EXTENDED SUMMARY

ALTERNATIVE MANUFACTURING METHODS FOR DEPLETED URANIUM DIOXIDE–STEEL CERMET SNF CASKS

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Cermets using depleted uranium dioxide (DUO_2) are being investigated [1, 2] as a material of construction for spent nuclear fuel (SNF) storage, transport, disposal, and multipurpose casks. The cermet (Fig. 1) consists of DUO_2 ceramic particulates and other (graphite, silicon carbide, etc) particulates, if needed, embedded in a steel matrix between two clean layers of steel.

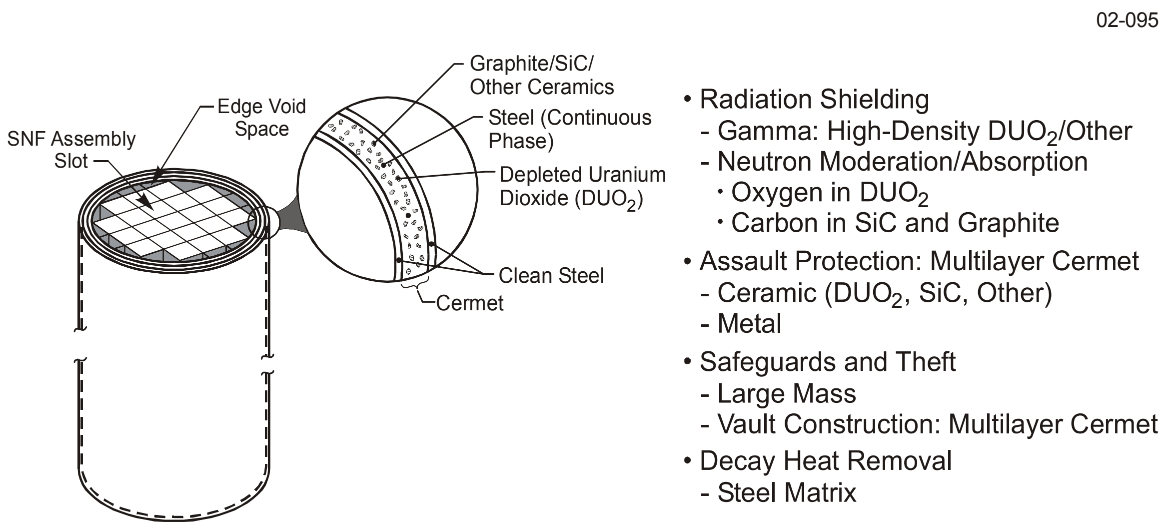

Fig. 1. Depleted Uranium Dioxide–Steel Spent Nuclear Fuel Cask.

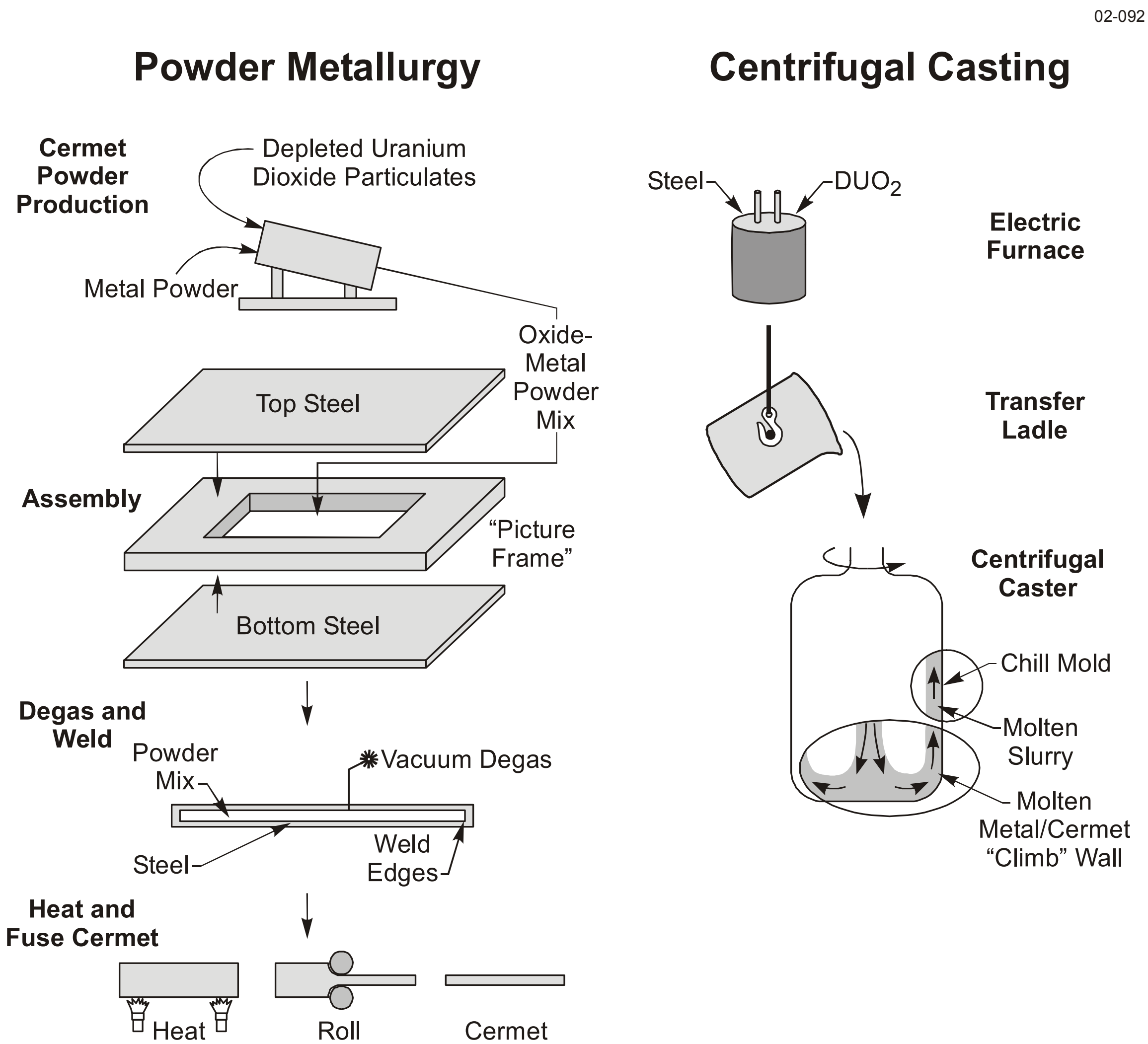

Fig. 2. Traditional Powder Metallurgy and Centrifugal Casting Cermet Production Methods.

Cermet SNF casks have the potential for very high performance compared to casks constructed of traditional materials. The high performance allows casks with greater capacity for the same given weight and size constraints. This performance is a consequence of the material properties. The DU is a high-performance gamma-radiation shielding material. The oxygen, carbon, silicon and other additives provide enhanced neutron shielding. Many types of armor are made of cermets. With the proper choice of particle sizes and materials, the cermet can provide higher resistance to assault and accidents than traditional materials.

All of these excellent properties follow from the fundamental characteristic of a cermet: the ability to encapsulate variable quantities of different ceramic particulates into a monolithic high-integrity metal matrix. The traditional problems (low thermal conductivity, low ductility) of ceramics in a SNF cask are avoided by the metal matrix. Cermets are traditionally used for tough tasks such as (1) tank and vault armor, (2) brake shoes, (3) tool bits, and (4) nuclear fuel in some test reactors.

While the potential performance is outstanding, the viability of using such an advanced high-performance material depends upon developing low-cost reliable fabrication technologies. Alternative cermet fabrication technologies were analyzed in terms of (1) performance and (2) costs. Two sets of fabrication technologies (Fig. 2) with multiple variants currently exist.

- *Casting*. Solid DUO_2 particulates can be added to molten steel. The resultant DUO_2 dispersion in molten steel is cast into a multipurpose cask via one of two casting options: stationary molds or centrifugal casting. In centrifugal casting, the mold is rotated at ~400 rpm while the dispersion of DUO_2 particulates in molten steel is added to produce a cylindrical shell. This technology allows the pouring of multiple layers of metal or cermet, with time allowed for metal solidification between each pour; thus, the cermet can be encased in clean steel. Centrifugal casting is a standard industrial process that is capable of producing objects the size of conventional SNF casks. However, it has not yet been used to produce cermet objects. Casting into stationary molds is used commercially to produce many cermets but has not been demonstrated with a DUO_2–steel cermet. Centrifugal casting generally provides a superior product because the high gravitational forces ensure the absence of porosity within the casting, full separation of any slag from the steel, and a uniform thickness.

- *Powder metallurgy*. Large "picture frames" are fabricated from thick steel sections with a mixture of iron powder and DUO_2 particulates placed within the picture frame. A sheet of clean uncontaminated steel is placed above and below the picture frame. The edges are welded together, and the compact is then vacuum degassed. The section is heated to a high temperature and rolled into a thinner plate to produce the final cermet. The technology has been used to produce a wide variety of UO_2–steel cermets as reactor fuel plates. The technology has not been used to construct thick DUO_2–steel cermets.

The powder metallurgy approach provides greater freedom in the design of the cermet. Casting methods require that molten metal "wet" the DUO_2 or other particulates (SiC, etc) to avoid the formation of void spaces caused by trapped gases between particulates. This requires the addition of selected alloying agents to the metal to improve wetability. Centrifugal casting of multiple layer (clean steel, DUO_2 cermet, etc.) casks requires that the outer layer have the highest melting point and that the inner layer have the lowest melting point. Gravitational effects in casting operations result in settling of the more dense DUO_2 in the molten steel. This defines the volume ratio of ceramic to metal for any given ceramic particle size distribution. The metal fills the void spaces in the particle bed. Powder metallurgical techniques can produce cermets made of materials that are normally considered to be incompatible. This approach makes it possible to include other materials in the cermet to enhance cask capabilities. The technique also allows variation in the three dimensions of the cermet properties by varying the ratio of metal to ceramic, the ceramic particulate size, and the ceramic composition. There are also several newer metallurgical methods that may be attractive for cermet production (details in final paper).

The characteristics of the two manufacturing processes differ significantly. The powder metallurgical methods limit the handling of radioactive DUO_2 to the filling of the preform (picture frame in Fig. 1), a room-temperature operation that requires little space. The casting operations require a greater volume of equipment to be in contact with the DUO_2. However, casting options allow the easy use of suspect contaminated recycle metal, with potential cost savings in materials. The operations of an electric furnace with DUO_2 particulates and clean steel or DUO_2 particulates and potentially contaminated steel are identical. If recycle of potentially contaminated steel is desired using the powder metallurgy route, an electric furnace is required to produce the metal powder—resulting in similar volumes of facilities exposed to contaminated materials for the two processes.

Because of the front-end capital investment, the economics of casting are strongly dependent upon the throughput. Centrifugal casting machines for objects the size of SNF casks are 15 m in height with the top of the casting machine below the floor level of the steel mill. Two electric furnaces are required: one for clean metal and one for the DUO_2 particulates dispersed in molten steel. Incremental production costs for each additional cask, after the facility is set up, are low. Powder metallurgy production techniques have the potential for low costs. Millions of tons of iron and steel powders are produced for the fabrication of many products; thus, the costs of raw materials are low. The preliminary economics and technical uncertainties of these alternative production techniques are described in the full paper.

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