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DESCRIPTION OF TYPE C TUK-145/C PACKAGE DESIGN. CERTIFICATION IN RUSSIA

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ABSTRACT
The paper describes the history of development and the peculiarities of design and certification of the world's first Type C package for the air transport of RR SNF (TUK-145/C) in compliance with the classification given in IAEA TS-R-1 Regulations. The main element of the TUK-145/C package is a new energy absorbing container (an overpack) developed for the existing Czech-made SKODA VPVR/M cask. At an impact of the TUK-145/C package onto a target, its hollow energy absorbing balls redistribute the energy and transform it into plastic deformation.
To certify the package, computer software was used for the finite element analysis of the TUK-145/C deformation under different impacts onto a target at a velocity of 90 m/s (in compliance with the TS-R-1 requirements). The analysis revealed the most unfavorable (from the viewpoint of nuclear and radiation safety) target orientation of the Type C package at impact. This was the target orientation provided during the certification test of the mockup TUK-145/C package on the rocket sled. Positive test results and the calculations made by a competent authority of Rosatom State Corporation made it possible to get a certificate of approval for the TUK-145/C package design verifying compliance with the regulations for the safe transport of the Type C package containing radioactive material.
In 2012, a dry run was carried out to demonstrate the TUK-145/C handling procedure including delivery of the energy absorbing container by road, delivery of the SKODA VPVR/M cask by rail, making up the TUK-145/C package at the airport, and two options of its loading on board the aircraft (on a truck and a roller system).

INTRODUCTION
For a considerable time, nuclear industry specialists from many countries have been wondering: Is air transport of spent nuclear fuel an opportunity for safer transport or just extra risk? What is air shipment - good or evil, safety or danger? Air shipment of spent nuclear fuel always had and will always have both its opponents and adherents. All specialists can be conventionally divided into "pros" and "cons".
An idea to use aircrafts for transporting spent nuclear fuel, that had been in minds of "pro" specialists, got a start for active development in 2009, when Sosny R&D Company (Russia) and its partners were offered an opportunity to create a SKODA VPVR/M-based transport packaging for shipment of fuel by air, i.e. to create, in terms of TS-R-1 Regulations, a Type C package. The package of this type shall meet rather strict safety requirements. The safety of the package is

assured by a number of tests among which are impact onto a target at a velocity of not less than 90 m/s, thermal test, drop onto a bar and others.

Preliminary investigations confirmed that creation of a Type C package on the basis of a SKODA VPVR/M cask was possible. Two ways could be chosen: the first one - to upgrade the impact absorbing property of the ISO container for SKODA VPVR/M cask transportation by filling its inner space with impact-absorbing material; the second one - to create a brand-new impact-absorbing system. When the ISO container is filled with impact-absorbing material, many areas of the SKODA VPVR/M cask (top and bottom of the cask, the areas facing the ISO container sides) remain poorly protected because of the container structure. So, a decision was taken to create a completely new impact-absorbing system. As the most severe test for the future packaging was an impact onto a target at a velocity of 90 m/s, a particular emphasis was placed on absorption of impact energy.

DESIGN FEATURES

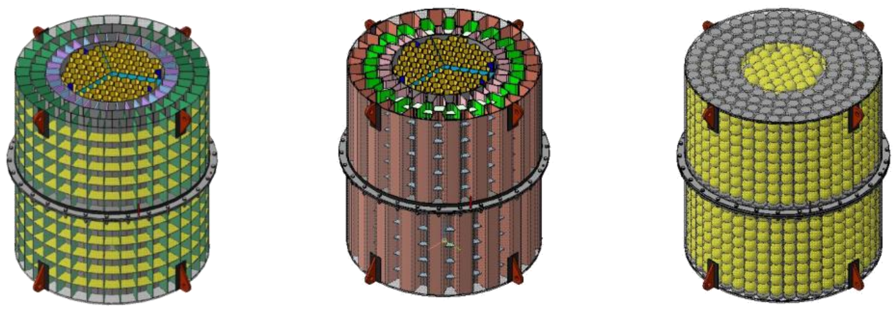
At the initial stage of design, the specialists analyzed the requirements of regulations and standards, considered possible transport plans and reviewed available materials and their application. All that allowed determining the main requirements for the design of the new packaging specified in the Technical Assignment:

- compliance with the TS-R-1 requirements for Type C package;
- possibility of multi-modal transport, including air transport;
- packaging constituents are a SKODA VPVR/M cask and an energy absorbing container (EAC);
- max mass of 35 tons;
- EAC is a vertical cylinder with maximum height 3.9 m and maximum diameter 3.8 m.

Different materials were considered for the energy absorber: wood, foam, honeycomb structures. The strength of each above-mentioned material was analyzed under dynamic load conditions. The results demonstrated that the considered materials would not assure proper integrity of the package and protection of its contents. Thus, a task arose to develop a new unique impact-absorbing system. OT4 titanium alloy was taken from a variety of metal and non-metal materials as the main one, because it is the strongest and lightest one as compared with other metals.

Preliminary studies selected three most prospective options of the EAC design (ref. Fig. 1):

- "Gussets" - a welded structure made of gusset plates;
- "Channels" - a welded structure made of formed sections;
- "Spheres" - a composing construction of hollow spheres.



a) "Gussets" b) "Channels" c) "Spheres"

Fig. 1. EAC options at the stage of the concept design

The "Gussets" and the "Channels" were similar in size with the "Spheres" but more advantageous over the latter in mass (ref. Table 1). But the "Gussets" and the "Channels" are assembled mainly by on-site welding, and that often requires additional relieving of internal stress in the welds. Thus only two of the three options were chosen for finite element analysis of their impact absorbing ability: formed sections and spheres.

Table 1. Characteristics of EAC options

Parameter	Gussets	Channels	Spheres
Length, width, mm	3100	3100	3170
Height, mm	3040	3040	3120
Mass, kg	12 700	11 300	19 200

Strength analysis of the "Channels" option, performed at the stage of concept design, demonstrated its insufficient impact absorption, which led to improvement of the structure. As a result, the mass of the EAC increased up to 22 500 kg, height – up to 3843 mm, diameter – up to 3000 mm.

So, the "Spheres" option was chosen as less labor-intensive and easier for further development.

At this stage, the packaging based on the SKODA VPVR/M cask and the EAC was included into the Transport Package Register of the Russian Federation as a TUK-145/C packaging.

At the stage of preliminary design the final design of the TUK-145/C was determined, the safety factor of package and its behavior in the fire environment were analyzed. The TUK-145/C packaging consists of an EAC and a SKODA VPVR/M cask. The EAC is a cylinder filled with titanium spheres. Each EAC half has an inner cavity for a SKODA VPVR/M cask. All titanium spheres are arranged inside the upper and the lower EAC parts and are conventionally divided into an end energy absorber and a side energy absorber. The spheres of the side energy absorber are installed in tubes to facilitate assembling.

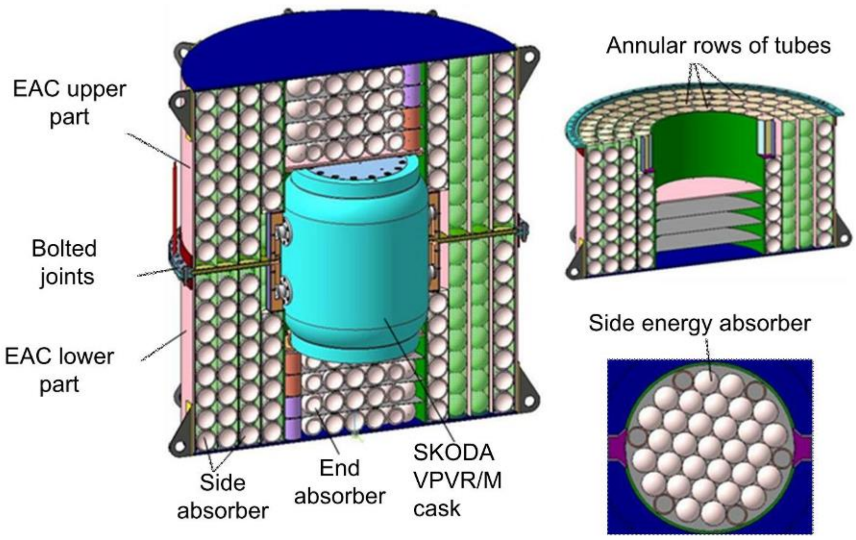


Fig. 2. TUK-145/C package (preliminary design stage)

In this design the main function of the EAC (impact absorption) is performed by transformation of the TUK-145/C kinetic energy into plastic deformation of the spheres as well as by re-distribution of the spheres to the most impact-absorbing position. The described processes were observed more vividly when modeling an impact of TUK-145/C package onto a target at a velocity of 90 m/s and analyzing the results with the software for finite element analysis. This impact modeling, an obligatory part of certification procedure, was performed for different orientation of the TUK-145/C package in relation to the target (end, side and corner).

CERTIFICATION IN RUSSIA

Certification in Russia required modeling of the following accidents (in compliance with TS-R-1):

- drop of the package onto a solid target from a height of 9 m;
- drop of a 500 kg mass from a height of 9 m onto the package;
- drop of the package onto a bar from a height of 3 m to test for penetration/puncture;
- fire with an average temperature of 800ºC during 60 minutes;
- impact on a target at a velocity of 90 m/s.

The computational model of the TUK-145/C package fully complied with the design documents (geometry, material properties, etc.).

Modeled drop of the package onto a solid target from a height of 9 m and drop of a 500 kg mass from a height of 9 m onto the package did not destroy the EAC, i.e. all elements of the impact absorbing system were strained in the elastic region.

Two variants of drop onto a bar were modeled:

- the bar punctured a sphere of the first layer;
- the bar penetrated between the spheres.

In both variants, destruction of only two of four layers of the end energy absorber was observed (ref. Fig. 3).

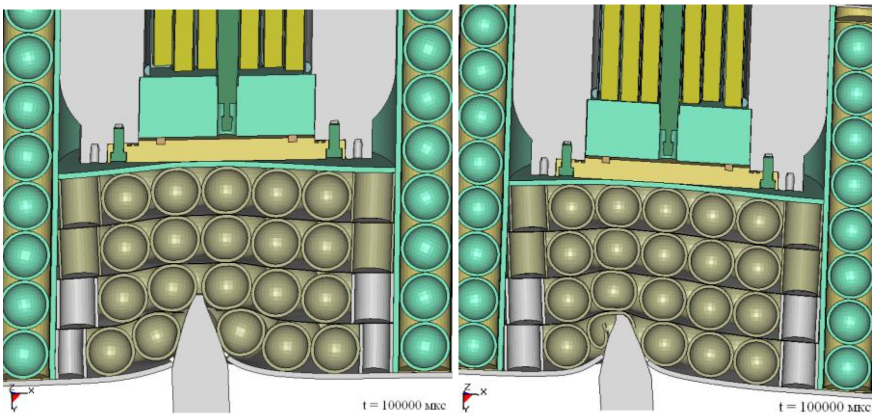


Fig. 3. Modeled penetration/puncture during drop onto a bar

Modeled fire also confirmed the reliability of the designed package, for during the standard time of thermal impact (which is similar to fire) the temperature of the SFAs within the cask was in the allowed limits.

In compliance with the IAEA regulations for TUK-145/C, nuclear and radiation safety analysis was performed. The results of the calculations made using a conservative approach confirmed the compliance of the developed package with the requirements for the safe transport of radioactive materials.

Modeled drop onto a target at a velocity of 90 m/s with different orientation of the TUK-145/C package in relation to the impact surface demonstrated that the SKODA VPVR/M cask remained intact and the absorber travel is conservative. The obtained data allowed determining the corner impact of the TUK-145/C package as the most dangerous; it resulted in the maximum deformation of the EAC and brought about the maximum (as compared to other orientations) strain in the SKODA VPVR/M cask (ref. Fig. 4). However, even in this case the radioactive contents do not escape from the package into the environment, i.e. the safety is provided.

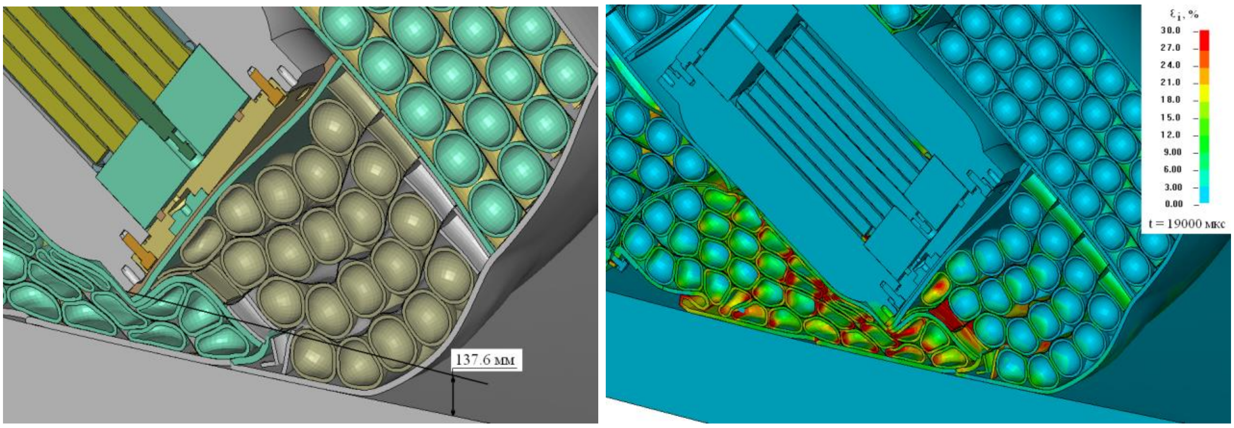


Fig. 4. TUK-145/C state at an angle impact at a velocity of 90 m/s

An obligatory requirement of the Russian Regulatory Authority was to perform full-scale tests of a mockup TUK-145/C on the rocket sled, even if all documents to validate the safety of the package had been submitted. For this purpose a mockup TUK-145/C package in the scale of 1:2.5 was made in April, 2011. This mockup package had the same structural elements as a full-scale TUK-145/C.

A test committee was established by the Rosatom order and included the representatives from all concerned Russian organizations.

Before testing an incoming inspection with the mockup TUK-145/C parameters registration was performed. The tests were held on May 18, 2011 on the rocket sled of FSUE “RFNC – VNIIEF” (Sarov) (ref. Fig. 5). On their completion the mockup TUK-145/C was inspected and its condition was analyzed (Fig. 6).

Fig. 5. Mockup TUK-145/C (1:2.5 scale) on the rocket sled

Fig. 6. Mockup TUK-145/C after tests

The tests results were recorded in the Mockup TUK-145/C Fault Detection Report and the Test Results Certificate approved by the First Deputy General Director of Rosatom. The members of the test committee confirmed that the test data correlated well with the data of impact modeling, and concluded that the TUK-145/C package met the air transportation safety requirements specified in TS-R-1 Regulations.

In order to obtain a Certificate of Approval on the TUK-145/C package design, in October 2011, an application was sent to the expert organization of Rosatom.

The Expert Assessment was approved in February, 2012, and then the draft certificate and the Expert Assessment were sent to Russian competent and regulative bodies.

All these activities resulted in the granting of the Certificate of Approval on package design in Russia in April 2012.

Thus, the safety of air transport was validated.

IMPLEMENTATION IN METAL

Along with the certification procedure, fabrication of the first EAC began in January, 2012. Production capability of tens of enterprises had to be analyzed during this crucial stage. Finally, VSMPO-AVISMA Corporation (Verkhnaya Salda, Russia) was chosen as a fabrication site for the first EAC. Over 300 people put their efforts and love for their job into the fabrication process. More than 22 tons of rare OT4 titanium alloy were produced. More than 2000 spheres were stamped and welded.

The EAC 1 was fabricated and tested in May 2012, and immediately delivered to Ulyanovsk-Vostochny Airport (Ulyanovsk, Russia) to test the process of assembling TUK-145/C package and loading it into an *AN-124-100* aircraft.

The tests were held in June 2012 witnessed by the representatives of many concerned organizations, Russian and foreign. The tests included:

- delivery of the assembled and disassembled EAC (ref. Fig. 7);
- loading (unloading) of the EAC to (from) different transport modes;
- buildup of the TUK-145/C package, loading of a SKODA VPVR/M cask (ref. Fig. 8);
- loading of the TUK-145/C package into the aircraft using a truck (a semi-trailer) and a roller system (ref. Fig. 9).

Fig. 7. The EAC delivery

Fig. 8. Buildup of the TUK-145/C package

Fig. 9. Loading of the TUK-145/C package into the AN-124-100 aircraft

The demonstration confirmed the good performance of the loading process and readiness for air shipment, as little time was left till the first one...

EPILOGUE

It was an early but rather hot morning of July 1, 2013, when the *AN-124-100* aircraft of JSC "Volga-Dnepr Airlines" appeared among the clouds in the sky. Nobody would attach any importance to this fact, if tens of people were not standing and waiting on the concrete pavement of Bien Hoa airport (Viet Nam). At about 6.00 a.m. of local time the landing gear of the aircraft touched the airstrip. The EAC arrived at the departure point of the first flight of the TUK-145/C package.

In the night of July 3, 2013, the *AN-124-100* aircraft took off. This meant the start of the first air shipment for the TUK-145/C package loaded with spent nuclear fuel.