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FIBERGLASS REINFORCED PLASTIC IP-2 CONTAINER FOR THE TRANSPORT OF URANIUM ORE SLURRY

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ABSTRACT

AREVA Resources Canada, Inc. (ARC) and Cameco Corporation requested Transnuclear, Inc. (TN) and AREVA Federal Services LLC (AFS) to redesign their transport containers used to transport uranium ore slurry from remote mines to processing facilities in Northern Saskatchewan, Canada. The design requirements stipulated that the containers must be compatible with the loading and unloading equipment at the facilities and meet International Atomic Energy Agency (IAEA) Industrial Packaging, Type 2 (IP-2) requirements. The slurry container is an upgrade to the all-steel 5 m^3 (177 ft^3) container now in service. Due to production increases at the mines, the design requirements emphasize optimizing operational efficiency, including increasing the carrying capacity of the containers.

AFS designed a Fiberglass Reinforced Plastic (FRP) container that is strong and light weight, and has an increased capacity of approximately 44% (from 5.0 m^3 to 7.2 m^3), the AREVA 7 m^3 slurry container, or ASC7. The ASC7 consists of a nominal 32 mm (1.26 in) thick FRP cylindrical shaped inner vessel housed in an approximately 2.6 m (8.5 ft) FRP cube shaped outer container with 16 mm (5/8 in) thick walls, reinforced with a structural steel inner frame. The ASC7 inner vessel is protected by specially designed closed cell polyurethane rigid foam poured in place between the inner vessel and the outer container. The foam provides thermal protection and, in accordance with IAEA IP-2 requirements, mitigates sufficient energy as the result of an impact in an upset condition. A horizontally mounted, pneumatically actuated, knife gate valve provides access to the inner vessel for loading and unloading the slurry. The ASC7 includes a non-structural fiberglass drip pan that acts as a cover to protect the valve from the elements and guides the fill or removal pipes to the inner vessel. The loaded ASC7 weighs up to 14,500 kg (3,200 lb). The ASC7 is mounted on a flat-bed trailer using industry standard ISO corner fittings integral to the ASC7's steel structural frame. The ASC7 is designed for use on paved and unpaved roads at ambient conditions ranging from +40^o C (+104^o F) to –50^o C (-58^o F).

The ASC7 qualified as an IAEA IP-2 package after a 60 cm (23.6 in) free drop testing program. The testing consisted of loading the ASC7 with simulated ore slurry, and performing a horizontal side free drop and a CG-over-top edge free drop. The testing program observed no loss of content or any damage to the inner vessel or the knife gate valve.

INTRODUCTION

ARC and Cameco operate several subsurface mines and processing mills in Northern Saskatchewan, Canada. Underground ore is mined and ground into slurry (Figure-1), then pumped to the surface where it is trucked to processing mills using 5 m^3 (177 ft^3) steel containers. A review of the high grade ore slurry transportation costs prompted ARC to explore a redesign of the currently used all-metal containers and make them more efficient and cost effective. For this reason, ARC and Cameco contracted TN and AFS to investigate an alternative container design.

To achieve this task, while maintaining the overall size and weight constraints as constants, the inner vessel could only grow in the vertical direction for more capacity. However, the overall height of the outer container had to be maintained, as well as the width and length. Therefore, the new container design could only include an inner vessel that would be taller, lighter and possess the necessary strength to carry greater loads.

A study was performed by AFS considering a variety of materials such as titanium, stainless steel, aluminum, and fiberglass reinforced plastic (FRP). The study also examined potential geometries, including a cylindrical shaped shown in Figure-2, as well as the final cubical configuration shown in Figure-3. The cylindrical conceptual design was simpler and more cost effective than the cubical; however, it was more challenging to meet the interface requirements with the facilities loading or unloading equipment and the existing mounting interface on the trailers. This design, however, may be more suitable for other similar applications. The design requirements for this application stipulated that the containers must be compatible with existing container loading and unloading equipment and the trailers' mounting footprints, in addition to meeting the IAEA IP-2 requirements.

The design group took advantage of the strength to weight ratio of the FRP material and developed a new cubical composite container (Figure-3) that is sufficiently strong and lighter than the current metal container. In order to increase the capacity of the container, the currently used ball valve was replaced by a lower profile knife gate valve, resulting in a volume increase of approximately 44%. The empty lighter FRP container weighs approximately 4,200 kg (9,260 lb) as compared to the all-metal container of 6,250 kg (13,780 lb.). A patent is pending on the design of ASC7 with TN as the owner of the design and three AFS engineers as the inventors.

Two (2) ASC7 prototype units were manufactured recently, for the IAEA IP-2 and customer functional qualification testing. One prototype has successfully gone through IP-2 testing and according to the Canadian Nuclear Safety Commission (CNSC, E-DOC: 4075406) it satisfied the IP-2 requirements. The second unit is currently going through rigorous functional and road testing.

PACKAGING DESIGN CRITERIA

The initial function of the ASC7 is to transport batches of natural uranium ore slurry across a distance of approximately 80 km (49.8 mi) in all weather conditions for Northern Saskatchewan, Canada. The trip duration is estimated at approximately two (2) hours, one way. The ASC7 is designed to haul slurry for trips approximately 1,000 km (621.4 mi), which may last 24 hours during winter time. The design prevents the slurry from freezing solid up to 300 hours in -50^o C (-58^o F) condition.

The transport configuration is to transport two (2) containers per trailer with two (2) trailers per conveyance, resulting in four (4) containers for each trip (Figure-4). The containers are filled or emptied while mounted on the trailers in specially designed enclosed loading or unloading facilities respectively. After the containers are in position for the loading or unloading operation within the facilities, the driver attaches the plant air lines and electric control cable to the quick connect couplings mounted on the side of the containers (Figure-5). The facilities control room operators use the pneumatic line and control cables to remotely open or close the valves on each individual container. With the line and cable attached, the driver proceeds to the control room to activate the filling or emptying sequence, which includes activating the valve systems on top of the containers.

The containers are hauled on a flatbed tandem trailer arrangement on a 24-hour, 365-day per year schedule. According to ARC and Cameco requirements, the ASC7 containers are secured to the trailer deck by four (4) ISO blocks at each lower corner, using the same twist-lock currently utilized by the all-metal containers (Figure-5). The containers may be exposed to extreme cold and varying paved and unpaved road conditions.

All of these design challenges were considered in the conceptual study and it was determined that a container design utilizing FRP would best meet the design criteria. The main objective of providing an optimum volume increase was achieved and estimated to be over 7 m^3 (247 ft^3) per container, while adhering to the maximum trailer and container weight limitation, overall size limitation, and all transport regulations.

The cubical geometry of the ASC7 is more compatible with facility interface requirements than the cylindrical design, and allows for ease of manufacturing. The ASC7 maintains the interfaces with the facilities loading and unloading equipment, and the interface with the trailer's standard tie-down provisions (ISO blocks). Furthermore, the FRP components provide for durability at a lower cost and lower weight that an all-metal design. In addition, the ASC7 meets all design requirements with positive margins of safety.

The ASC7 has the following main design characteristics:

- It has been designed to meet IAEA IP-2 requirements which include but are not limited to the following main constraints:
    - The external radiation level at 3 m (9.8 ft) from the unshielded material must not exceed 10 mSv/hr.
    - A 60 cm (23.6 in) free fall on the worst orientation.
- The combined weight of an ASC7 plus its content does not exceed 14,500 kg (16 tons).
- It is designed to be mounted on the B-train tandem trailers now in use and are attached using standard ISO blocks while meeting the transportation regulations.
- It is compatible with current loading and unloading facility infrastructure.

ASC7 CONTAINER DESCRIPTION

A set of sizing calculations consisting of shielding, structural, thermal, and impact evaluations was performed. These generated minimum fabrication criteria for various ASC7 components. The fabricator used these criteria to fabricate the components for the first two (2) ASC7 prototypes. The processes used for FRP components are either spiral wound such as the reinforcement layers on the inner vessel, hand layup such as corner overlays, or infused such as the outer box flat panels. Examples of some laminates with relative thicknesses used in the construction of the ASC7 are shown in Figures -8 and -9. Polyvinyl resin with UV additives is used with woven or mat E-glass fibers for the construction of the FRP laminates. A coupon of the exact laminate for each FRP component is produced and tested to ensure the laminate meets the strength requirements as prescribed by the fabrication specification. Quality Assurance (QA) ensures that the test laminates are duplicated precisely for the actual components.

Typical use of a spiral winding process is when a cylindrical part is desired. Several continuous strands of fiberglass are wound around a cylindrical tool (mandrel) to form a cylinder. While the fibers are winding, resin is injected onto the fibers that are rotating with a constant speed on the rotating mandrel. This process is used for the main body of the inner vessel. In an infusion process, multiple layers of fiberglass mats are laid on top of one another with the resin injected in between for a predetermined laminate size. The wet laminate is vacuum bagged over a certain period of time to ensure the uniform distribution of the resin over the entire part. This process is used where relatively large and simple parts are required such as the outer box side panels. The hand layup process is similar to infusion process except, instead of vacuum manual hand pressing with rollers is used to distribute the resin and squeeze the excess resin to create a uniform thickness for a part. The hand layup process is used for more complex parts and where less thickness uniformity of the part is required.

A typical FRP laminate, using either hand layup, infusion or spiral wound process for the ASC7 components, has a density of approximately 1.9 kg/cm^3 (0.07 lb/in^3), having approximately 65% glass reinforcements by weight. The minimum ultimate strength of the FRP laminates for structural components was tested to be 241 Mpa (35 ksi). These properties in addition to the thermal conductivity property for the ASC7 are shown in Table-1, and compared with the relative properties of A36 steel. Based on these values, which are verified by the successful impact test of the ASC7 prototype, the FRP material's strength to weight ratio has proven to have a great advantage over the metals in this application. In fact, most applications, especially where high ductility is not a major concern, can benefit from this advantage. For this reason many industries have been taking advantage of the substantial cost saving using FRP materials instead of metals. Large heavy duty storage tanks, pipes, bins and cargo containers are commonly made of FRP materials.

Table-1. Some Physical Properties of FRP and Steel Materials

Material	Density Kg/cm^3 (lb/in^3)	Min. Tensile Mpa (ksi)	Thermal Cond. W/m-^{o}K (Btu/hr-ft-^{o}F)
FRP (ASTM D-638)	1.9 (0.07)	241 (35)	0.03 (0.017)
Steel (ASTM A36)	7.75 (0.28)	400 (58)	16 (9.3)

The patent pending ASC7 consists of five (5) major components, as shown in Figures -6 and -7: The Inner Vessel, the Foam, the Valve System, the Outer Box (Outer Shell), and the Drip Pan (Lid).

The Inner Vessel

The inner vessel is a bottle shaped container with a 203 mm (8 in) flanged nozzle at the top for loading or unloading of the slurry. It is designed to hold 7.2 m^3 (254 ft^3) of natural uranium slurry material. The material used in the construction of the inner vessel is a special FRP laminate selected for its strength, impermeability, thermal conductivity and shielding properties with minimum weight consideration. The inner vessel is made from two (2) spiral wound 2.4 m (7.9 ft) diameter cylindrical halves; each molded to include a torispherical head. The two (2) cylindrical halves are, then, joined at the center with hand layup layers in such a manner to ensure that all joints meet the sealing and strength integrity of the design requirements. Not only the torispherical head provides increased strength, it provides a defined low point to minimize slurry left over during removal. The completed bottle shaped vessel is finally wrapped with more hand layup layers to seal the joints and to obtain the desired thickness for added strength. The inner vessel also includes a 2.5 mm (0.1 in) thick abrasion resistant liner made of silicon carbide on the interior surface to minimize the effect of abrasion from the slurry material over the designed life of 30 years. The total nominal thickness is 32 mm (1.26 in) and the overall height is 2.2 m (7.2 ft). The general configuration of the inner vessel is shown in the exploded view of Figure-6 and cross section view of Figure-7.

The Foam

IAEA IP-2 requirements specify a 60 cm (23.6 in) worst orientation free drop test on an unyielding surface that must result in no leakage. The ASC7 must also prevent the slurry from freezing solid for up to 20 hours when exposed to an extreme temperature of -50^{o}C (-58^{o}F). For these reasons, a foam material with special characteristics was specified, tested, and used to meet these requirements. The 80 kg/m^3 (5 pcf) closed cell polyurethane rigid foam performed exceptionally well during the free drop test. It effectively mitigated sufficient energy from the drop impact such that the inner vessel was intact without any cracks and without leakage from the vessel or the valve-to-nozzle joint. Also, a thermal analysis determined that the slurry will not freeze solid after 300 hours of exposure to severe cold conditions as specified. This freeze protection is due to the foam’s very low thermal conductivity coefficient of 0.03 W/m-K (0.017 BTU/ft-hr-^{o} F).

The Valve

A custom designed knife gate valve, shown in Figure-10, is used as a secure access port. The all stainless steel gate valve includes a 203 mm (8 in.) opening for loading or unloading the slurry at the facilities. The valve is pneumatically actuated with positive lock in closed position during transport. The low profile of this valve contributed greatly to the overall capacity increase of the inner vessel. The gate valve passed a functional test at -50^o C (-58^o F) in an independent lab, and during qualification testing of the ASC7, it performed successfully as was expected.

Use of a gate valve instead of the current ball valve on the metal container, allowed substantial amount of space for the inner vessel to grow vertically for optimum capacity increase. However, lack of a positive stop on the gate from opening during transport posed a question. It is possible that during the transport of the slurry material on the road, an adequate unknown force may actuate the main cylinder rod of the actuator against the residual air pressure that may exist in the cylinder of the actuator. This may open the gate and slurry material could leak out. For this reason, a unique pneumatically operated rod clamp mechanism was designed and included in the gate valve system. The challenge was to maintain the two existing pneumatically operated lines from the control rooms of the facilities and not to impose any new lines or components to the existing operating conditions at the facilities. This required that the additional lines for the locking clamp device and the required logic valves to operate with the actuator of the main gate valve all in a precise and logical sequence and be integrated as part of the valve system. This system is currently being functionally tested on the road.

The Outer Box

The outer box protects the foam and the inner vessel from both impact and harsh environmental conditions during storage and transportation. It includes a structural frame made of Hollow Structural Section, HSS 76×76×5 mm (HSS 3×3×3/16 in.) and a set of FRP panels 16 mm (5/8 in.) thick bolted to the frame with 9 mm (3/8 in) carriage bolts all around. The steel frame is a welded structure that stiffens all corners and edges, and provides stability to the entire box. The weldment includes a set of cargo industry standard ISO blocks that provides a mounting footprint on the trailers. In addition, it consists of a set of steel tubing on the bottom to reinforce the bottom FRP panel from deflection when the loaded container is crane lifted. The frame serves as the support for the FRP panels located on the four (4) vertical sides and the bottom. The FRP panels are made of multiple fiberglass layers of woven material laminated through an infusion process. This process is used to achieve maximum flatness with a smooth surface finish and to improve cost efficiency for large quantity production. The FRP panels are bolted to the frame at the corners and edges. All exterior and interior corners and edges are then overlaid by FRP hand layup material to minimize contamination entrapments and to increase rigidity. The outer box is sized to fit on the existing trailers and be used interchangeably with the metal container as shown in Figure-11.

The Drip Pan

The drip pan is a hand layup FRP laminate, cone shaped and approximately 9 mm (3/8 in) thick. It acts as a lid to cover the entire container and protects the upper components such as the valve, air and electrical lines, and fittings from the environmental elements during transport. At the center, it fits inside a stainless steel ring over the valve opening to provide a guide for the facility fill pipes. Through its outer perimeter wall, it is secured to the outer box by eight (8) each 13 mm (1/2 in) diameter ball lock pins, which adds rigidity to upper section of the outer box. The pan's unique design guides any contaminants or any rain/wash water to the nozzle for drainage into the inner vessel. Its cone shaped design is specific to the washing machine resting footprint that is designed for the current metal containers at the facilities. This drip pan is shown in Figure-6.

QUALIFICATION TESTING

The ASC7 has satisfied the IAEA IP-2 requirements according to CNSC, for the purpose of transporting natural uranium ore slurry. Qualification testing employed a free drop test as prescribed in paragraph 622 of IAEA TS-R-1 for IP-2 [1]. To ensure the worst case orientation was tested, the drop test was performed in a side orientation and in the center-of-gravity over top edge orientation. The first test would represent the maximum impact (acceleration g load to the container) and the second, the maximum deformation in the region of the valve for potential leakage through the nozzle.

The drop test used a full scale prototype ASC7 container that was fully loaded with a slurry simulant with an average specific gravity of 1.5. The total weight of the ASC7 plus the simulated slurry was 14,500 kg (16 tons). The test consisted of two (2) 60 cm (23.6 in) free drops and included pre and post-drop-leak testing and observations. No leakage was observed.

The ASC7 also met the principal acceptance criteria that, following the worst case free drop it would not result in loss or dispersal of the radioactive contents or loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package.

OPERATION AND MAINTENANCE

The ASC7 containers are designed to operate in the same or more severe environmental conditions as the metal containers currently in service, using the equipment now in use for transportation, and for loading and unloading natural uranium ore slurry.

The ASC7 containers are designed to interface with the trailer ISO tie-downs with the exact foot print on the trailers currently in service. No other tie-downs are required to secure the containers to the trailers. The ASC7 design accommodates the interface with the electrical and pneumatic service currently employed, as well as the positioning platform for loading and unloading the inner vessel. Minor changes to the limit switches/instrumentation will be required in order to fill the container to the larger capacity. Operational testing will confirm whether any other changes are required.

The drip pan of the ASC7 has an integrated alignment frame designed to interface with the facilities' platforms without the need for an external alignment frame. The positioning rollers of the facility platforms stop at the corners of the drip pan flange in exactly the same way as with the alignment frame used for the current containers. The ASC7 has integrated fork-lift tubes that allow lifting of the container from the trailer using a fork lift or overhead crane.

All of the filling, washing, and drying processes are automated and observable from the control room. At the filling facility at the mine site, the surfaces of the container that could potentially be contaminated during filling are washed, dried, and the exterior surfaces are visually checked for external material using a remote camera mounted on the filling equipment. In addition, the surfaces of the containers are radiologically surveyed. After the four containers on the trailers have been filled, washed, dried and visually checked, the driver detaches the air lines and control cables. The truck then proceeds to the unloading facility at the mill site facility.

The containers are emptied at the mill site facility using a process that is essentially identical to that used at the loading facility. The containers are emptied using a vacuum suction hose that is inserted through the knife gate valve and a secondary check valve which is located in the vessel and mounted below the gate valve on the flange of the inner vessel nozzle. After unloading, the exterior surfaces are washed and checked for contamination. Material on the drip pan is washed into the inner vessel, which is then rinsed and all remaining contents are removed.

The uranium slurry transfer containers are periodically removed from service for routine maintenance. The principal maintenance services are the ISO blocks and the valve that allows hose access to the inner vessel. In addition, the check valve below the knife-gate valve requires inspection and periodic replacement as necessary. Because of the inherently superior corrosion resistivity of the FRP materials over metals, no painting or repainting is required for the ASC7.

The pigment is impregnated in the walls of the FRP laminates. Therefore, any potential chipping or surface scratches as the result of impact with flying objects during transport or otherwise, does not impair productivity caused by high maintenance costs.

Figure-1. View Showing Uranium Slurry being poured out of a can

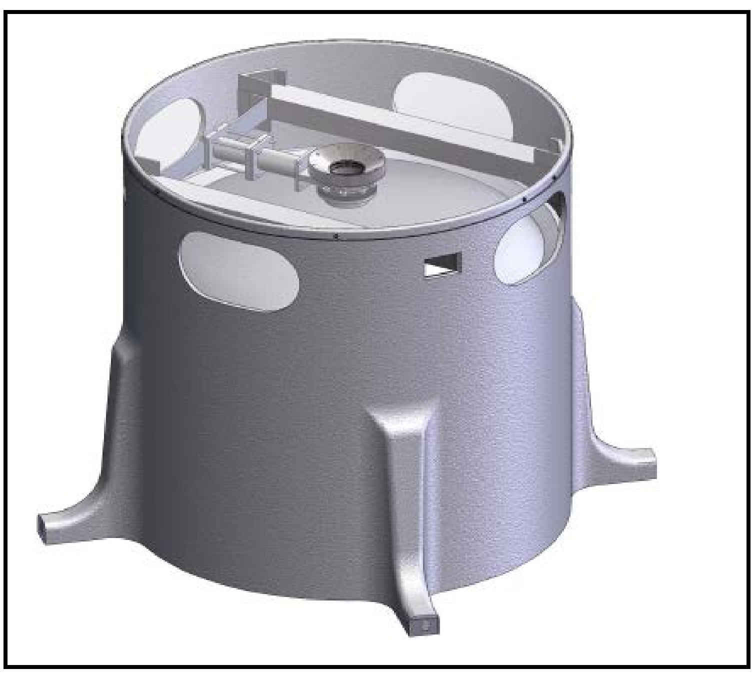

Figure-2. ASC7 Preliminary Cylindrical Conceptual Design

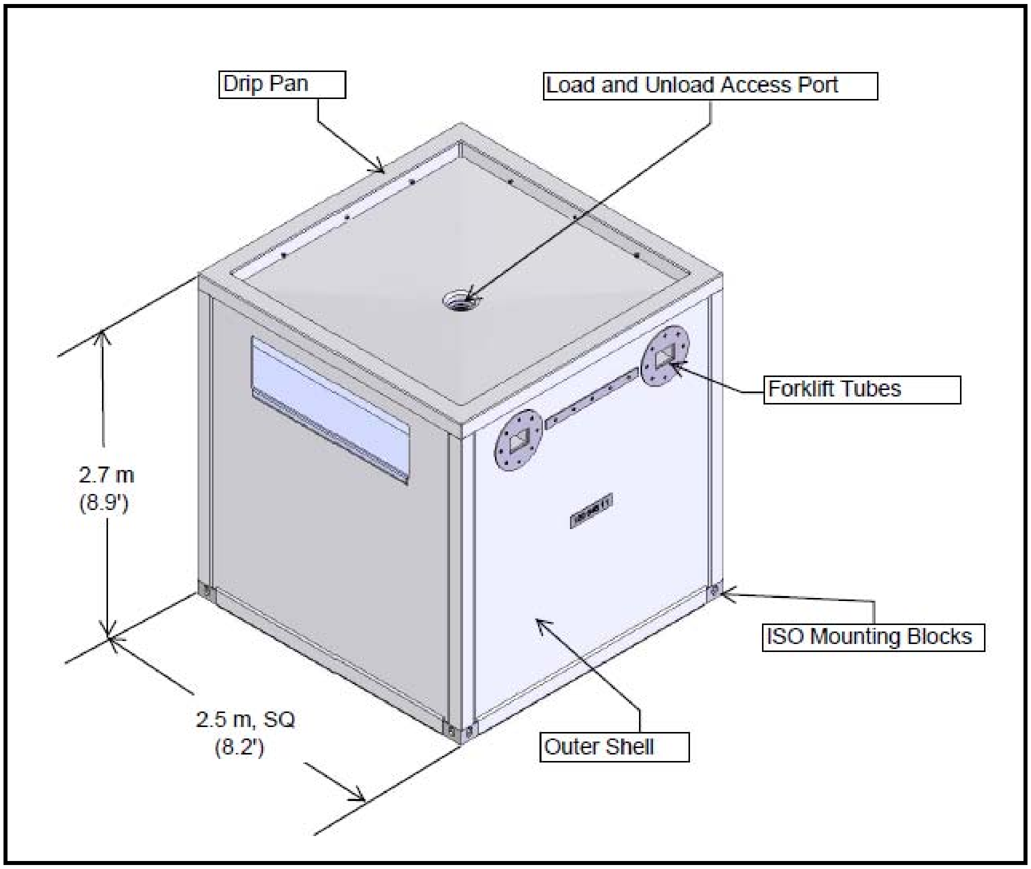

Figure-3. ASC7 Final Cubical Design

Figure-4. Trailer's Loading Configuration (all metal containers)

Figure-5. Trailer's Current Mounting Configuration and Quick Connects

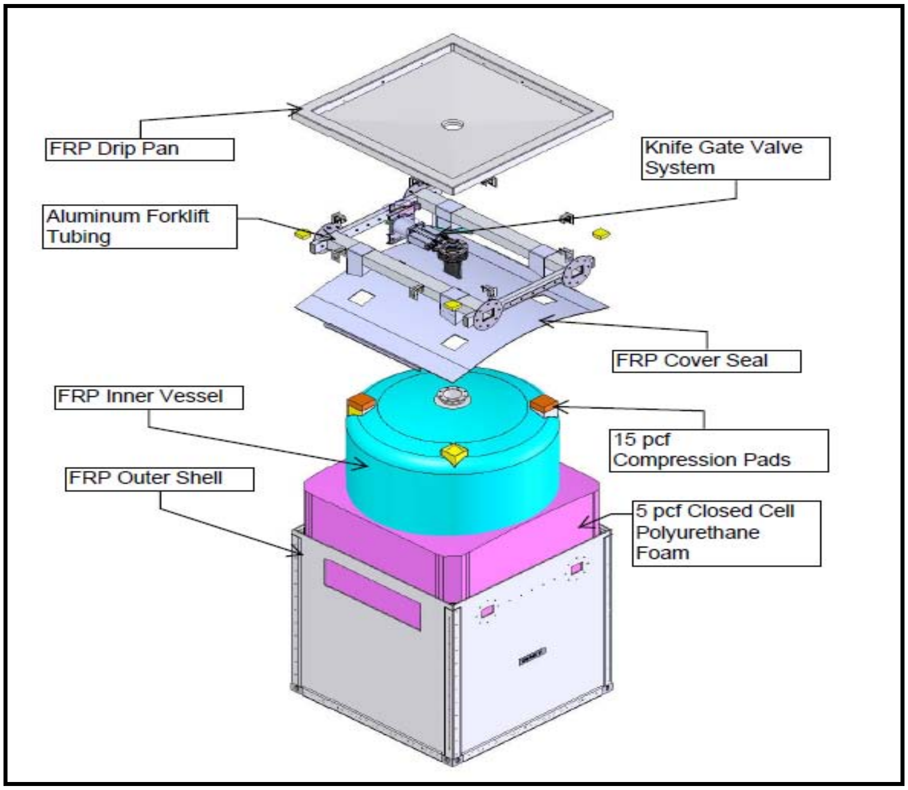

Figure-6. ASC7 Exploded View

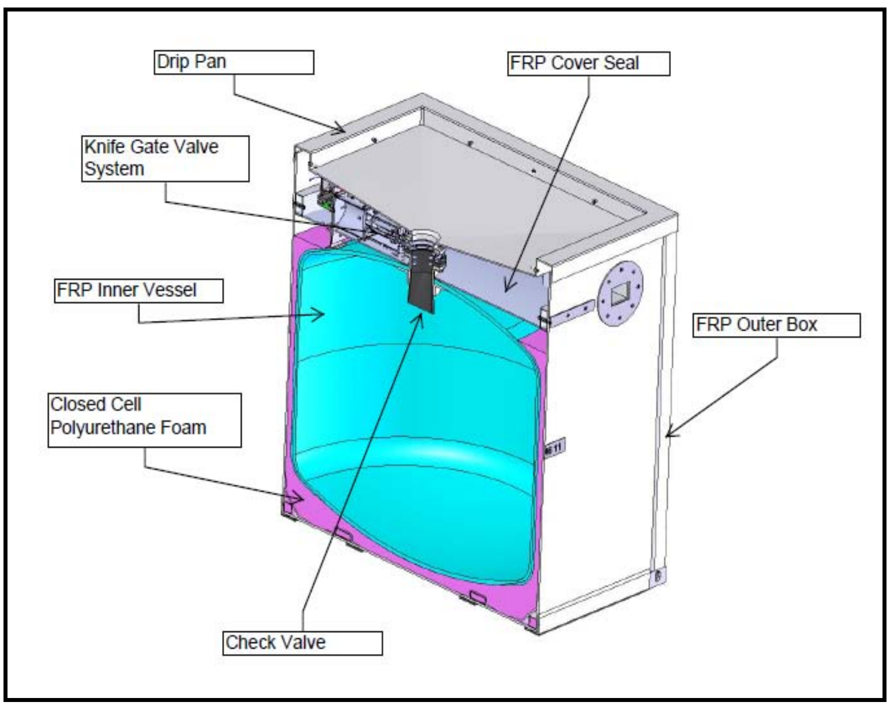

Figure-7. ASC7 ISO Cross Section View

Figure-8. FRP Hand Layup Laminate

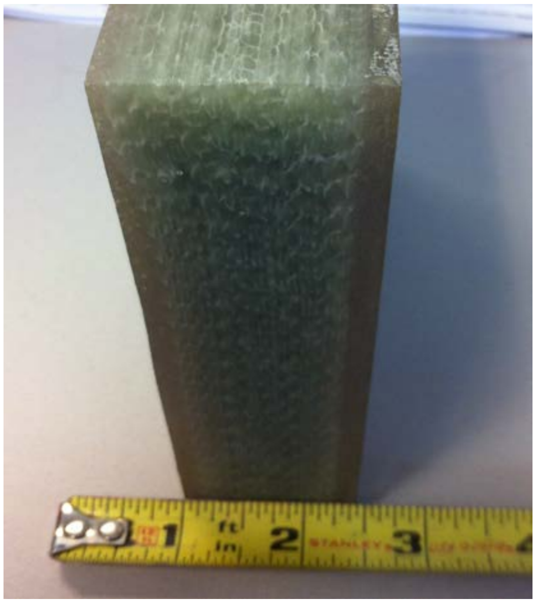

Figure-9. FRP Infused Laminate

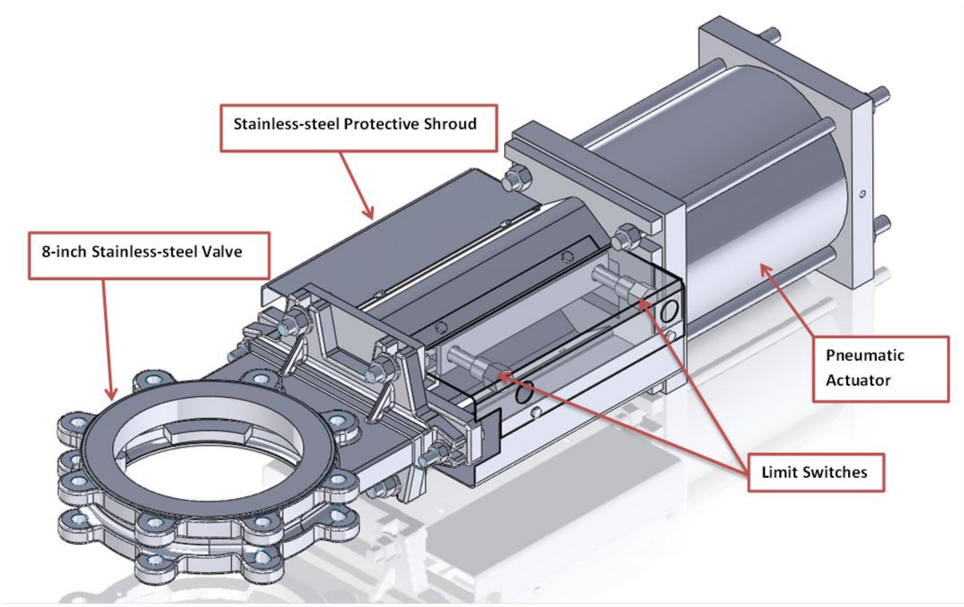

Figure-10. Knife Gate Valve

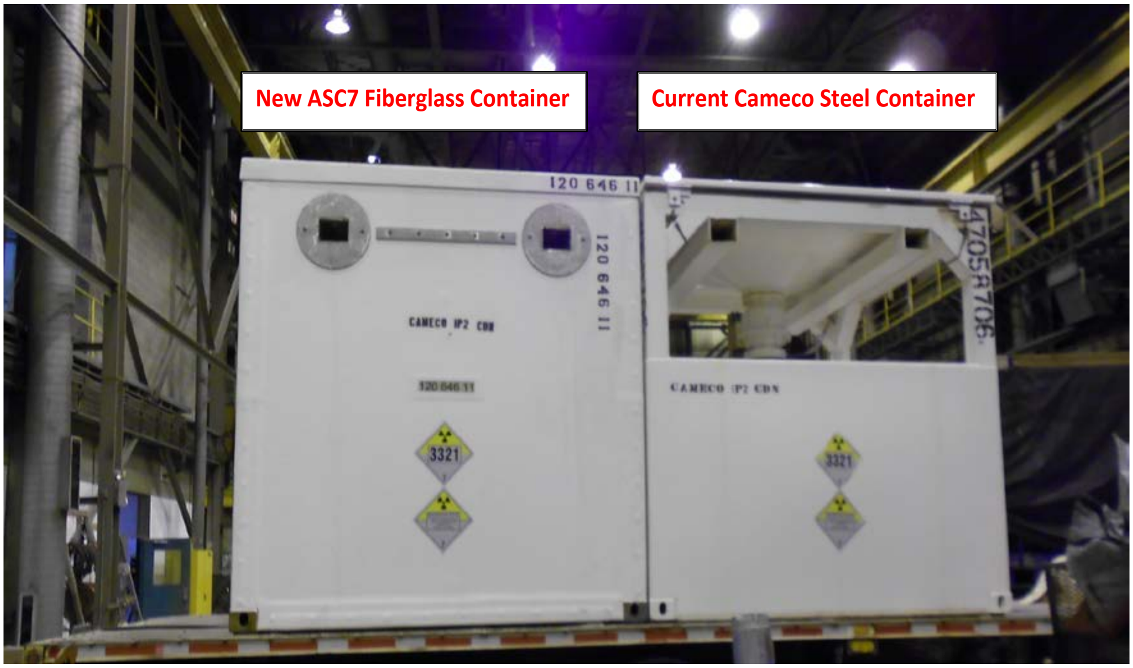

Figure-11. ASC7 Mounted on Trailer Adjacent to a Metal Container for Operational Testing

CONCLUSION

The ASC7 container consists of an outer box comprised of FRP panels fastened to a tubular steel frame and a robust FRP inner vessel that serves as containment for natural uranium slurry. The ASC7 is mounted on a flatbed trailer and is designed to withstand the rigors of travel on unpaved roads under an ambient temperature range from -50° C (-58° F) to + 40° C (104° F). Closed-cell polyurethane foam fills the void between the inner and outer vessels and provides thermal insulation and impact protection in the event of an upset condition. The inner vessel is filled and emptied using pipes that access the inner vessel by means of a pneumatically actuated knife-gate valve. The ASC7 container was qualified as an IP-2 with respect to the requirements of TS-R-1. The ASC7 is a durable container that provides a significantly increased payload capacity over the existing steel container for the same transport weight due to its FRP material's strength to weight ratio advantage. This technology offers a high potential for a great life-cycle savings in many industries where metal containers are used for the transport of goods.

ACKNOWLEDGMENTS

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REFERENCES

1- 1996 TS-R-1, *Regulations for the Safe Transport of Radioactive Material*, International Atomic Energy Agency, (IAEA).