

Conception of Universal Cask Based on Cermet for SNF Transportation and Storage

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Abstract - The paper is devoted to development of the new generation of a multipurpose universal transport cask having improved safety. The cask is intended for transportation and storage of spent nuclear fuel from Russian and foreign power reactors WWER, RBMK, PWR, and BWR, and it should comply with all IAEA safety requirements. The cask should have improved resistance under conditions of undesigned accidents and terrorist attacks.

Compliance with all requirements of IAEA in safety both in normal operational conditions and in accident conditions, as well as improved resistance of TC with SNF in the environments of undesigned accidents and terrorist attacks is achieved in the design of the multipurpose universal TC by application of new composite material CERMET in it. CERMET was produced basing on stainless steel and dioxide of depleted uranium. In the suggested design of multipurpose universal transport cask, composite material CERMET is simultaneously used as an effective anti-radiation protection and structural material. Though having specified sizes, it allowed to provide the maximum loading of the cask with spent nuclear fuel, to comply with all requirements of the IAEA in safety, and to provide improved resistance of the cask with SNF in the environments of undesigned accidents and terrorist attacks.

I. INTRODUCTION.

Recent years the problem of creation of the new generation of casks for SNF transportation from energetic reactors has become rather urgent in Russia. The available fleet of casks was arranged more than 20 years ago. The casks are morally and physically out of date now. Duration of their guarantee will be expired soon, their capabilities for SNF loading are low. These reasons cause high cost of SNF transportations. Most of the casks refer to package type B(M) according to IAEA classification, which can not be operated in the temperature range from -40 to +38 °C without performing additional arrangements and technical measures.

Taking it into account, Institutes of Rosatom (VNIIEF, VNIINM and VNIKhT) with support of Oak Ridge National Laboratory (ORNL), USA, developed the concept [1] of an up-to-date universal cask for transportation and temporal storage of SNF from Russian and foreign power reactors WWER, RBMK, PWR, and BWR.

The most distinctive feature of this cask is that the cask is made of new composite material CERMET basing on stainless steel and dioxide of depleted uranium. In the cask design, CERMET is simultaneously used as an effective anti-radiation protection and structural material. This composite material was developed under the frameworks of joint efforts of Rosatom Institutes (VNIIEF, VNIINM and VNIKhT), ORNL, and the U.S. Department of Energy [2]. This composite material was produced with use of the effective and low-cost technology based on casting procedures.

The composite material CERMET has a series of certain advantages comparing to the traditional materials used presently in cask production:

- Since density of this composite material (density of cast uranium CERMET is $\sim 9.5\text{g/cm}^3$) is higher than densities of steels and metal-concrete, this composite material has better anti-radiation protection. And because of high content of oxygen in uranium dioxide (1.3g/cm^3), it partially provides neutron protection as well. It allowed to increase the specific loading of SNF in cermet casks to the maximum as compared to steel and metal-concrete casks.

- Contrary to metal depleted uranium, it is a material more resistible against effect of aggressive media. It allowed to use cermet casks for long-time (in geological time scales) storage of SNF and for disposal of it in underground depositories.

- Because of content of uranium dioxide in composite material CERMET, it is a material indispensable for providing nuclear safety of underground depositories of SNF, as well as for mitigation of SNF degradation and reduction of radionuclide release from a depository.

Therefore, use of new composite material CERMET allowed creating a multipurpose universal cask with record loading of SNF. So, it is possible to load 36 spent fuel assemblies (SFA) of reactor WWER-1000 simultaneously. It is about 15 tons in uranium.

II. BASIC TECHNICAL CHARACTERISTICS OF MULTIPURPOSE UNIVERSAL CERMET-BASED CASK.

In terms of packing, the multipurpose universal cask basing on uranium cermet complies with the requirements for a packing of the type B(U) containing fissile substance in accordance with the IAEA classification.

The multipurpose universal TC consists of a protective cask and a basket for ordered placement of spent fuel assemblies.

The weight and dimension characteristics of the developed cask provide possibility to perform the required procedures with it in appropriate buildings of NPP and in a cask depository of SNF, as well as transportation of it by railways of general use.

The presented cask has the following dimension and weight characteristics:

Weight of empty cask about 100 tons.
 Weight of cask loaded with 36 SFA of reactor WWER-1000 about 140 tons.
 Height of cask (dimensions) 6000mm.
 External diameter of cask casing (dimensions) 2750mm.
 Diameter of internal cavity 1940mm.

TC can be used for transportation and storage of spent fuel assemblies having the following characteristics:

Initial enrichment in U^{235} , equal to 5% or less.
 Mean depth of fuel burnout 40MwattDay/kgU.
 Maximum depth of fuel burnout, equal to 65MwattDay/kgU or less.
 Time of holding in reservoir, equal to 3 years or more.
 Total heat release of assemblies in TC, equal to 40 kwatt or less.

III. COMPARATIVE EVALUATION OF MULTIPURPOSE UNIVERSAL CERMET-BASED CASK WITH BEST FOREIGN ANALOGS.

Table 1 presents results of the performed preliminary technical and economical evaluations, as well as comparisons of characteristics of CERMET-based cask with the best foreign analogs, which confirmed

efficiency of application of new composite material CERMET in designs of casks for SNF.

Table 1. Results of the performed preliminary technical and economical evaluations.

Characteristics	Cask under development	Analog 1	Analog 2
Name of cask	Multipurpose universal TC	NAC-STC	Castor V/21
Company-manufacturer (country)		"NAC International", USA	GNB, Germany
Cost of product unit	Multipurpose universal TC basing on CERMET is competitive to NAC-STC и Castor V/21		
Height, mm	6000	4900	4886
External diameter (dimension), mm	2750	2515	2400
Protection against gamma-radiation	Composite material CERMET basing on stainless steel and dioxide of depleted uranium	Stainless steel, lead	cast iron with spherical graphite
Neutron protection	Composite material CERMET and siloxane rubber	Pitch	Bars made of polyethylene
Weight of cask with SFA, t	140	116	106
Amount loaded in cask (units, SFA)	36 SFA from WWER-1000 (~ 15t U)	26 PWR or 57 BWR (10t U)	21 PWR (8.4t U)
Requirements for heat loading, Kwatt, not higher	40.0	22.1	20.0

IV. DESCRIPTION OF DESIGN OF MULTIPURPOSE UNIVERSAL CERMET-BASED CASK.

The design-assembly scheme of the CERMET-based cask is presented in fig.1. Fig.2 presents the design-assembly scheme of the basket for ordered placement of 36 SFA of WWER-1000.

It is planned to develop appropriate baskets for placement of SFA from reactors RBMK, BWR, PWR in the universal cask.

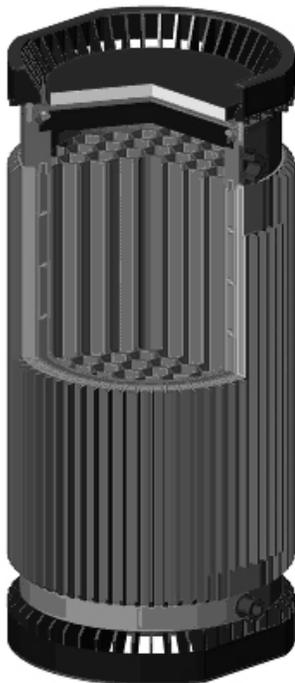


Fig. 1 Design-assembly scheme of protective cask based on composite material CERMET.

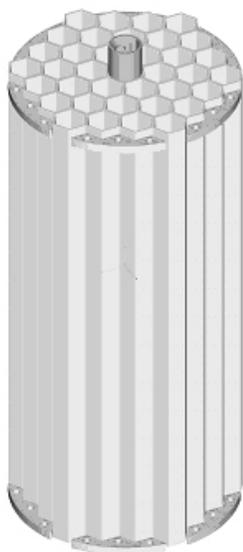


Fig. 2 Design-assembly scheme of basket for ordered placement of 36 SFA of WWER-1000.

The protective cask is a thick-wall, multilayer cylindrical casing with a bottom. It can be closed by two lids. The external lid of the protective cask is made of stainless steel 12Kh18N10T, the internal lid is made of structural steel 09G2S. Each lid is sealed by two gaskets.

The cylindrical casing of the protective cask is made of composite material CERMET, which serves simultaneously as an anti-radiation protection and a load-bearing element of the cask casing. The shell made of CERMET is covered with sheets of steel 12Kh18N10T at its internal and external sides. The coaming and the bottom are welded to the internal cover of the CERMET shell. The coaming is made of steel 12Kh18N10T, and the bottom is made of steel 09G2S. In the ends of the cask casing, the role of anti-radiation protection is played by the bottom and the internal lid.

The solid neutron protection is made of siloxane rubber. It is placed directly after the external cover of the CERMET shell. From the outside, the side neutron protection is coated with a thin-wall shell made of steel 12Kh18N10T. Also a solid neutron protection is mounted in the bottom part of the cask casing and on the internal lid.

To remove residual heat release of SNF, the cask design includes a unique system of heat removal, which provides effectively the required heat regimes at the total heat release of SNF up to 40kwatt.

The cask includes a unique damping system, which provides high level of reduction of mechanical loadings at accidents and under unregulated effects on TC. At drops of the cask against a rigid barrier from the height of 9 meters, the damping system provides reduction of loading to the level ensuring operation of the cask elements responsible for safety in the elastic area and excluding fracture of fuel rods and fuel scattering. Taking into consideration the modern requirements for providing safety when handling SNF, the damping system joint (nonremovable) to the cask is the most preferable as compared to removable dampers, which are used only during transportation, since it allows to improve significantly safety when handling TC with SNF at NPP and in depository during designed and undersigned accidents, including terrorist attacks.

The cask includes a unique basket design made of atabor (that is stainless steel with boron content of ~ 5%) providing nuclear safety of the cask with 36 SFA of WWER-1000 under normal and accident conditions.

V. CALCULATION EVALUATIONS OF SAFETY OF DESIGN OF MULTIPURPOSE UNIVERSAL CASK BASING ON CERMET.

Under the frames of development of the concept of multipurpose universal cask for SNF from Russian and foreign power reactors, preliminary numerical-theoretical studies of various aspects of cask safety were performed. The studied aspects included:

- Strength and tightness of cask design.
- Thermal regimes.
- Nuclear safety.
- Radiation safety.
- Resistance against terrorist attacks (for most probable scenarios).

V.A. Strength and Tightness of Cask Design.

Calculation study of deformation dynamics of the cask design was performed by the finite element method with use of the code packages (CP) DINAMIKA-2 and DINAMIKA-3 intended for solving of geometrically and physically non-linear problems in coherent arrangement of non-stationary contact interaction of elastic-plastic constructions and non-deformed bodies with surrounding and filling media. Calculation study of strength and tightness of the cask was performed with subjection of it to loadings occurred under normal operational conditions and during accidents. The following calculated cases of the cask loading were considered:

- Effect of internal pressure $P=15\text{atm}$ in the cask cavity.
- Heat-resistance of the cask design elements in the conditions of stationary source of heat and thermal field of fire.
- Vibration-resistance of the cask during transportation by railway transport.
- Drop of the cask from height of 0.3m against non-deformed barrier.
- Drop of the cask from height of 9m against non-deformed barrier.
- Drop of the cask from height of 1m against a bar.
- Submergence of the cask in water to depth of 200m.

In the normal operational conditions:

- Under effect of internal pressure $P=15\text{atm}$, the cask design satisfies the strength norms.
- During transportation by railway transport, the cask design is vibration-resistant. The lowest natural frequency of the cask design is 65Hz that is 1.6 times higher than the top value of drive frequency when transporting the cask by railway transport. It complies with the requirement for natural frequencies of designs.
- Heat-resistance of the cask design elements is provided by operation of stationary source of heat of 40Kwatt; the load-bearing casing of the cask is operated in the elastic area. During effect of thermal field of fire, the load-bearing casing of the cask is operated behind the elasticity limit. The minimum reserve in limiting deformation is equal to 4.

- Strength and tightness of the cask design are provided during drop of it from the height of 0.3m.

During accidents:

- Under effect of external hydrostatic pressure $P=20\text{atm}$, the cask design satisfies the requirements of the strength norms.
- The shock-absorption system, which is used in the cask design for all directions of drop of it from the height of 9m against non-deformed barrier, provides overloading level for the cask as a solid body less than 100 units. The cask design keeps its strength and tightness.

Basing on the calculation results, the conclusion can be made that the CERMET-based multipurpose universal cask design keeps its strength and tightness under effects of loading simulating normal and accident

conditions of transportation in accordance with the IAEA Rules requirements.

V.B. Thermal Regimes of Cask.

Calculations of thermal state of the cask loaded with 36 SFA of WWER-1000 were performed by the code package (CP) AJAX_69 based on the finite element method. Calculations of thermal state of the cask were performed for normal operational conditions and for accidents. The following calculation cases were considered:

- Thermal state of the cask under effect of internal source of heat from 36 SFA of WWER-1000.
- Thermal state of the cask in conditions of fire at $T=800^{\circ}\text{C}$, $t=30$ min followed by cooling down at $T_{\text{aver}}=38^{\circ}\text{C}$ (~24 hours) with account for internal source of heat from 36 SFA of WWER-1000.
- Thermal state of the cask in conditions of total failure of heat removal from its external surface for ~24 hours with account for stationary source of heat from 36 SFA of WWER-1000.

As a result of the calculations, it was revealed that the maximum temperatures at the fuel rods, in the places of location of sealing gaskets and on the cask casing are less than the maximum permissible values outlined in the normative documents, namely:

- The maximum temperature of the hottest fuel rods is not higher than $\sim 330^{\circ}\text{C}$ that is less than the maximum permissible temperature of 350°C .
- The maximum temperature in the places of location of sealing gaskets is not higher than $\sim 320^{\circ}\text{C}$ that is less than the maximum permissible temperature of 500°C .
- The maximum temperature of the external surface of the cask is not higher than the maximum permissible temperature of 85°C .

V.C. Nuclear Safety of Cask.

Calculations of nuclear safety of the cask were performed by the Monte-Carlo method with use of the code package (CP) S-95. The calculations revealed that the cask design loaded with 36 SFA of WWER-1000 satisfies the requirement on nuclear safety ($K_{\text{eff}} < 0.95$). Both in the normal operational conditions and in all accident conditions, subcriticality of the cask will be not higher than $K_{\text{eff}}=0.92$.

V.D. Radiation Safety of Cask.

Calculations of radiation safety were performed by the Monte-Carlo method with use of the code package (CP) S-95. Both the normal operational conditions and accident cases were considered in the calculations. The calculations revealed that the requirements for radiation safety (keeping less than 200mRem/hour on TC surface and keeping less than 10mRem/hour at distance of 2m from the surfaces limiting a vehicle, as well as keeping less than 1000mRem/hour at distance of 1m from TC surface) are met.

In the normal operational conditions.

- on TC surface – 35.7mRem/hour;
- at distance of 2m – 8.4mRem/hour.

During accidents.

- at distance of 1m – 864.8mRem/hour.

V.E. Cask Resistance Against Terrorist Attacks.

When performing calculation evaluations of cask resistance against undesigned accidents, including terrorist attacks, the following initial events were considered:

- Fall of a slab having weight of 120t from the height of 18m against vertically-staying cask.
- Fall of a plane with velocity $V=100\text{m/s}$ against vertically-staying cask.
- Shooting through vertically staying cask from a sniper rifle by armor-piercing igniting bullet having caliber of 12.7mm.
- Shooting through vertically staying cask from a hand antitank grenade cup discharge by cumulative grenade with caliber of 90mm.
- Detonation of explosive having weight of 50kg placed on lid of vertically-staying cask.

It follows from the calculation results that

- During fall of a slab having weight of 120t, the cask casing, lids and elements of their fastening are elastically deformed. The cask keeps its strength and tightness.
- During impact of a plane against the cask with the velocity of 100m/s, the cask casing is elastically deformed in the impact area. Outside the impact area, the casing is elastically deformed. The lids and elements of their fastening keep their strengths.
- Armor-piercing igniting bullet with caliber of 12.7mm does not penetrate through TC, the cask keeps its tightness.
- Grenade with caliber of 90mm breaks the cask casing. However, scales of radiation accident caused by shooting the cask from a hand antitank grenade cup discharge by cumulative grenade with caliber of 90mm during terrorist attack have local character. Length of contaminated territory, where there is need for removal of population and for reconstruction efforts, is $\sim 3.8\text{km}$, and its area is $\sim 0.69\text{km}^2$.
- During detonation of HE having weight of 50kg, the cask design has large plastic deformations. However, the cask keeps its tightness.

VI. POTENTIAL PLANTS-MANUFACTURERS OF MULTIPURPOSE UNIVERSAL CERMET-BASED CASK.

Plants-manufacturers of multipurpose universal CERMET-based cask.

A plant-manufacturer of large-size steel details of the cask (sidewalls, coaming, bottom, lids, etc.), which can perform the final assembly of the cask, can be the plant Krasnyi Oktyabr in Volgograd, as well as Izhorsk plants in Saint-Petersburg.

A plant-manufacturer of the load-bearing CERMET-based shell of the cask is Chepetsk Mechanical Plant in Glazov. The foundry equipment and equipment for mechanical treatment, which are presently capable at Chepetsk Mechanical Plant, allow

to produce a shell using composite material CERMET for sizes of this cask.

A plant-manufacturer of the basket for SFA of WWER-1000 can be any tube-rolling mill, which manufactures large-size steel tubes.

With account for procedures of preparation of plants participating in cask manufacture, time for production of a pilot sample is evaluated as $\sim 1.5 - 2$ years.

Cost of the multipurpose universal CERMET-based cask will be lower than cost of a cask made of metal. More precise cost of the CERMET-based cask will be calculated in the technical project in the section devoted to technical-economic justification of the cask.

VII. CONCLUSION

1. The design of the multipurpose universal CERMET-based cask, which is considered in the frames of the suggested concept, complies with all requirements formulated for the casks intended for transportation and storage of SNF from power reactors both in normal operational conditions and during accidents. The multipurpose universal CERMET-based cask has improved resistance against effects during undesigned accidents, including terrorist attacks. The multipurpose universal CERMET-based cask can be used for transportation and storage of SNF from Russian and foreign power reactors.

2. The activities directed for creation of the multipurpose universal CERMET-based cask, which has the maximum loading with SNF, provide solution of the following problems:

- Improve consumer quality of TC due to increase of holding capacity for fuel.
- Create a mini-depository for SNF basing on the multipurpose universal cask with satisfying all requirements in safety during storage.
- Improve the protection level of TC with SNF against effects during undesigned accidents, including terrorist attacks.
- Facilitate recycling of accumulated resources of depleted uranium, which are not widely applied and are piled that cause the thread of pollution of the environments.

REFERENCES.

1. Conceptual project "Multipurpose universal CERMET-based cask for transportation and temporary storage of SNF from power reactors".

2. Project № 2693 of the International Science and Technology Center "Production and research of cast cermet based on stainless steel and dioxide of depleted uranium as applied to use of it as protective material in designs of casks for spent nuclear fuel and radioactive wastes".