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DEVELOPMENT OF A NEW UNIFIED TRANSPORT PACKAGING FOR SHIPMENT OF PWR REACTOR FRESH FUEL ASSEMBLIES

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ABSTRACT

The paper describes a transport packaging (TUK TK-C69) designed for transportation of fresh fuel assemblies from PWR reactor (fuel assemblies QUADRAT) that meets the international and Russian requirements on safe transportation.

The State Corporation (SC) for atomic energy "Rosatom" issued certificates-approvals for TUK TK-C69 design as well as for the packaging transportation by all means of transport except air transportation.

A pilot batch of TUK TK-C69 has been produced and serial production of the packaging has been prepared. At present the experts from Sweden and Finland in collaboration with PC TVEL are preparing a set of documents required for certification of TK-C69 packaging in these counties.

INTRODUCTION

Currently the Russian specialists are developing a basic series of fuel assemblies QUADRAT, intended to be used in PWR reactors of some foreign nuclear power plants. This project is based on vast experience gained at the Rosatom Corporation in the field of nuclear-power engineering, up-to-date atomic material technologies and state-of-the-art nuclear technologies. Fuel assemblies QUADRAT developed and fabricated at the Rosatom enterprises are to be used at some foreign nuclear power plants with PWR reactors. A transport packaging TUK TK-C69 has been developed to deliver fuel assemblies QUADRAT to these nuclear plants. TUK TK-C69 is designed for transportation and temporary storage of all types of fuel assemblies QUADRAT basic series, different in length and wrench width.

The project on TUK TK-C69 development was initiated by "TVEL" public corporation in cooperation with public corporation "NZKhK", closed corporation "Center for Analysis and Expertise of Multipurpose Safe Constructions" and the Russian Federal Nuclear Center -VNIIEF. Specialists from NZKhK have developed design documentation for the TUK and its production technology. A pilot batch of TUK TK-C69 has been produced and a manufacturing area for serial production of the packaging has been prepared. The concept of TUK 0 has been developed at the Center for analysis and expertise of multipurpose safe constructions "CAE MBK" and computational basis for all safety aspects of the packaging has been prepared in accord to IAEA Regulations and the Russian requirements for radioactive materials safe transportation. The safety design analysis was carried out using the licensed software packages LS-DYNA and ANSYS.

A certificate testing of full-scale models of the packaging was performed to ensure compliance with the international and Russian safety regulations. The experts from RFNC-VNIIEF carried out an expertise of materials providing the TUK safety and prepared projects of certificates-approvals for the design and transportation of TUK TK-C69 containing fuel assemblies QUADRAT. The State Corporation Rosatom issued certificates-approvals RUS/3171/IF-96 and RUS/3171/IF-96T for the packaging design and transportation respectively.

At present the experts from Sweden and Finland in cooperation with the "TVEL" corporation are preparing a packaging of documents required for the packaging TK-C69 design certification in these countries in order to deliver fuel assemblies QUADRAT to foreign nuclear power plants with PWR reactors, in particular in Sweden and in Finland.

THE PACKAGING DESIGN DESCRIPTION

The developed TUK TK-C69 is designed for transportation and temporary storage of two fresh fuel assemblies (FA) QUADRAT with the following parameters:

- FA-QUADRAT wrench width, mm 200….217;
- FA-QUADRAT length max, mm 4300;
- FA-QUADRAT max weight, kg 800;
- mass fraction of ^{235}U for fuel element pellets, % max. 5.0;

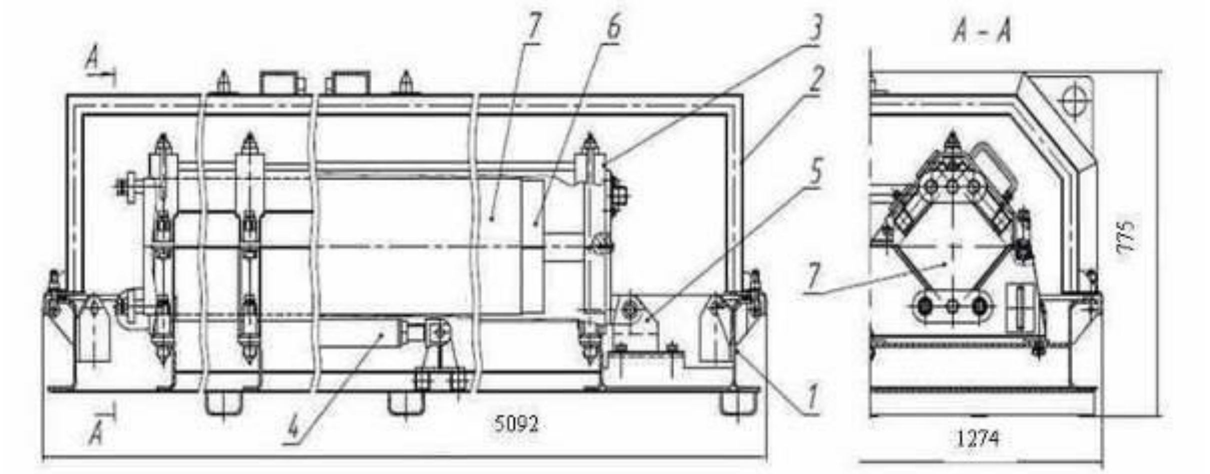
The packaging TUK TK-C69 consists of a shielding body made in the form of a rectangular parallelepiped with chamfered upper corners. Inside the body there is a platform with cradles for two fresh fuel assemblies QUADRAT (Figure1, 2).

The TUK structural components are made from chromium-nickel steel of austenitic class that provides high elasticity and enhanced impact strength at negative temperature as well.

TUK TK-C69 specifications:

- Length, mm 5092;
- Width, mm 1274;
- Height, mm 775;
- TUK estimated weight, kg 2500;
- Estimated weight of the packaging (containing two fuel assemblies), kg 4100.

Weight and dimensions of TUK TK-C69 allow performing the necessary operations with the packaging containing a platform with fuel assemblies QUADRAT in the appropriate rooms of the QUADRAT fuel assemblies manufacturing plant and at the foreign nuclear power plants as well as transporting TUK TK C-69 by railway, trucks or by water transport.



1 - Base; 2 - Lid; 3 - Platform; 4 – Rack; 5 - Support; 6 - Adapter;
7 – Fuel assembly QUADRAT

Figure 1 – TUK TK-C69 layout drawing

Figure 2. – TUK TK-C69 overview (the lid is raised)

The TUK TK-C69 shielding body consists of a base and a lid. The base and the lid are connected by link bolts with nuts. The side and end walls of the base are channels. The base bottom is a two-layer welded structure made of steel sheets connected by ribs from square-section tubes.

Four lifting eyes are located at the base to perform load-lifting operations. Two of the lifting eyes are used to install the base with the platform vertically while loading or unloading QUADRAT fuel assemblies.

The TUK lid is a two-layer welded structure from sheets and a load-bearing set (ribs). The lid flange is made in the form of an L-bar to ensure protection of the inside volume from atmospheric precipitation.

Four lifting eyes are made at the lid to carry out load-lifting operations with TUK and to remove/install the lid from/at the base.

A rubber seal is installed at the joint between the base and the lid to protect TUK internal volume from moisture under standard and normal conditions.

The TUK lid is equipped with special locks and the base surface is equipped with openings for the locks to provide safe stacking of TUKs.

A platform with cradles covered by lids is used to install two fuel assemblies QUADRAT inside the TUK TK-C69 shielding body. Fuel assemblies QUADRAT are placed inside the cradles. (Figure 3 and 4).

Figure 3. TUK TK-C69 containment system including a platform with cradles covered by lids

Figure 4. TUK TK-C69 containment system including a platform with cradles. One lid of the cradle is opened and a QUADRAT fuel assembly is visible.

The developed platform is a frame structure that ensures integrity and keeps the QUADRAT fuel assembly inside it under the drops simulating normal and accidental transportation conditions.

The platform is pivotally connected to the base from the side of the QUADRAT fuel assembly tail and there are two lifting eyes from the head of the QUADRAT to put the platform in vertical position.

The platform in horizontal position is connected to the cross bars of the base load-bearing ribs using captive bolts.

The platform in vertical position bears upon the TUK basement by special area from the side of the hinged joint with the base. The platform is held fixed by two racks.

Fuel assemblies QUADRAT of different "wrench" width are fixed at the platform by changing the height of the cradle lid position using adjusting bolts. Due to the adjusting bolts at the cradle lids there is no need in readjusting or changing the elements of axial contraction when the wrench width is changed.

QUADRAT fuel assemblies of different length are fixed at the platform using changeable adapters.

SAFETY JUSTIFICATION FOR TUK TK-C69

Safety justification of the TUK TK-C69 design and transportation containing two fresh fuel assemblies QUADRAT (hereinafter the packaging) was performed in accordance with the requirements of the international and Russian regulations on safe transportation of radioactive materials as well as special agreements concerning the international carriage of dangerous goods by different means of transport (ADR, IMDG code, ADN).

A comprehensive design analysis on all safety aspects as well as the testing of the packaging full-scale models was used to prove the packaging compliance to the above mentioned requirements.

The results of the design analysis based on the licensed software packages prove the following.

1. <u>The packaging strength</u>

The following computations were performed in order to assess the strength of the TK-C69 packaging in usual, normal and accidental transportation conditions:

- static calculation of TUK load-lifting and tie-down components strength;
- static calculation of TUK load-bearing elements strength under the packaging stacking;
- calculation of the packaging vibration strength;
- dynamic calculations of the packaging strength under drops simulating normal and accidental conditions of transportation.

Based on the computation results we made a conclusion concerning TUK TK-C69 strength. The QUADRAT fuel assembly stays within the packaging containment system under normal and accidental transportation conditions.

2. The packaging thermal state

The results of thermal analysis prove that maximal temperature at the packaging surface under normal transportation conditions is within the range specified in the regulations. Maximum temperature at the QUADRAT fuel assembly under accidental transportation condition is much less than the melting temperature of the fuel element shell material.

3. Nuclear safety

Calculations of the packaging subcriticality were carried out using the software based on the Monte Carlo method. The worst state of the packaging under normal and accidental conditions in terms of neutron multiplication was considered. The packaging state was obtained based on the results of the design analysis as well as on the data of certification testing of the packaging full-scale models. The performed analysis proved compliance with requirements on nuclear safety under normal and accidental transportation conditions. Maximum design value K_{eff} for a single packaging is less than $K_{eff} < 0.3$ under normal conditions, and less than $K_{eff} < 0.95$ under accidental conditions. Criticality safety index CSI = 2.1.

4. Radiation safety

The design maximum level of radiation at the packaging surface is less than $1.31 \cdot 10^{-3}$ mSv/h, that is by several orders of magnitude lower than the allowable value of 2mSv/h. Such a small value of radiation at the packaging surface ensures compliance with all the rest requirements on radiation safety including requirements for a transport vehicle.

CERTIFICATION TESTING OF THE PACKAGING TK-C69

Testing of the TUK TK-C69 full-scale models aimed at validation of the design solutions of the packaging construction, specifying the packaging strength resource and the packaging state under accidental mechanical impacts was performed in accordance with the international and Russian safety requirements. The testing was performed at the certified test base in RFNC-VNIIEF. The prototypes under the testing were corresponded to regular TUK TK-C69. Dynamic mockups of fuel assemblies QUADRAT were corresponded to regular fuel assemblies QUADRAT in design, fuel pellets from uranium dioxide were changed for lead pellets.

Tests on mechanical damage (impacts) were carries out using two specimens of the packaging. Based on computational analysis of the packaging strength under accidental mechanical impacts the following two test procedures were chosen that resulted in maximum damage. Two specimens of the packaging were subjected to the tests.

1. Figure 5 shows the test procedure of the packaging first specimen including the following stages:

- the packaging drop from 1.2m onto the target.
- axial drop of the packaging lid from 9m onto the target from the side of fuel assembly head. The angle between the TUK lid plane and a normal to the target was $\theta \approx 8.6°$. The angle θ was specified so that the normal to the target passes through the contact point and the packaging mass center.

The packaging state after the first test series is shown in pictures 6-8.

2. Tests of the second specimen of the packaging are shown in picture 9 and they included the following:

- the package drop from a height of 9 m by the lid onto the target.
- the packaging drop from a height of 1 m by the lid onto a bar; impact direction is close to the packaging mass center.

The state of the specimen after the second test series is shown in figures 10-13.

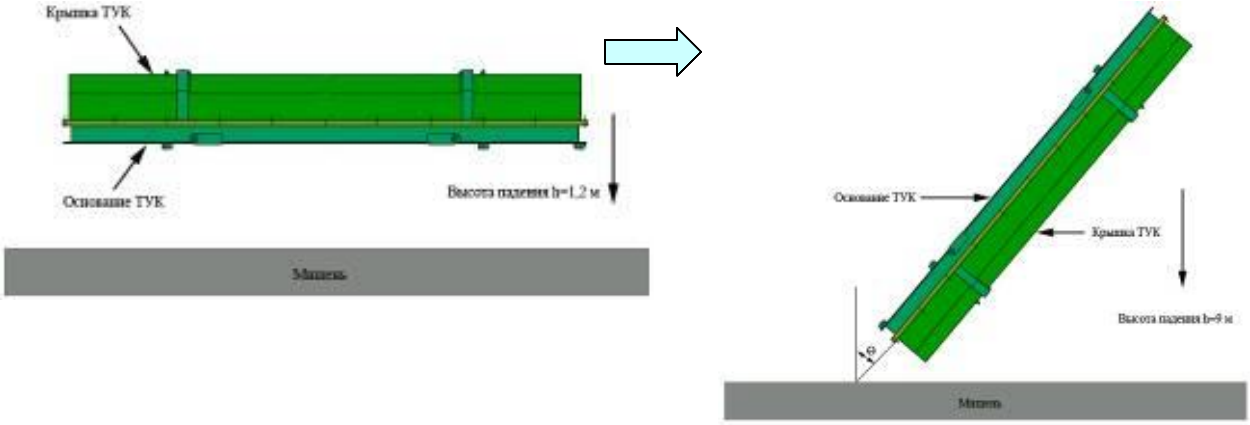


Figure 5 – Test procedure for the first specimen of the packaging

Figure 6 – The specimen state after its drop from a height of 1.2m onto the target

Figure 7 – The specimen state after its angular drop from a height of 9m onto the target from the side of the lid

Figure 8 – The QUADRAT dynamic mockup state after the first test series

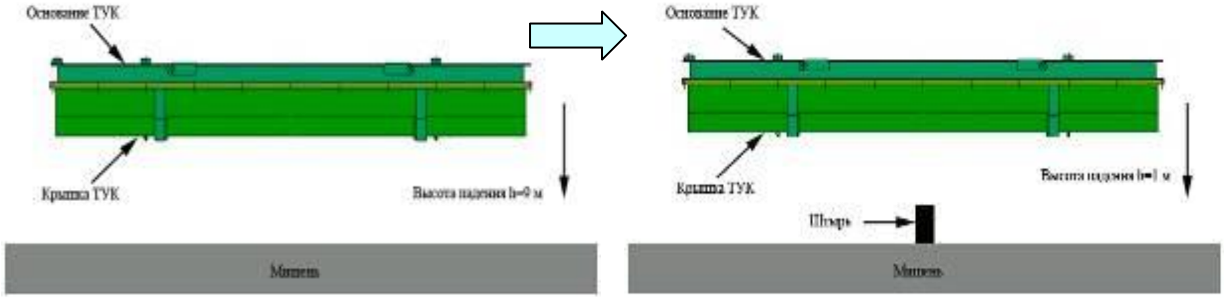


Figure 9 – Test procedure for the second specimen of the packaging

Figure 10 – Maximal damage of the packaging (TUK lid) after drop from a height of 9m by lid onto the target (in the area of ribs)

Figure 11 – The lid of the packaging specimen after its drop from a height of 1 m onto a bar

Figure 12– Platform, cradles and mounting hardware

Figure 13 – The QUADRAT dynamic mockup state

Test results prove that:

1. The packaging damages after mechanical tests (drop from a height of 1.2 and 9 m, drop from 1 m onto a bar) do not result in significant changes of the initial geometry and degradation of TUK TK-C69 shielding parameters. Drop test onto a bar resulted in local damage (fracture) of the TUK lid outer shell in the impact area and the internal shell turned down. However there was no impact of the

bar on the fuel assembly as the bar did not reach the cradle lid, so fuel assemblies were subjected only to low level inertial loading.

2. The TUK lid bolts kept their integrity; the lid stayed fixed to the base, the lids of the platform cradles stayed closed.

3. The QUADRAT fuel assemblies were kept inside the cradle, fuel elements retained their integrity and initial geometry.

Thus the tests proved the results of the strength calculations that the TUK TK-C69 packaging retained its integrity under normal and accidental condition of transport and kept QUADRAT within the packaging containment system.

TRANSPORT TESTING OF THE PACKAGING

Full-scale specimens of the packaging TK-C69 were subjected to the transport test. The specimens were transported in the B-60CKM. The length of the transport test was approximately 3000 km. The packaging specimens were stacked at the travelling frame (a ramp) inside a railcar and fixed at the frame using standard railcar hardware (support bars, traverses, strainers, clamps). Vibration parameters were measured at the TUK TK-C69 components and at the attaching points of the QUADRAT dynamic mockups. The measurements were made within frequency range up to 200 Hz using piezoelectric accelerometers «PCB PIEZOTRONICS» and a portable eight-channel recorder of vibration signals SCADAS Mobile» of «LMS International» company.

Figure 14 presents the specimens at the travelling frame inside the railcar B-60CKM.

Figure 14 – General overview of the tested specimens inside a railcar.

The results of the transport testing prove that:

- there is no displacement of the packaging in regard to their initial installation at the railcar ramp that indicates reliable fixing of the packaging inside the railcar using the fastening schemes developed by the consignor;
- TUK TK-C69 and its components did not receive any mechanical damages, the tightening torques of the link bolt nuts to attach the lids to the bases and the platform holding elements complied with the requirements of the design documentation;
- Test data on vibration parameters at the TUK TK-C69 components and the attaching points of the QUADRATE mockups proved the packaging vibration strength under the loading during the railway transportation.

Test results are proved by the computational assessment of vibration strength and TUK TK-C69 resistance to acceleration.

Taking into account that the Regulations specifies lower values of overloading for automobile and water transport than for the railway transport we can make such conclusions also for the carriage by roads and waterways.

CONCLUSIONS

The TUK TK-C69 packaging for transportation of fresh fuel assemblies from PWR reactors developed under the initiative of TVEL Corporation in cooperation with NZKhK, RFNC-VNIIEF and CAE MBK meets all the requirements of the international and Russian regulations for safe transportation of radioactive materials.

The State Corporation for atomic energy “Rosatom” issued certificates-approvals for TUK TK-C69 design as well as for the packaging transportation by all means of transport except air transportation.

A pilot batch of TUK TK-C69 has been produced and serial production of the packaging has been prepared.