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ABSTRACT

The design of spent nuclear fuel (SNF) casks used in the present SNF disposition systems has evolved from early concepts about the nuclear fuel cycle. The reality today is much different from that envisioned by early nuclear scientists. Most SNF is placed in pool storage, awaiting reprocessing (as in Russia) or disposal at a geologic SNF repository (as in the United States). Very little transport of SNF occurs. This paper examines the requirements for SNF casks from today's perspective and attempts to answer this question: What type of SNF cask would be produced if we were to start over and design SNF casks based on today's requirements? The characteristics for a next-generation SNF cask system are examined and are found to be essentially the same in Russia and the United States. It appears that the new depleted uranium dioxide (DUO₂)-steel cermet material will enable these requirements to be met. Depleted uranium (DU) is uranium in which a portion of the ²³⁵U isotope has been removed during a uranium enrichment process. The DUO₂-steel cermet material is described. The United States and Russia are cooperating toward the development of a next-generation, dual-purpose, storage and transport SNF system.

INTRODUCTION

The design of spent nuclear fuel (SNF) casks used in the present SNF disposition systems has evolved from early concepts about the nuclear fuel cycle. In these conceptual systems, SNF was to be removed from reactors and reprocessed within several years. Fissile and fertile materials were then to be recycled as refabricated fuel assemblies, and the high-level radioactive waste was to be sent to geologic repositories. Almost negligible SNF storage was anticipated in such a scenario. The reality today is much different from that envisioned by early nuclear scientists.

- *Once-through SNF repository requirements.* In once-through fuel cycles, SNF is stored for several decades to reduce the radioactive decay heat. This reduces disposal costs by allowing the use of larger waste packages (WPs) and reduces uncertainties in repository performance. Temperature limits are set for SNF and WPs in the repository to slow SNF, WP, and near-field repository degradation with time. Aged SNF produces less decay heat, thus more SNF can be put in a WP for the same WP temperature limit. The size of the repository is also reduced because the total decay heat from the SNF is reduced.
- *Siting and licensing delays.* Many siting and licensing delays have delayed reprocessing or direct disposal of aged SNF in repositories.

SNF is currently stored at reactor sites for long periods of time, and because of public concerns, almost no transport of SNF occurs. This paper examines the requirements for SNF casks from today's perspective and attempts to answer this question: What type of SNF cask would be produced if we were to start over and design SNF casks based on today's requirements?

The Oak Ridge National Laboratory (ORNL) (United States), the All-Russian Research Institute of Experimental Physics (VNIIEF) at Sarov, Russia, and private industry in both countries are collaborating on the design of next-generation SNF casks. New uranium composite materials have been invented to satisfy the criteria described above, and laboratory tests are being conducted on these materials. Plans are to fabricate and test prototype 1/4-scale demonstration casks in Russia. This paper describes these activities.

SNF STORAGE, TRANSPORT, AND DISPOSAL IN RUSSIA

There are three major types of nuclear reactors in Russia—the VVER-440, VVER-1000 and RBMK-1000. After pool storage for several years at VVER-440 nuclear reactors, SNF is transported to the RT-1 conversion plant for recovery of fissile and fertile materials. Following a relatively short period of pool storage, SNF from VVER-1000 will be transported to a centralized storage facility for long-term “wet” storage until the RT-2 conversion plant is operational. The VVERs are the Russian light-water reactors (LWRs). The recovery of fissile and fertile materials from RBMK-1000 SNF is not economic. The fuel has a lower burnup and enrichment than LWR SNF. This type of SNF is currently stored in pools at nuclear power plants. In the near future, this SNF will be transported to a centralized storage facility for long-term, dry storage (this is the so-called “postponed” storage); later, this SNF could be buried in a geological repository [1].

Russia has a fleet of transport casks that were built several decades ago to transport SNF from nuclear power plant storage pools to conversion plants or long-term repositories. The existing casks have some drawbacks, among them:

- *Small capacity.* The SNF capacity of these casks is small, resulting in high costs per SNF assembly transported or stored.
- *Diverse cask fleet.* There is no unified cask system, i.e., each cask type is designed for a specific fuel type. This increases the complexity and cost of cask operation.
- *Changing regulatory requirements.* Cask designs do not meet current Russian Federation and international requirements for safe SNF transportation. Russian casks loaded with SNF are package type B(M), according to IAEA classification. The allowable operation dates for current casks are expiring.

Consequently, a next-generation cask design is needed. The primary Russian requirements for the next generation SNF cask are the following:

1. The cask must have a dual purpose, providing both transportation and long-term (up to 50 years) “dry” SNF storage. The long-range strategy assumes the burial of casks in a geological formation, i.e., a SNF geologic repository.
2. The fleet of casks ought to be unified. That is, a single, unique cask ought to be developed for all kinds of SNF in Russia (VVER-440, VVER-1000, RBMK-1000) and abroad [boiling water reactor (BWR), pressurized water reactor (PWR)]. It is envisioned that there will be a basket designed for each type of SNF that will fit into the universal cask.
3. The next generation cask must have the highest possible SNF loading, consistent with safety requirements. Loading a larger number of SNF assemblies in each cask permits minimizing the number of shipments, thereby reducing transportation costs and reducing the probability of accidents.

4. The cask design must resist accidents and terrorist assaults.
5. The cask must be transportable by truck (up to 100 km), railcar, and ship.
6. The dimensions and weight of the cask must be such that transport by railways is possible.
7. The cost of a single cask (per ton of SNF) should be equal to or lower than the cost of SNF casks in other countries.

SPENT NUCLEAR FUEL STORAGE, TRANSPORT, AND DISPOSAL IN THE UNITED STATES

The United States does not reprocess SNF. Spent fuel from its fleet of commercial PWR and BWR plants are destined for the proposed Yucca Mountain geologic repository.

Most SNF in the United States is stored in pools at nuclear reactor sites to dissipate decay heat. However, much of this fuel has been stored for many years, and pool storage capacity is limited. More SNF storage is required. In addition, at some reactors there are strong incentives to reduce SNF pool storage to (1) provide more pool space for reactor operations (some of the same pools are also used to store and repair reactor internals during refueling operations) and (2) enhance security and safety by reducing pool SNF inventories. Reducing the SNF inventory reduces the decay heat removal requirements for the storage pools and reduces other restrictions on pool operations. Therefore, dry storage using a next-generation cask system is needed. Some features of a next-generation cask system might include the following:

1. *Enhanced Nonproliferation Through Use of Multipurpose Casks.* A multipurpose canister or cask (MPC) handles many SNF assemblies at one time. An MPC is loaded with SNF at a reactor; is sealed; and is then used for storage, transport, and ultimate disposal of the SNF. Because an MPC is a sealed safeguard package, fewer nuclear items (part count) must be accounted for, and it is easier to track large 100-ton objects. The MPC system also eliminates most handling operations associated with individual SNF assemblies. Therefore, this type of system enhances nuclear nonproliferation objectives. The development and use of such a system by the nuclear weapons states is a necessary step if non-weapons states are to adopt such systems.
2. *Physical Protection.* Next-generation SNF casks must offer more physical protection against terrorist assaults. New materials offer increased protection against rocket and missile attack. Thus, casks have the potential for superior resistance to terrorist assault compared with conventional SNF pool storage.
3. *Dry Storage.* To the extent practical, casks should be designed to permit dry SNF storage for extended periods of time. In the United States, significant inventories of SNF will be stored to allow reduction of decay heat and thus increase the repository capacity.
4. *Enhanced Passive Cooling.* Casks should be designed for passive cooling. Avoiding the use of active cooling systems, such as those used in SNF storage pools, offers major advantages in terms of operations, economics, safety, and security.
5. *Decay Heat Load.* A primary consideration in cask design today is the need to maximize the cask capability to reject decay heat from the SNF. A high heat load for a cask shortens SNF pool storage time and/or increases the number of fuel assemblies that can be stored in a given cask.
6. *Weight.* Cask weight needs to be reduced to enable transport by truck and/or railcar. The economics of scale favors large casks that are factory manufactured and then moved to the site where they are used.

7. *Dimensions.* Casks need to have smaller dimensions. For example, cask movement is often limited by door size at the reactor site and by restricted widths and heights during transport.

These requirements are essentially identical for both Russia and the United States. The requirements vary a little according to peculiarities of the nuclear fuel cycle in each country. But, the need to develop a new cask system is similar, and the tasks of developing, designing, and deploying a next-generation cask system are similar in both Russia and the United States. Therefore, Russian and American scientists are working together to solve the problem of next-generation SNF cask in the most efficient way.

The United States and Russia have a history of jointly conducting research. The joint development of next-generation SNF transport and storage cask is a continuation of these efforts. A memorandum of understanding (MOU) designed to promote cooperation in science and technology was signed by the U.S. Department of Energy (DOE) and the Russian Academy of Science on March 24, 1999. This MOU is being conducted under the auspices of the U.S.–Russian Federation Science and Technology Agreement that has been in effect since December 16, 1993. The managing body for the MOU is the Joint Coordinating Committee on Science and Technology (JCCST). The JCCST, at its September 2003 meeting, recognizing previous successes in the joint collaboration regarding developing beneficial uses of DU research, signed an implementing agreement on DU cooperation.

DUO₂-STEEL CERMET MATERIAL

Conceptual studies of a next-generation SNF cask, performed by Russian institutes [RFNC-VNIIEF, All-Russian Research Institute of Inorganic Materials (VNIINM) and All-Russian Research Institute of Applied Chemistry (VNIKhT)], ORNL, and Sandia National Laboratories, in collaboration with an American private company, Holtec International, make it clear that casks based on DU will meet the listed requirements. Comparative evaluation of working parameters of casks (with similar dimensions and weight) made of different materials (steel, cast iron, reinforced concrete, DU materials) indicates that casks produced from DU materials provide

- the highest possible number of SNF assemblies loading per cask;
- maximum stability to accidents and terrorist assaults;
- the lowest cost per ton of SNF loaded.

The most promising DU material is the composite material based on DUO₂-steel cermet [2, 3]. A schematic of a DUO₂-steel cermet cask is shown in Fig. 1.

Cermets provide better gamma shielding than steel because DUO₂ (10.9 g/cm³) has a higher density than steel (7.8 g/cm³). Because of the high oxygen content associated with DUO₂, which moderates neutrons, cermets have better neutron attenuation capabilities than steel. The cermet may include a neutron absorber material such as gadolinium oxide for efficient absorption of thermal neutrons. More efficient shielding materials are prohibited by one or more storage, transport, or disposal criteria. An examination of these criteria eliminates (1) chemically reactive materials such as uranium metal [4]; (2) high-cost materials such as tungsten; and (3) Resource Conservation and Recovery Act [toxic] metals such as lead.

High-performance shielding materials minimize cask weight and wall thickness [4]; in turn, this maximizes cask capacity for any given set of handling constraints in storage and during transport. The greater the SNF capacity of each cask, the fewer number of casks handled. This has a major impact on the economic viability of dual-purpose casks. High-performance shielding that minimizes cask wall thickness allows larger casks to be used at nuclear reactors and minimizes storage area requirements. High-performance shielding lowers cask weight for any given SNF cask capacity. Cask wall thickness also should be minimized to reduce weight.

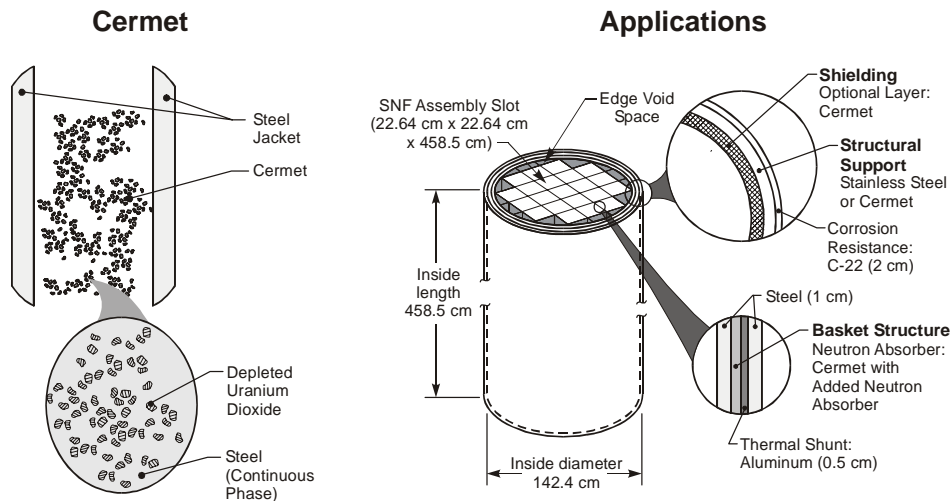


Fig. 1. Cermet cast construction.

In addition to the cask benefits of using DU, there are other benefits [5]. About a million tons of DU is in storage. Beneficial use reduces storage and potential disposal costs. DU in the form of a cermet is a very high-integrity storage form. If the cask is used for SNF disposal, the DU can enhance repository performance by slowing the degradation of SNF over geological time and reduce the potential for nuclear criticality in a repository [5]. Last, the use of DU in casks co-locates the SNF and the DU. If the SNF is later processed for recovery of fissile and fertile materials, the DU is also available for use in future reactors.

THE PATHWAY FORWARD

Currently, the scientific centers of Minatom RF (RFNC-VNIIEF, VNIIEKhT, VNIINM), working with ORNL are developing and testing cast cermets based on steel and DUO_2 within the framework of the ISTC Project #2693.

To prove the viability and to commercialize cermet casks, marketplace in both Russia and the United States, it is necessary to carry out the following tasks during the next 3–5 years:

1. further develop the concept of a unified multipurpose cask system based on cast cermet material and the cask structural and basket arrangements, taking into account the (PWR and BWR) SNF differences in Russia and the United States;
2. develop the technology of producing bulky cask elements from cast cermet;
3. produce two 1/4-scale cask prototypes from cast cermet; one prototype will be tested in Russia; the other prototype will be shipped to the United States and tested there;
4. test the 1/4-scale cask prototype according to safety requirements;
5. evaluate economical and other advantages of the unified multipurpose cask system made of cast cermet, in comparison with other competing SNF cask types.

A preconceptual, dual-purpose cask will be based on Holtec International's HI-STAR 100 cask system. Initially, the concept is to replace the steel shielding with DUO₂-steel cermet. The basket will utilize Holtec's multipurpose canister concept.

It is estimated that the scope of work to be carried out by Rosatom scientific centers (RFNC-VNIIEF, VNIINM and VNIKhT) will cost ~\$1.1 million U.S. dollars. This work will be in collaboration with ORNL and Russian and American private companies within the framework of the International Science and Technology Center Project (or other funding sources). The execution of this project will provide the technical information necessary for licensing and commercialization of the SNF cermet cask, based on DU, in Russia and the United States.

CONCLUSIONS

The United States and Russia are working together to develop a next-generation SNF storage, transport, and disposal cask system that meets modern-day requirements. The requirements for next-generation SNF casks in Russia and the United States are nearly identical. The leading candidate new material that will enable meeting these requirements is DUO₂-steel cermets. Bench-scale laboratory studies of this new radiation shielding material are nearing completion, and the fabrication and testing of 1/4-scale demonstration casks are planned.

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