 0.1(RW-2)
0	9.42E+12	1.40E+13	1.08E+13	1.03E+13	9.88E+12
10	6.11E+12	1.06E+13	7.45E+12	7.00E+12	6.55E+12
50	2.34E+12	4.13E+12	2.87E+12	2.70E+12	2.52E+12
100	7.37E+11	1.32E+12	9.12E+11	8.54E+11	7.95E+11
500	8.79E+09	5.21E+09	7.72E+09	8.07E+09	8.43E+09
1,000	4.24E+09	1.46E+09	3.41E+09	3.69E+09	3.96E+09
10,000	5.90E+08	1.08E+09	7.38E+08	6.89E+08	6.39E+08
100,000	4.25E+08	8.95E+08	5.66E+08	5.19E+08	4.72E+08
1,000,000	1.23E+08	3.35E+08	1.86E+08	1.65E+08	1.44E+08

Table 8. Energy release of RW-1 (WWER-440), RW-2 (BN-600) and their mixtures per 1 kg of vitrified RW

Cooling time, years	Energy release, W/kg				
	RW-1 (WWER-440)	RW-2 (Bn-600)	0.7(RW-1) + 0.3(RW-2)	0.8(RW-1) + 0.2(RW-2)	0.9(RW-1) + 0.1(RW-2)
0	7.16E−01	1.02E+00	8.08E−01	7.77E−01	7.46E−01
10	4.77E−01	7.90E−01	5.71E−01	5.40E−01	5.09E−01
50	1.90E−01	3.07E−01	2.25E−01	2.13E−01	2.02E−01
100	6.79E−02	9.58E−02	7.63E−02	7.35E−02	7.07E−02
500	7.32E−03	5.90E−04	5.30E−03	5.97E−03	6.64E−03
1,000	3.32E−03	2.80E−04	2.41E−03	2.71E−03	3.01E−03
10,000	4.95E−05	4.06E−05	4.68E−05	4.77E−05	4.86E−05
100,000	2.25E−05	5.90E−05	3.35E−05	2.98E−05	2.62E−05
1,000,000	2.63E−05	8.84E−05	4.49E−05	3.87E−05	3.25E−05

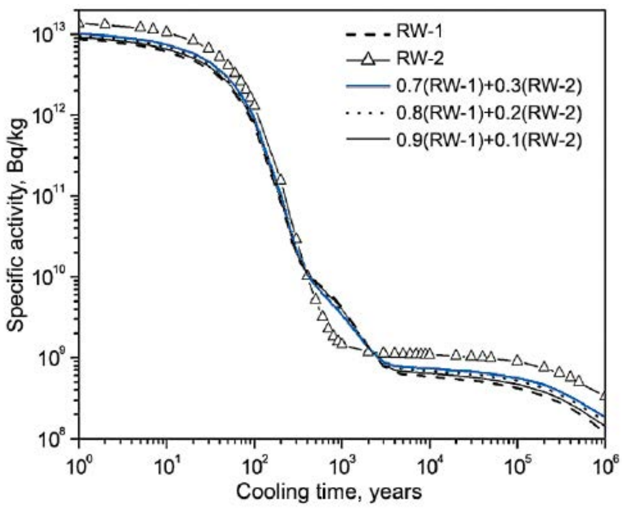

Figure 21. Relationship between the specific activities and the cooling times for different vitrified RW compositions

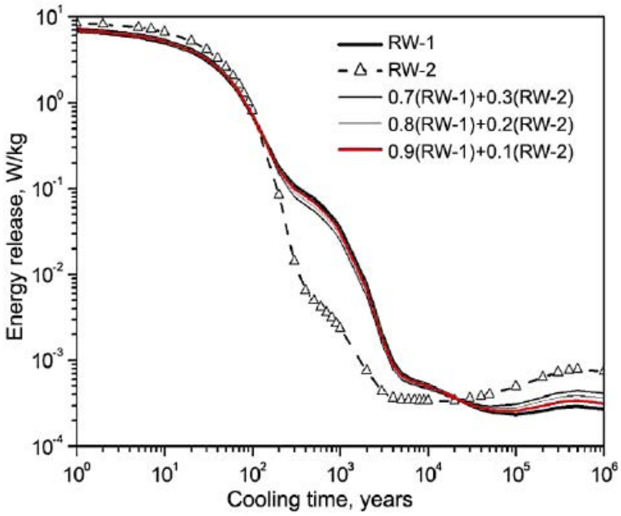

Figure 22. Relationship between the energy release and the cooling times for different vitrified RW compositions

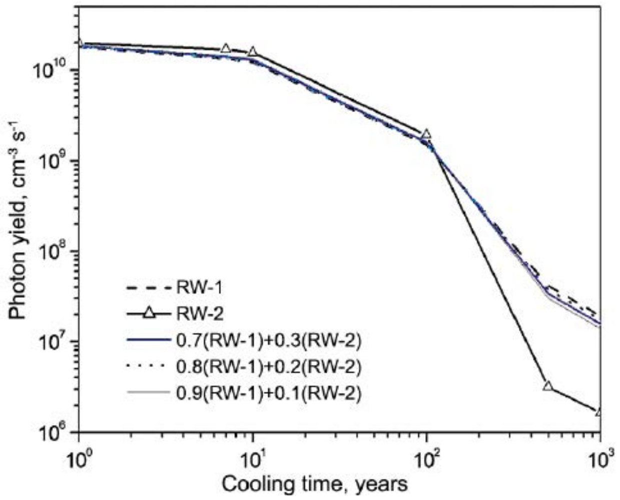

Figure 23. Relationship between the photon yields and the cooling times for different vitrified RW compositions

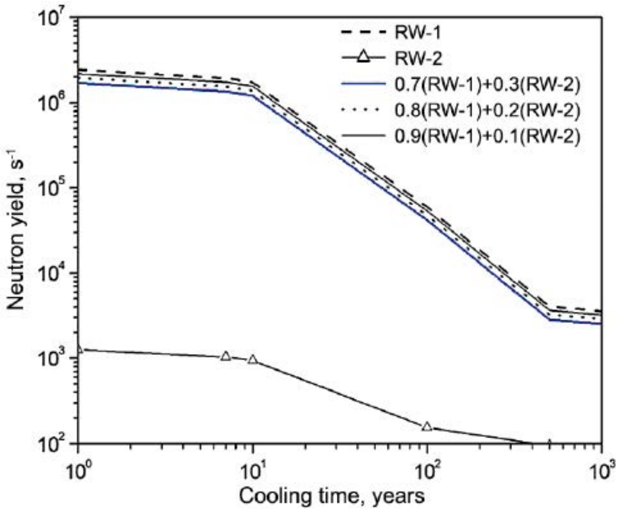

Figure 24. Relationship between the neutron yield and the cooling times for different vitrified RW compositions

Evaluated radiation APG characteristics calculated assuming various SNF reprocessing ratios showed that BN-600 fuel should be accounted for to generate data on specific APG batches. It particularly concerns such characteristics as the specific activity of radionuclides considered important for the assessment of the long-term RW disposal safety, the energy release and the residual amount of U and Pu elements.

Conclusion

In recent years, IBRAE RAS has been developing the TRACT code to assess the radiation characteristics of radioactive waste and spent nuclear fuel. This stage of the software development allowed to demonstrate its design capacities based on a case study of WWER-440 and BN-600 SNF compositions given various initial conditions and burnup levels. Good agreement between the calculated parameters (activity, energy release) and commonly used reference and recommended data was demonstrated.

Fuel compositions were calculated to support further numerical studies of radiation RW characteristics, namely, considering RW Class 1 generated from SNF reprocessing. TRACT code implements a purposely developed algorithm and interface to provide automatic generation of input data for complex RW assessment, such as vitrified RW from SNF reprocessing.

The case study with the calculated RW Class 1 compositions from the reprocessing of various WWER-440 and BN-600 SNF mixtures showed how important it is to consider both components in the assessment of important RW parameters (content of relevant radionuclides, energy release, etc.). Further numerical studies of such RW compositions should be focused on the evaluation of SNF reprocessing records, including passport data on the reprocessed fuel, the amount of glass produced per one tone of reprocessed fuel, etc.

If fully fledged initial data are available, the TRACT code is capable of assessing and predicting the radiation characteristics of RW Class 1. Nevertheless, to confirm the obtained data these should be verified based on the measured RW characteristics, including the results of measurements performed to evaluate the radionuclide composition. At the same time, at the current stage of research, multivariate calculations are recommended to identify possible ranges of integral and differential RW characteristics, as well as to take into account other SNF types, for example, SNF from research reactors.

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Information about the authors

Blokhin Anatoly Ivanovich, Ph.D., Leading researcher, Nuclear Safety Institute of RAS (52, Bolshaya Tulskaya st., Moscow, 115191, Russia), e-mail: bai@ibrae.ac.ru.

Blokhin Pavel Anatolievich, Ph.D., Head of the Laboratory, Nuclear Safety Institute of RAS (52, Bolshaya Tulskaya st.,Moscow, 115191, Russia), e-mail: blokhin@ibrae.ac.ru.

Kazieva Sabina Temergalievna, Junior researcher, Nuclear Safety Institute of RAS (52, Bolshaya Tulskaya st., Moscow, 115191, Russia), e-mail: sipachev@ibrae.ac.ru.

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