Experiences in certification of packages for transportation of fresh nuclear fuel in the context of new safety requirements established by IAEA Regulations (IAEA-96 Regulations, ST-1) for air transportation of nuclear materials (requirements to C-type packages)

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Every year in Russia, a large amount of domestic and international transportation of fresh nuclear fuel (FNF) used in Russian and foreign energy and research atomic reactors and referred to fissile materials based on IAEA Regulations is performed. Here, bulk transportation is performed by air, and it concerns international transportation in particular.

According to national "Main Regulations for Safe Transport and physical Protection of Nuclear Materials (OPBZ-83)" and "Regulations for the Safe Transport of Radioactive Materials" of the International Atomic Energy Agency (IAEA Regulations), nuclear and radiation security under normal (accident free) and accident conditions of transport must be completely provided by the package design. In this context, high requirements to fissile packages exposed to heat and mechanical loads in transport accidents are imposed.

With this in mind, existing packages used to transport fissile materials (FM) are sophisticated designs that comprise systems and elements of protection, localization, containment, and shock absorption, designed to prevent nuclear and radiation danger while conveying packages in the main hypothetically probable accidents of vehicles. It is no mere chance, that according to Russian and International Classification fissile packages are categorized as nuclear structures.

A long-standing experience in accident free transportation of FM has shown that such approach to provide nuclear and radiation security pays for itself completely.

Nevertheless, once in 10 years the International Atomic Energy Agency on every revision of the "Regulations for the Safe Transport of Radioactive Materials" places more stringent requirements upon the FM and transportation thereof, resulting from the objectively increasing risk associated with constant rise in volume and density of transportation, and also strained social and economical situation in a number of regions in the world.

In the new edition of the IAEA Regulations (ST-1), published in 1996 and brought into force in 2001 (IAEA-96 Regulations), the requirements to FM packages conveyed by aircraft were radically changed. These requirements are completely presented in new Russian "Regulations for the Safe Transport of Radioactive Materials" (PBTRM-2004) which will be brought into force in the time ahead.

In accordance with new regulations, FM packages conveyed by air transport must ensure safety after additional strengthening tests simulating the accident of an aircraft, and including two series of transportation accidents as follows:

First series (complex tests):

- the test unit is free falling on a rigid barrier from a height of 9 m;
- test on dynamic damage when a 500 kg body is falling on the package from a height of 9 m;
- test on puncture/ rupture when a 250 kg package is falling on a pin (or pin on the package) from a height of 3 m;
- exposure of the package to an external heat field with an average temperature of 800°C for about 60 minutes.

The package condition in this series must be assessed based on observed damages in the specified order of accident effects.

Second series:

- The shock impact of the package on a target (hard undeformable barrier) with the velocity of not less than 90m/s at an angle to the target, ending in maximum damage of the package.

The existing now in Russia arsenal of standard packages to transport nuclear fuel (NF) for energy and research reactors was designed in compliance with the requirements imposed by the IAEA-85/90 Regulations on transportation of FM by aircraft following which one did not need to inspect the packages by performing additional severe tests simulating the aircraft accident.

Thus, subsequent to the issue of new IAEA-96 Regulations in 1996 the Minatom (the Ministry of Atomic Energy) and its institutions that produce and supply nuclear fuel enjoyed dilemma: to give up completely the aircraft transportation of NF both at home and abroad, or without any greater delay to turn to the development and certification of national arsenal of packages meeting the new IAEA-96 Requirements so as to the moment of brining them into force (from January 2001, as specified by the IAEA) this work is to be accomplished.

Results of examination have shown that the abandonment of the aircraft transportation of NF will result in significant complication, rise in prices, and reduction of security in NF transportation, and international in particular, and in a number of events will lead to terminate the contracts, severance of stable ties.

In this connection, since 1997 a group of institutions and enterprises of the Minatom including DBEES, JSC "TVEL", RFNC-VNIIEF, GSC FEI of RF, JSC "MSZ", JSC "NPCC", launched the activities on the development of Russian arsenal of NF packages, meeting the new IAEA-96 Requirements for transportation of fissile materials by aircraft.

Two lines of attack on this problem were considered and assessed.

1. Development, fabrication, test and certification of the new arsenal of packages designed to transport by aircraft. Results of examination have shown that the development and manufacture of five new types of the packages being the basis for the NF packages arsenal of the energy and research reactors will require unjustified high funds, to find which in the shortest possible time was a problem. Even if the funds were found the development and commission of all these five types of the packages in the shortest possible time prior to bring the IAEA-96 Regulations into force would be considered unreal.

2.As an alternative to the first line, one proposed the following:

- to perform computational and theoretical studies of the safety assurance factor, nuclear and radiation security specified for standard package designs in the basic chain of the arsenal with up-to-date precision computation program complex (codes) being available in RFNC-VNIIEF, and on this basis to define the minimal scope of the refinement of the current standard patterns to improve their resistance to comply with the new requirements that do not call for variation in the traditional production and transport routine of handling the packages in every stage of their service life;
- thereafter one is to perform tests on refined and strengthened package patterns, and in the event of positive results – to certify the modified versions of packages of the five types.

The line as such is considered to be less expensive and shorter from the point of view of realization, however, there was a risk that it could not result in the development of the new arsenal of packages conforming to the IAEA-96 Requirements, besides the moment would be passed and great sums would be spent.

To reduce this risk decision was made on performing the entire cycle of the activities initially at one TK-C4 installation for fuel assemlies of WWER-440 reactor, and on modifying other types of packages when positive results are obtained

To solve the problem, the Minatom has faced, of the development of national arsenal of NF packages conforming up-to-date security requirements placed by the IAEA on aircraft transport of FM in the shortest possible time, a large complex of scientific and methodic, computational and theoretical, design, technological and experimental works have been performed, the main of which are given below:

1. In RFNC-VNIIEF based on up-to-date program complexes, the precision computation methods (codes) to investigate the response of all types of NF packages to high-intensive thermal and physical loads that simulate an aircraft accident, and to define their limiting conditions have been developed. Algorithms for the assessment of nuclear and radiation safety of NF packages in aircraft accident have been developed.

2. A unique method for testing NF packages in wide range of mass and overall dimension on the shock impact on an undeformable target (barrier) with the velocity of not less than 90m/s has been developed and certified by the RF GAN (State Atomic Supervision). The method is based on the employment of a horizontal rocket track, available in RFNC-VNIIEF, by rail guides of which the packages are accelerated to a specified velocity with the help of rocket sleds (Figures 1, 2).

Fig.1. RFNC-VNIIEF horizontal rocket track used to test on shock impact of packages on a target with the velocity of not less than 90m/s

Fig.2. Rocket train containing ТК-С5 package on rail guides of the horizontal rocket track

To realize this method, vertical target (barrier) was designed for the package that flies horizontally at a specified angle to impinge on. The vertical barrier is a complex structure weighing about 600 tons, which is full accord with the IAEA requirements, and ensures testing packages weighing about 6 tons. Figures 3-5 are general view of the target, and some stages of its construction.

Fig.3. General view of the target designed to conduct impact tests on packages

Fig.4. Stages to construct a target to conduct package impact tests, front part installation

Fig.5. Stages to construct a target to conduct package impact tests, additional clamps of steel pipes

Moreover, to measure parameters of the impacts of the package on the target, a number of unique metrologically certified techniques for measurement have been devised.

The method for testing having been developed in the context of said work to simulate the aircraft accident has analogy neither in Russia nor abroad.

3. A large complex of computational and theoretical studies of the strength and nuclear and radiation security of all the five existing standard packages with the use of the devised and certified methods has been performed. As a result, three of the five types of packages, namely, NF package (and its TK-C16 version) of the TK-C14 research reactor, TK-C15 and TK-C7 for FA EGP-6 reactors have safety assurance sufficient to withstand tests on simulating aircraft accident without refinement.

For two types of the packages, namely TK-C4 for FA of the WWER-440 reactor and TK-C5 for FA of the WWER-1000 reactor, it was shown that the safety assurance is not sufficient to stand up the aircraft accident. The most favourable design that enable to refine the existing arsenal of the given packages at minimal costs and keeping constant the traditional production and transport routes of handling the packages in every stage of their service life;

Individual stages of numerical investigations employed in computational and theoretical and experimental justification of the security have been shown in the example of the TK-C7 for FA of the EGP-6 reactor (Figures 6-8).

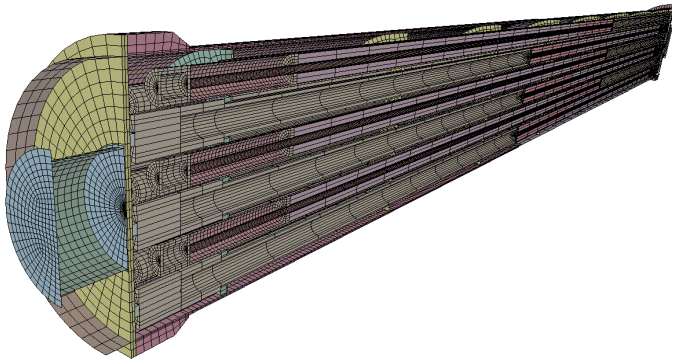


Fig.6. Formation of a computer-aided model of the TK-C7 package for numerical simulation of the impact process

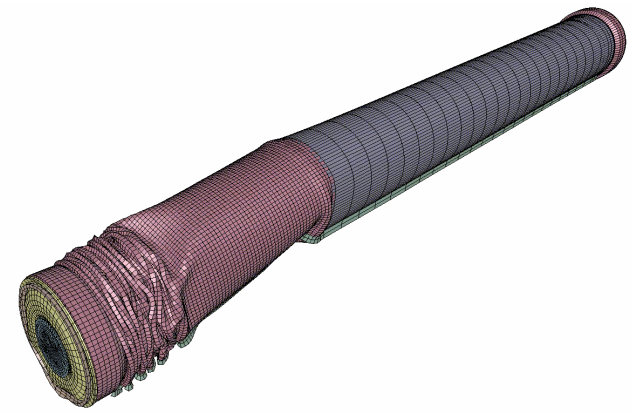


Fig.7. Designed deformation of the TK-C7 package, obtained via computer-aided model

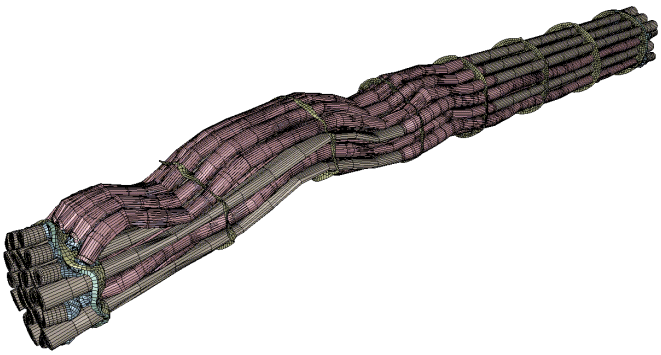


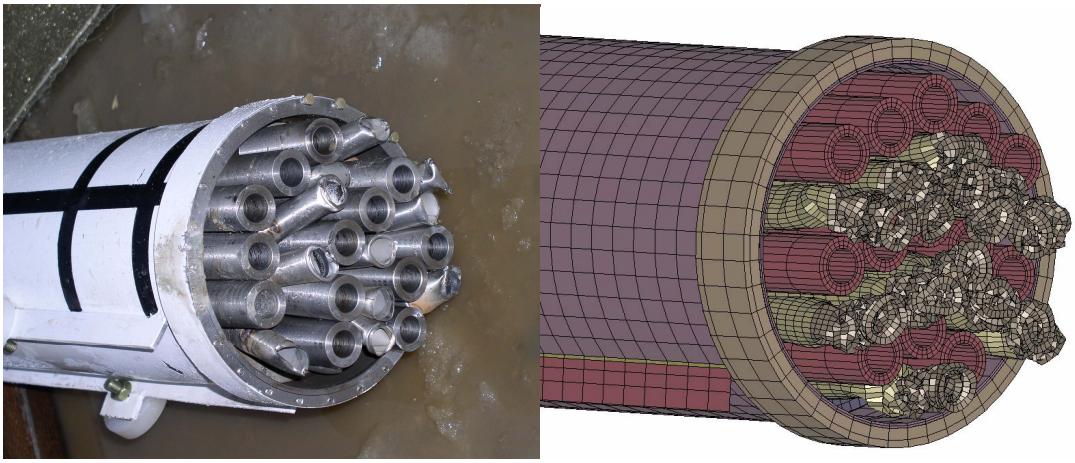
Fig.8. Designed deformation of the FA EGP-6, obtained via computer-aided model

4. Experimental prototypes for five types of packages with dynamic FM-free FA models designed to conduct tests have been developed, justified, and fabricated.

5. Tests on the impact of all types of packages on the target with the velocity of 90m/s at various angles to the target were conducted at the RFNC-VNIIEF rocket track with the use of the test method developed in the context of this work. On the whole eight tests of full-scale packages and two tests of one-fourth scale prototypes were conducted.

Comparative analysis of the test results, and computational and theoretical studies have shown a good agreement both the general presentation of package damage in accidents, and precise disclosure of poor structure elements, testifying the high precision of the computational methods used (Figures 9, 12).

Fig.9. Comparison between the experiment and simulation of the impact of the ТК-С7 package on the target with the velocity of 90 m/s



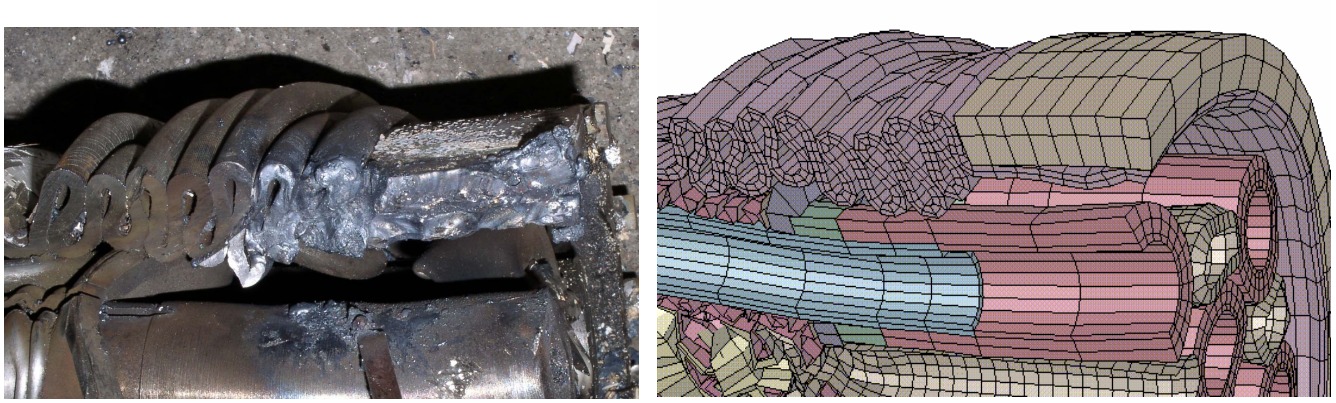


Fig.10. Comparison between the experiment and simulation of the impact of the TK-C7 package on the target with the velocity of 90 m/s

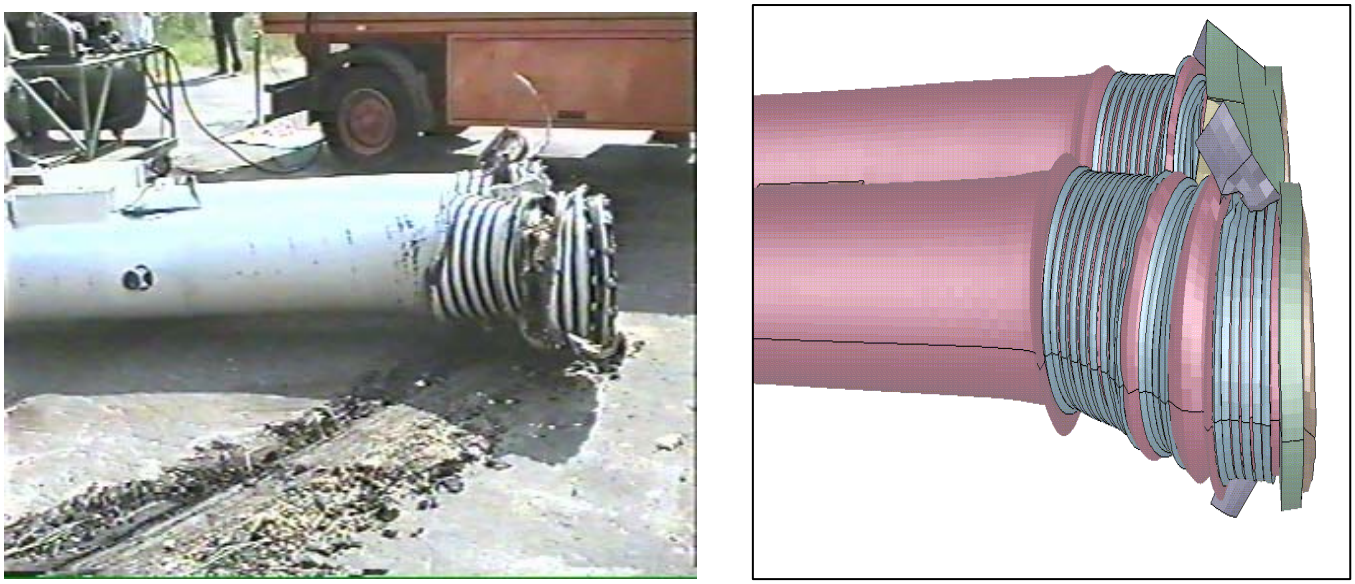


Fig.11. Comparison between the experiment and simulation of the impact of the TK-C5 package on the target with the velocity of 90 m/s

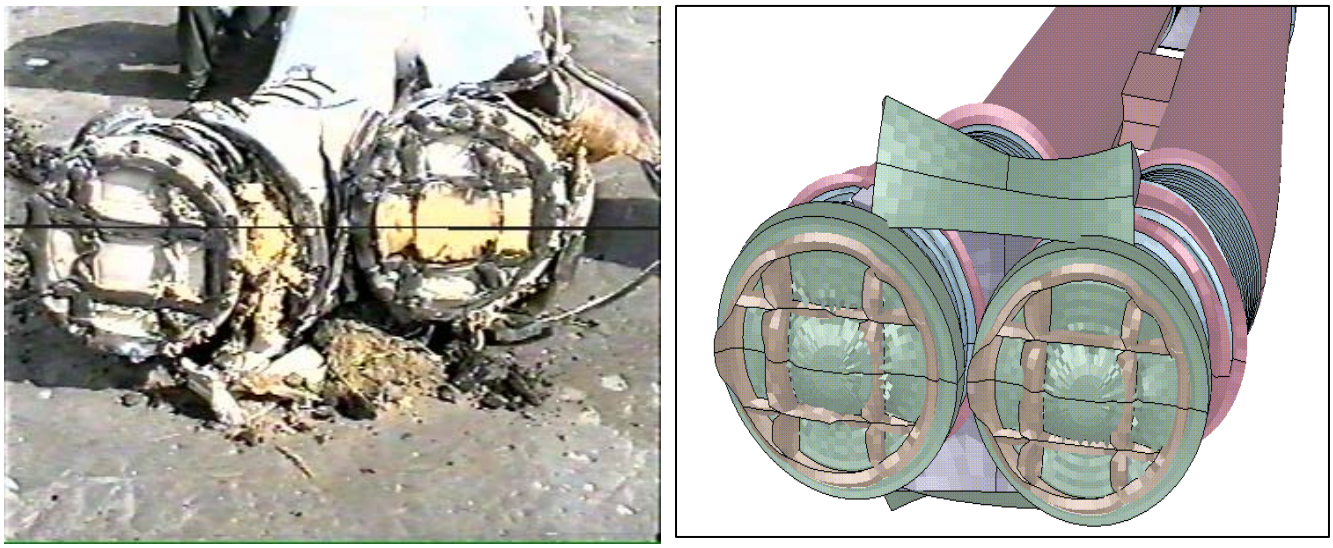


Fig.12. Comparison between the experiment and simulation of the impact of the TK-C5 package on the target with the velocity of 90 m/s

6. Relying on the test results and computational investigations, the modified arsenal of packages designed to transport FNF was certified with the conformity to the IAEA-96 Regulations. Certificate-permissions on the design and transportation by all types of transport, including air transportation, have been given each package type by the State competent body.

The methodology developed is also suitable for certifying air transportation of packages containing radioactive materials of higher total activity (C-type packages according to the IAEA-96 Regulations). In 2001, the C-type UKTIIV-RITEG package designed to transfer a Plutonium-238 radionuclide source-containing generator was certified by the given methodology.

It should be pointed out that the said methodology has been approved by the RF GAN (State Atomic Supervision of Russian Federation), and represented by the new Russian PBTRM-2004 Regulations; it has also been indicated to be employed in Europe countries carrying out FM transport by aircraft.

As a result of the complex of activities performed in Russia by the Minatom institutions and enterprises in the shortest possible time, the arsenal of national FNF packages for power generating and research reactors completely certified with the conformity to the IAEA-96 Requirements and the “Technical Regulations for Safe Transport of hazardous cargo by air” developed by the International Civil Aviation Organization (ICAO) has been brought into being. The RF Minatom’s certificate-permissions have been recognized by Competent bodies of all foreign countries, where Russia conducts FNF transport to, and a number of international air transportation has been conducted.