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RUSSIAN FLEET OF TRANSPORT PACKAGINGS CERTIFIED FOR SHIPMENT OF FRESH AND IRRADIATED NUCLEAR MATERIALS BY AIR

V.I.Shapovalov, A.I.Morenko, P.N.Kalmykov, A.V.Melnik, L.V.Barabenkova, O.L.Amelicheva
(VNIIEF, Sarov, RF)

ABSTRACT

The paper describes capabilities of RFNC-VNIIEF as one of the leading institution of Rosatom applied to verify and justify safety and security of the TUK packaging intended for fresh and spent nuclear fuel and nuclear materials transportation and storage as well as to expertise the documents justifying TUK safety, and to develop projects of approval certificates for design and transportation of TUK containing nuclear materials in accordance with the IEAE Regulations (TS-R-1).

INTRODUCTION

International air transportation of fresh and spent nuclear fuel from power and research reactors as well as components of nuclear fuel and various fissile nuclear materials has become an urgent problem under present-day conditions.

This is caused by the following factors:

- International air shipments of fissile materials (FM) do not require multilateral approval of the Competent Authorities of those countries where the transportation is carried out. This factor significantly accelerates the procedure of transportation preparation and performance and makes it easier.
- FM transportation is prohibited over the territory of several European countries.
- SNF transportation from some European and Mideast countries can be performed only by air.
- SNF and FM land and sea transportations are rather vulnerable in terms of physical safety and security.

The IAEA Regulations (version TS-R-1 of 1996) have introduced more restrict requirements for the packages with FM transported by air. In 2000 the TS-R-1 Regulations introduced a new type of the packaging –Type C packages. In accordance with the TS-R-1 Regulations such packaging must ensure nuclear and radiation safety and security (remain subcritical) after additional enhanced testing simulating an air crash.

So in the years of 1998-2000 RFNC-VNIIEF developed a computational methodological and test base to provide certification of the packaging containing fissile materials and high-level radioactive materials (type C packages) intended for air transportation in accord to the safety requirements from the IAEA Regulations (TS-R-1) and the Russian Regulations NP-053-04.

RFNC-VNIIEF TEST BASE

A unique test method that has no analogue in Russia and abroad has been developed at RFNC-VNIIEF. The method is used to test the packaging for impacts onto a rigid target at a velocity of no less than 90m/sec. The method simulates intense dynamic loading at the packaging under severe air accidents and disasters. This technique uses a horizontal rocket track available at RFNC-VNIIEF. The packagings are accelerated at the rail track up to the necessary speed using rocket trolleys. The technical capabilities of the track can provide the packaging runaway speed up to 130m/sec and more.

A vertical target was built for the impact testing of the packaging moving horizontally under the certain angle. The vertical target is a complex engineering facility of ~500 tons, which meets the IAEA requirements completely and provides testing of the packaging up to 5 tons-weight (fig.1).

Figure 1 General view of the target used for the packaging impact testing

The rocket train is accelerated using a solid-propellant rocket engine installed at the rocket trolley (figures 2 and 3). The rocket engine starts up and the rocket train starts moving at the rail track. When the rocket engine work is over and the rocket train reaches the specified speed, the solid-propellant gas generators of the rocket trolley break system start working while the packaging continues moving along the rail track due to the obtained impulse (figure 4). After leaving the rail track the packaging continues free-flight moving for ~40 meters till meeting the target (figure 5).

All the processes of the rocket train movement at the rail track, the packaging flight and its impact with the target are recorded using film, photo and video equipment. The packaging velocity at the rail track as well as the impact velocity and the angle of the packaging meeting with the target are measure during the testing.

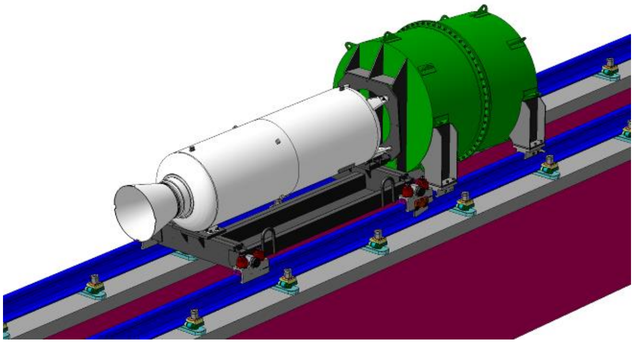


Figure 2 Rocket train overview

Figure 3 Rocket train with the TK-C5B packaging at the RFNC-VNIIEF rail track

Figure 4 The TK-C5 packaging after detaching from the rocket trolley

Figure 5 The TK-C5 packaging after leaving from the rail rocket track

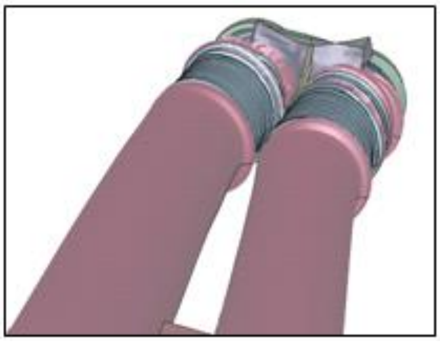
Since 2000 till 2003 a large scope of scientific-methodological, design-theoretical and experimental work was carried out at RFNC-VNIIEF. This work resulted in certification of the basic packaging designed for fresh nuclear fuel transportation by all kind of transport from power and research reactors, namely:

- TUK TK-C55 for fuel assemblies from WWER-440 reactor;
- TUK TK-C5-B for fuel assemblies from WWER-1000 reactor;
- TUK TK-C7M for fuel assemblies from EGP-6 reactor;
- TUK TK-C14, TK-C15, TK-C16 – packagings for fresh nuclear fuel from research reactors.

Testing of all the above types of the packaging for impacts onto a target at velocity of no less than 90m/sec under different angles was carried out at the RFNC-VNIIEF rail track using the test method developed under this project. Fifteen unique tests of the packaging which weight varied from 250 kg till 4 tons were performed: thirteen tests of full-scale packaging and two testing of prototypes in the scale 1:4.

It should be pointed out that before the testing we had carried out a computational analysis to define the packaging state after its impact onto a target under different angles at a velocity of 90m/sec min. This analysis resulted in test revision identifying impact direction that caused maximal damage of the packaging.

High level of design data coincidence with experiments data can be illustrated by Figure 6. This picture presents the deformed states of the TUK TK-C5B packaging intended for fresh nuclear fuel air transportation from WWER-1000 reactor after the packaging impact onto a target at 90m/sec, obtained by computer simulation (left picture) and experimentally (right picture).



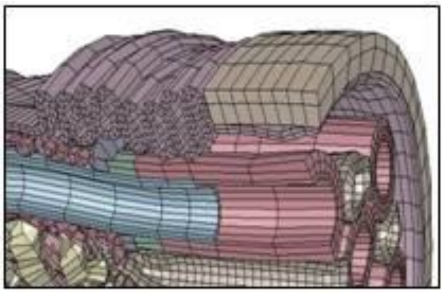


Figure 6. Comparison of computational and test data for TUK TK-C5B.

TUK-145/C FOR SNF TRANSPORTATION FROM RESEARCH REACTORS

In 2012 under the US-Russian collaborative project on nuclear fuel transportation from nuclear power facilities and research centers of different countries the first packaging of C type (TUK-145/C) for air transportation of SNF from research reactors was successfully developed. The packaging TUK-145/C is developed on the base of SKODA VPVR/M container and a protective-damping cover (PDC).

The RFNC-VNIIEF experts performed computations and tests in accordance with the NP-053-04 and TS-R-1 Regulations on safety and security of the packaging under normal and accidental transportation conditions. Computations and tests covered the following aspects:

- Strength and sealing;
- Thermal modes;
- Radiation safety (radiation levels and loss of radioactive content);
- Nuclear safety.

Moreover, special researches were carried out to assess sealing changes of the SKODA VPVR/M container depending on value of joint opening between the secondary lid and the container body. Experimental data proved that the initial sealing level of SKODA VPVR/M container was ensured under the joint opening equivalent to the secondary lid bolts weakening up to 0.5mm.

According to the NP-053-04 and TS-R-1 Regulations the TUK-145/C packaging containing FM as a packaging of Type C should provide safety and security after two series of enhanced testing including impacts onto a target at 90m/sec that simulates air crash. The PDC should provide the reduction of impact loading at the SKODA VPVR/M container up to the level, when the container keeps its integrity and sealing required to ensure requirements on radioactive content loss.

Due to expensive production of TUK-145/C and huge mass-dimension characteristics it was not possible to carry out a full-scale packaging testing at the RFNC-VNIIEF rocket track. Based on the theory of similarity and simulation mentioned in the NP-053-04 and TS-R-1 Regulations the TUK-145/C model in the scale 1:2.5 was chosen for the certification testing. According to the theory of similarity the levels of loading, stresses and deformations implemented at the scaled model during the impact testing reproduce the loading levels of the original in adequate manner.

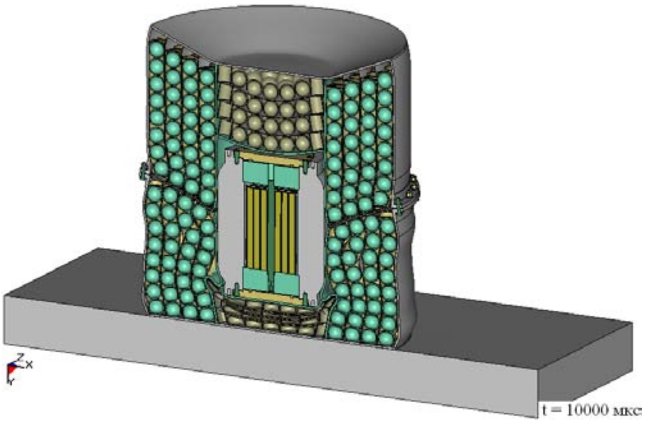
The RFNC-VNIIEF experts have performed preliminary computation analysis of a full-scale packaging and its scaled prototype (1:2.5) state under different angles of impact (axial impact, lateral impact, angular impact 5º, 7º, 10º, 21º, 42°, 45°) onto a rigid target at 95m/sec.

The following criteria were considered to assess the PDC efficiency:

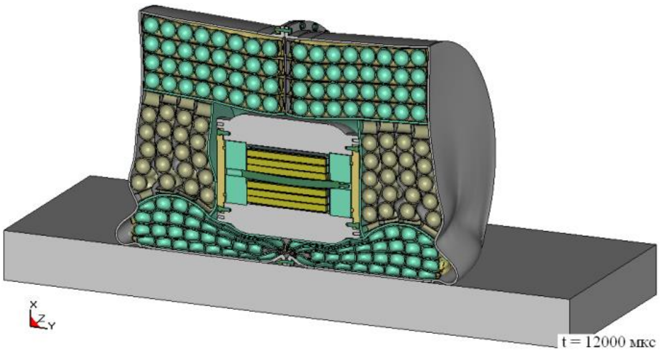
- Absence of closure of the SKODA VPVR/M container with the target under the impact;
- Ensure efficiency of bolt joints of the container secondary lids and body in the elastic range;
- The level of loading applied to the spent fuel assembly must be close to the levels obtained under the cask drop from 9 meters. Spent fuel assembly must not be damaged and fragmented.

Implementation of these criteria ensures nuclear and radiation safety of the packaging during the air crash.

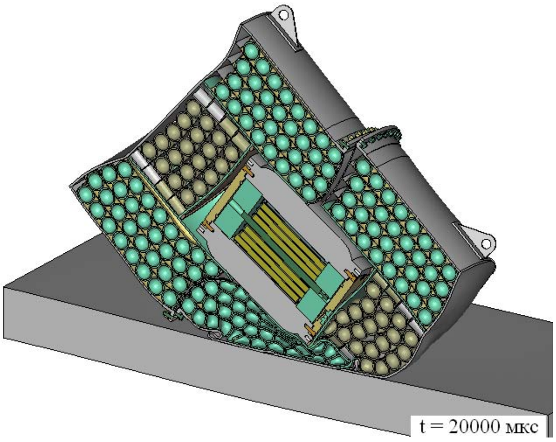
Figure 7 describes the results of TUK-145/C computations at various angles of impact onto a rigid target at 95 m/sec.



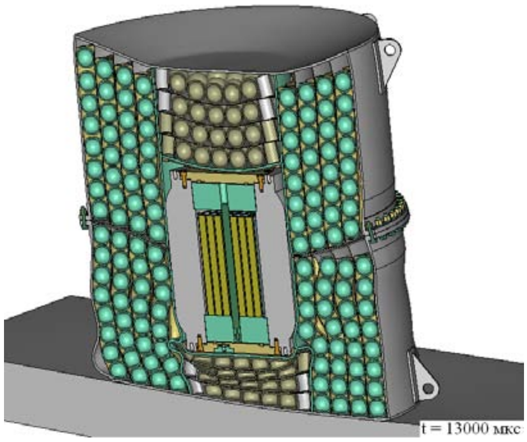
Axial impact onto the target



Lateral impact onto the target



Impact onto the target at an angle of 42º



Impact onto the target at an angle of 7º

Figure 7 The results of TUK-145/C computations at various angles of impact onto a rigid target at 95 m/sec.

The computational results prove that:

- modes of deformation of a full-scale TUK-145/C and its scaled model (1:2.5) during the impact and after impact onto a target are identical that allows using the results of a scaled model testing to assess a full-scale TUK-145/C state with high level of reliability;

- the most dangerous case from the point of critical levels of the construction element parameters (overloading, mode of deformation) is the impact of TUK-145/C onto a target at an angle of 5...10º.

In 2011 the certification testing of TUK-145/C scaled prototype (1:2.5) for impact onto a rigid target at 91.58±0.9 m/sec was carried out at the RFNC-VNIIEF rocket track (Figure 8). The inter-agency commission participated in that testing. The impact angle between the packaging axis and normal to the target surface was 6.76º±0.2º.

Inspection of TUK-145/C prototype after the testing revealed the following:

- The PDC was jammed for 70-100 mm from the impact side;

- some spherical damping elements (spheres) were thrown outside as a result of detaching of the PDC body's upper plate; the rest spheres from the impact side were deformed (the deformation levels are closed to the computational data);

- the PDC provided the reduction of impact loading at the SKODA VPVR/M container during the impact onto a target at ~92 m/sec up to the level, when the container keeps its integrity and sealing.

The TUK-145/C packaging at RFNC-VNIIEF rocket track

Overview of the target and the packaging after the impact

The packaging from the impact side

The packaging after its impact onto the target

SKODA VPVR/M container in protective-damping casing

Overview of SKODA VPVR/M container

Figure 8 TUK-145/C testing at the RFNC-VNIIEF rocket track.

The results of computations and testing proved high coincidence and were used to analyze the TUK-145/C state after the testing for nuclear and radiation safety and security.

In accord to the NP-053-04 and TS-R-1 Regulations the design of TUK-145/C containing spent fuel assemblies from research reactors as a packaging of C type must ensure the level of radiation of 10mSv\h max at a distance of 1 meter from the packaging surface under accidental air transportation conditions. Such accidental conditions are simulated by two series of enhanced accidental testing.

Computations prove that maximum dose rate will be not more than 0.007mSv/h at a distance of 1 meter from the packaging surface after the enhanced accidental testing of TUK-145/C that is much lower than the permissible rate for the packaging of C type.

Computations also prove that TUK-145/C packaging completely meets the requirements of the NP-053-04 and TS-R-1 Regulations for permissible losses of radioactive content.

The assessment of nuclear safety made in conservative statement with total damage of spent fuel assembly of IRT-2M type (with maximal content of uranium-235) and homogeneous mixing of SNF with water within the housing cells ensures nuclear safety of the packaging after its impact onto a target at 95 m/sec, K_{eff} =0.942. A single isolated packaging and a group of packagings under normal and accidental transportation conditions remain subcritical in accordance with the NP-053-04 and TS-R-1 Regulations.

Computational and test results prove that the TUK-145/C packaging meets the IAEA Regulations TS-R-1 and the Russian regulations NP-053-04 on safe transportation of radioactive materials inside the packaging of C type. Based on this fact the State Competent Authority Rosatom issued an approval certificate for the packaging design RUS/3166/CF-96, for transportation of spent fuel assemblies in TUK-145/C from the following types of research reactors: IRT-2M, IRT-3M, IRT-4M, VVR-M, VVR-M2, VVR-M5, VVR-M7, VVR-(C)M, C-36, EK-10, TWR-C (in boxes, maximum 12 units per box).

CONCLUSION

Thus at present day RFNC-VNIIEF is the only institution within Rosatom that has successfully implemented a certified computational-methodological and test base to certify packaging containing fissile materials for air transportation (packaging of C type) in accordance with the IAEA Regulations TS-R-1 and the Russian regulations NP-053-04. This base has no analogues over the world.