A Spent Fuel Transportation Cask for the 21st Century

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INTRODUCTION

The Nuclear Waste Policy Act of 1982 authorized the U.S. Department of Energy (DOE) to establish a national integrated system for the disposal of spent fuel and high-level radioactive waste. The Act also made the DOE responsible for the transportation of spent fuel from reactors to the repository or to any other federal handling or storage facility developed under the Act. The DOE, through its Office of Civilian Radioactive Waste Management, has initiated the development of spent fuel transportation casks with the objective of having a licensed, tested, and proven operational cask fleet by the end of this century. Cask systems for all three transportation modes (truck, rail and barge) are being developed under that program. This paper presents a road cask design for Legal Weight Truck (LWT) shipments of spent fuel that offers a significant increase in payload compared to existing casks in the same weight class.

The cask design represents a significant departure from conventional cask systems in that it uses a titanium alloy, a structural material with a high strength-to-weight ratio. This application has no precedent in NRC transportation cask certification. The design approach that led to the selection of that alloy for the cask, the projected increase in payload and the associated benefits of reduced life cycle costs, and lower personnel exposures are discussed. The results used were obtained from a feasibility study of the proposed approach that placed special focus on addressing the certification challenges presented in demonstrating the adequacy of the new material. The proposed certification strategy and the overall conclusions from the feasibility study are also presented.

DESIGN APPROACH

Shielded casks for the transport of spent nuclear fuel and high-level waste have been in use for about 40 years. With increasing emphasis on improving payload within gross vehicle weight limitations, cask designers have focused primarily on the use of improved gamma shielding materials. Thus, the casks have evolved from solid steel construction to steel and lead designs, and more recently, to steel and depleted uranium designs.

Depleted uranium represents the most efficient and practical gamma shielding material that is readily available. The weight savings possible with the use of depleted uranium and the associated improvement in payload have made this material economically attractive for application to road casks.

The most efficient gamma shielding materials available are therefore currently being used in road casks designed for spent fuel and high-level waste. Light-weight neutron shielding materials have also been used in recent cask designs. The remaining area in the cask offering potential for significant reduction in weight is in the design of components which provide the structural strength necessary to withstand the various design loading conditions (10 CFR Part 71). The use of high strength-to-weight structural materials was therefore investigated for this application. The family of titanium alloys provided the most attractive alternative to the austenitic stainless steels used in current cask designs.

Titanium alloys have been successfully used in the aircraft industry for its high strength-to-weight ratio, excellent fatigue strength, and weldability. Their outstanding corrosion resistance has also made titanium alloys an attractive choice for the chemical and nuclear industries. Of the various titanium alloys that are available, Ti 6Al-4V (ASTM Gr.5) has become the workhorse of the industry. A leaner alloy, Ti 3Al-2.5V (ASTM Gr.9) using the same alloying elements as Gr.5 was developed about 20 years ago. Ti-Gr.9 is superior to Ti-Gr.5 in terms of ductility, formability, fracture toughness and weldability, though it possesses lower strength. Ti-Gr.9 is also on the verge of being approved as an ASME Code material through a Boiler and Pressure Vessel, Section VIII Code Case. For these reasons, Ti-Gr.9 alloy was selected as the preferred structural material for the LWT cask.

The replacement of stainless steel with Ti-Gr.9 as the primary structural material for the LWT cask provides a direct benefit in terms of reduced weight gained through not only the smaller wall thicknesses required, but also by being able to make more efficient use of depleted uranium for gamma shielding. The overall weight savings possible with this approach provide the necessary margin to increase the cask cavity diameter and accommodate additional fuel assemblies.

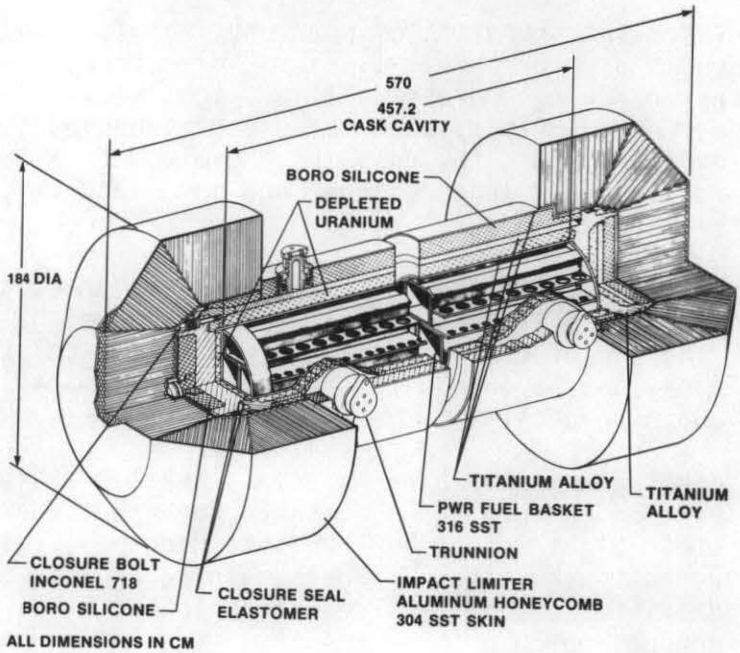

Figure 1. Legal Weight Truck Cask Concept

DESIGN DESCRIPTION

The design configuration of the LWT cask currently being developed is shown in Figure 1. The cask structure is of double-walled construction using Ti-Gr.9 alloy in the form of extruded cylinders and machined forgings. Depleted uranium is installed in the annular space between the two walls of the cylindrical section. Depleted uranium is also installed between the inner and outer Ti-Gr.9 alloy walls of the bottom head and the closure lid. The closure lid is secured to the cask body with a conventional bolting arrangement.

A solid elastomeric neutron shield is installed on the outside of the outer cask structural boundary. This material is protected from the elements and radioactive contamination by a thin covering of Ti-Gr.2 (CP titanium).

The cask configuration shown includes aluminum honeycomb impact limiters. The honeycomb material is encased in a stainless steel sheathing to provide protection against the elements.

The common use version of the LWT cask incorporates interchangeable baskets for transporting either PWR or BWR fuel. The basket (not shown in Figure 1) employs a conventional design using stainless steel with neutron poison plates.

BENEFITS OF PROPOSED DESIGN APPROACH

A comprehensive feasibility study of a LWT cask based on Ti-Gr.9 alloy as the structural material was conducted and the results of that study provide the basis for the benefits discussed below.

Payload

Payload estimates were made for 10 year old fuel with burnups of 35,000 MWD/tonne for PWRs and 30,000 MWD/tonne for BWRs. A common use LWT cask with interchangeable fuel baskets can accommodate 3 PWR fuel assemblies or 7 BWR fuel assemblies. With dedicated casks for PWR and BWR fuels, even higher capacities can be achieved. These capacities are calculated for a gross vehicle weight of 80,000 lb. (36,300 Kg.) and a weight allocation of 54,000 lb. (24,500 Kg.) for the loaded cask. The projected capacities for the titanium alloy cask represent a significant increase compared to existing LWT casks in the U.S. that can transport 1 PWR assembly or 2 BWR assemblies.

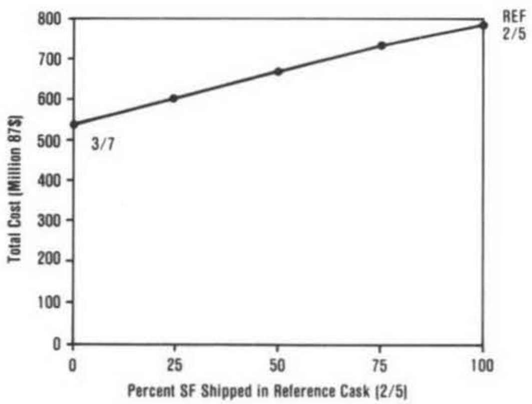

Figure 2. Truck Cask System Life Cycle Costs

Life Cycle Costs

Life Cycle Cost (LCC) savings possible with the titanium alloy cask were estimated from the data provided in (Hoffman, 1988). That approach was based on the following assumptions and input data:

- Life cycle activities modeled for a total shipment of 110,000 MTU
- Modal mix of one-third truck and two-thirds rail shipments
- 60 percent PWR fuel, 40 percent BWR fuel
- One origin and one destination
- Development/Certification and cask fleet acquisition costs
- Cask Decommissioning/Salvage costs
- 25 year design life for the cask

The life cycle costs shown in Figure 2 are based on a generic cask design with a payload of 2 PWR assemblies or 5 BWR assemblies as the reference case. It is seen that for the common use titanium alloy cask with a capacity of 3 PWR assemblies or 7 BWR assemblies, the LCC savings compared to the reference case is approximately $250 million. Modifying this value by the incremental costs of a titanium alloy cask fleet over a stainless steel cask fleet (approximately $10 million) and the incremental development/certification costs (approximately $4 million), a total LCC savings of $236 million can be realized with an all-titanium cask fleet. Even greater LCC savings can be obtained by the use of higher capacity dedicated casks.

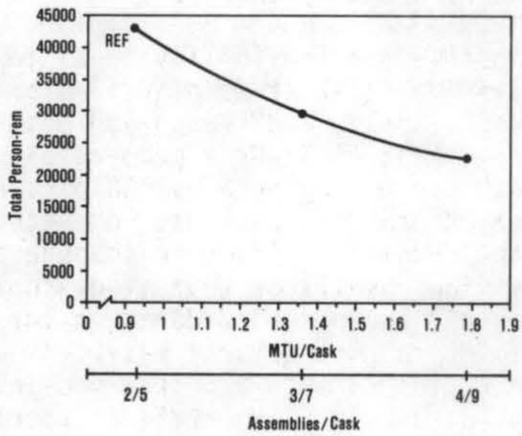

Figure 3. Truck Cask Total Exposure

Personnel Exposure

(Dippold, 1988) presents data on occupational and public exposures for truck and rail shipments of spent fuel. Those estimates consider cask operations at the reactor and repository, in-transit exposures including stops, and population zones. Figure 3 shows the total personnel exposures as a function of cask capacity. With the common use titanium alloy cask design, the reduced number of shipments and fewer number of casks result in an overall reduction in personnel exposure of approximately 30 percent compared to the reference stainless steel cask. With dedicated titanium alloy casks, the overall reduction in personnel exposure is approximately 47 percent. Data included in (Dippold, 1988) also shows that the exposure reduction is approximately the same for both worker and public exposures.

CERTIFICATION CONSIDERATIONS

A formidable challenge is presented in obtaining an NRC Certificate of Compliance for a transportation cask using a new structural material. Key issues are fracture toughness, ductility, weldability, and structural margins of safety. As the Ti-Gr.9 alloy is not currently in the ASME Code, it has to be qualified to the requirements of the BPVC, Section III for Class 1 vessels. An engineering test program to develop the material property data is an essential prerequisite to including the alloy in the Code. While inclusion of the alloy in Section III of the BPVC will go a long way towards obtaining NRC acceptance of the material, it will not be entirely sufficient. In particular, the fracture toughness characteristics at low ambient temperature and ductility have to be demonstrated to more stringent criteria of the NRC than required by the Code.

A survey was conducted during the feasibility study to determine which of the material properties of interest were available. (Shannon, 1980), (Forney and Schemel, 1987), and (Russo and Seagle, 1982) provide a comprehensive listing of Ti-Gr.9 properties. Discussions with personnel from the David W. Taylor Naval Ship Research and Development Center revealed that the Navy had completed a development test program to study the ductility, fracture toughness, and weldability of Ti-Gr.9. The results of that study (not available to the general public) provided further confidence in the suitability of Ti-Gr.9 as a transportation cask structural material. An engineering test program was therefore identified in order to develop the necessary properties not available in the references cited earlier. Table 1 shows the material property measurements that will be obtained through testing.

TABLE 1

Status of Property Data for Ti-Gr.9 and Engineering Tests Planned

	Room Temp Properties Available	Temp Dependent Properties Available	Tests Planned
MECHANICAL PROPERTIES			
Yield Stress	X	X	
Ultimate Stress	X	X	
Modulus of Elasticity	X		X
Ultimate Strain (Elongation)	X		X
Poisson's Ratio	X		X
Density	X		
Coef. of Therm. Exp.	X		X
Fatigue Life			X
THERMAL PROPERTIES			
Conductivity	X	X	
Specific Heat	X		X
Thermal Diffusivity	X		X
Emmisivity			X
OTHER			
Stress Rupture	X	X	
Fracture Toughness	X	X	X
Fracture Mechanics	X		X

The following certification strategy is proposed to demonstrate regulatory compliance for Ti-Gr.9:

- o Use independently verified material properties that were developed by the Titanium Development Association to support their ASME inquiry to include that alloy as a BPVC, Section VIII, Division 1 Code Case.

- o Implement a program of engineering tests to obtain data on the remaining material properties, including fracture toughness, fracture mechanics data and fatigue life.

- o Develop qualified welding and nondestructive examination procedures.

- o Develop a sound rationale for establishing allowable stress values for the alloy that will ensure that adequate design safety margins are maintained compared to materials used in existing NRC-certified casks.

- o Initiate an inquiry with the ASME to include the alloy in Section III, Division 1 through a Code Case.

Preliminary interactions with the NRC have indicated that the proposed engineering test program would be adequate to provide the data for assessing the acceptability of Ti-Gr.9 alloy.

CONCLUSIONS

The results of the feasibility study reported in this paper show that a common use LWT cask design using Ti-Gr.9 alloy as the primary structural material with depleted uranium as the primary gamma shield can accommodate 3 PWR fuel assemblies or 7 BWR fuel assemblies while meeting the gross vehicle weight limitations. With dedicated casks for the shipment of PWR and BWR fuel, the payloads can be increased even further. These payloads represent a significant increase over existing road casks of the same weight class that can transport 1 PWR assembly or 2 BWR assemblies.

The higher payloads made possible with the innovative design approach will result in significant benefits in terms of lower life cycle costs, and reduced personnel exposure to radiation. These benefits are derived directly from the reduction in the required number of shipments. The life cycle cost reductions far outweigh the additional developmental and fleet acquisition costs for the proposed design as compared to conventional cask systems.

The major challenge in the implementation of a cask design using a new material is to demonstrate regulatory compliance. From the evaluation of the currently available material property data base, Ti-Gr.9 appears to be an excellent structural material for transportation casks with no identifiable weaknesses. The planned program of engineering tests should confirm that the alloy possesses suitable values for characteristics such as strength, toughness, ductility, weldability, and fatigue life. Based on the feasibility study, it is concluded that the titanium alloy cask design has a high probability of being successfully licensed by the NRC within the schedule established by the DOE.

The benefits obtained for the LWT cask design using Ti-Gr.9 can also be derived when applied to Overweight Truck casks or to future cask designs for the shipment of non-standard fuel, defense high-level waste,and other waste forms.

The titanium alloy cask design represents a major advancement in transportation cask technology that meets the DOE's objectives for the safe, reliable, and economical transportation of spent fuel in the twenty-first century.

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