DEPLETED URANIUM DIOXIDE–STEEL CERMET MULTIPURPOSE CASKS FOR ENHANCED SNF PROTECTION

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Introduction

An alternative spent nuclear fuel (SNF) management system [1] is being investigated that may offer enhanced physical protection of SNF while reducing costs. Multipurpose casks are made of a depleted uranium dioxide (DUO_2)-steel cermet ("cer" for ceramic and "met" for metal) in which DUO_2 particulates are embedded within the steel used to construct the cask body. The cask is loaded with SNF at the reactor. The sealed cask is then used for storage, transport, and ultimate disposal of the SNF. Overpacks are used to bridge the performance requirements for storage of short-cooled SNF and ultimate disposal. The knowledge gained in the repository licensing process, potential physical-protection requirements to address possible terrorism, and new technologies create the option for an improved SNF disposal system as a second phase of repository development.

The DUO_2-steel cermet (1) reduces cask weight and size and consequently handling constraints compared with other materials because of its superior shielding performance, (2) beneficially uses excess DU, and (3) potentially improves repository performance. For a multipurpose cask [2] with the same capacity (21-pressurized-water reactor fuel assemblies) as the waste package for the proposed Yucca Mountain repository, cask cermet walls (25 cm thick) are assumed to be 50 vol % DUO_2 (36,900 kg) and 50 vol % steel (26,500 kg). The combined system, cask, and cermet characteristics enhance the potential resistance to assault and accidents.

System Characteristics

The multipurpose cask system minimizes SNF handling and thus access to SNF. The SNF is loaded into a cask and never unloaded. The heavy cask provides a secure package for safeguards and minimizes risk of theft.

Cask Characteristics

Because of their intrinsic characteristics, casks have high resistance to assault and accidents. The SNF inventory of each cask is limited, thus (1) limiting the consequences of any single incident and (2) allowing passive cooling, which minimizes potential SNF overheating under accident and assault conditions.

In aircraft collisions, fire is a primary threat to the cask. The high thermal inertia of a cask protects against very high external heat fluxes experienced over a finite (or short) period of time while the modular characteristics of casks limit the duration of any fire. In refineries and other facilities, the ground is (1) sloped to allow liquid fuels to drain away from equipment to burn pits or (2) covered with crushed rock to allow drainage of fuel underground (away from air, thus extinguishing the fire). The same approach is applicable to casks in storage.

Thick cask walls, required for shielding, provide significant protection against aircraft impacts. In Germany, metal casks have been successfully tested against aircraft collisions by firing 1-tonne heavy metal poles (the size of jet engine rotors—the strongest and most damaging component in an aircraft) into SNF casks at 300 m/s [3]. Casks do not have foundations and thus will move under high-impact loadings. This process dissipates the energy in severe events and makes it more difficult to destroy a cask than to destroy a building of the same wall structure and thickness.

Cermet Characteristics

Armor is used as protection against natural and manmade assaults. Armor design involves tradeoffs to provide good resistance to multiple types of threats: high-speed long-rod projectiles (military shells and tornado-driven poles), explosive shape charges, high temperatures (thermite bombs and fires), and cutting tools. An armor designed for a single threat could be highly vulnerable to other threats. Military armor, bank vaults, secure structures, and critical safety systems are usually designed with alternative layers of hard (ceramic) and ductile materials (metals) to maximize resistance to a wide variety of assaults.

Many types of military armor are cermets (but not DU cermets). The DUO_2 cermet in a multipurpose cask is chosen for its shielding capability and repository performance. These requirements define the materials of construction and the relative amounts of DUO_2 and steel. However, assault resistance strongly depends upon the ceramic (DUO_2) particle size and location of the ceramic within in the metal (steel) matrix. Consequently, optimization of the cermet design (within other constraints) can enhance assault resistance.

In a ceramic/metal composite armor system, the hard ceramic face-plate is backed by a ductile metal plate. At Lawrence Livermore National Laboratory, analytical and detailed ballistic testing [4, 5] was used to investigate the mechanisms of defeat. The ceramic initially erodes the front of the projectile (or shape charge jet) and thus reduces its kinetic energy and mass. The ceramic also causes the force of the projectile to be spread over a wider area of the metal backup plate. The role of the metal is to hold the ceramic in place as long as possible to allow erosion of the projectile. The addition of metal into ceramics can provide this increased toughness and greatly improve the ballistic resistance and multi-hit capabilities of a system. The proper distribution of DUO_2 and steel could significantly improve resistance to assault without impacting other requirements or the economics. Alternatively, additional materials could be added to further enhance capabilities.

Conclusions

System, cask, and material characteristics have large impacts on the capability of casks to protect SNF. Enhanced protection of SNF does not necessarily imply higher costs. Two casks with the same materials may have very different capabilities to protect SNF—depending upon design. A DUO_2–steel cermet cask would be a new second-generation approach to SNF management that may offer major advantages. Additional research is required to fully understand performance and costs.

References

Additional information on DU applications in a geological repository can be found at the following URL: "web.ead.anl.gov/uranium/uses/index.cfm." Copies of many of the references are also available at this site.

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