Application of the LR-56 Radioactive Liquid Waste Transport System at DOE Facilities in the United States

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SUMMARY

The ability to ship Type B liquid packages will be necessary for the nuclear industry to meet the energy production requirements of the next century. There are no packages licensed in the United States for transportation of large quantities of such liquids, at present. Packages designed for transporting liquids must address technical challenges and incorporate features which are not common to packages designed for solid contents. These issues and the methods of addressing them are illustrated by the safety analysis performed for utilization of the LR-56 Liquid Package at US DOE facilities.

INTRODUCTION

Shipment of Type B quantities (i.e. quantities having significant radiological consequences) of radioactive liquids between different sites has been essential to the development of the nuclear energy program in France. Based on the experience acquired at the Commissariat a l'Energie Atomique (CEA) nuclear centers, a series of tank trailers has been developed to meet this need. In the United States, implementation of the program to process wastes to stable end forms at DOE sites has created a need to move similar radioactive liquids. The LR-56, developed by CEA to transport liquids of medium to high activity, was selected for these US applications, based on its design features and successful operating experience in France.

There are no comparable Type B liquid packages certified in the United States. Certified packages employed in transport of Type B quantities of liquids in commerce are only suitable for small volumes. Liquid waste tank trucks, which are not certified, are used within site boundaries. Extensive administrative controls are imposed on the use of these tank trucks, to insure that an adequate level of safety is maintained.

Type B radioactive materials packages (RAM packages) are typically simple, robust containers which are designed and fabricated in accordance with the ASME Boiler and Pressure Vessel Code to provide containment under the normal conditions of transport (NCT) and hypothetical accident conditions (HAC) established by the regulations. Packages designed for liquid contents must address a number of technical issues which are not common to packages for solid contents.

THE LR-56 PACKAGE SYSTEM

The LR-56 Package. (see attached Figure) consists of a horizontal cylindrical containment vessel, of approximately 1000 gal. capacity, surrounded by a secondary vessel, lead shielding, mechanical support vessel, wood impact and thermal shield and outer envelope (Reference 1).

The containment vessel is fabricated from 8 mm thick, Uranus B6® stainless steel. This alloy was chosen for use with the aggressive chemicals in the contents. These include phosphoric, sulfuric and hydrochloric acids. Three service wells are provided in the vessel for loading and unloading. The primary containment vessel is enclosed by a 6 mm thick, 316L stainless steel secondary vessel. With the exception of the Savannah River LR-56, this secondary vessel is a confinement vessel which collects and limits release of any spills or possible leaks, should they occur. The secondary vessel closure, however is not leak tight. For the Savannah River application, in keeping with the regulatory requirement for double containment of plutonium, the secondary vessel itself and closures have been redesigned to be leak tight and to be leak testable.

A 35 mm lead blanket surrounding the secondary vessel provides biological shielding. Additional shielding is provided around the service wells to ensure continuity of shielding. The lead blanket is assembled by welding performed sections. Compared to casting the lead in place, this method insures against porosity defects and permits recycling of the components.

A 30 mm thick, carbon steel structural vessel encloses and supports the containment vessels and lead blanket. The structural vessel provides mechanical support for the interior components, mechanical protection and additional biological shielding.

Thermal and impact protection for the interior components is provided by a layer of balsa and redwood, arranged in checker-board fashion, 150 to 550 mm thick. The wood layer is contained within an outer, carbon steel shell.

The liquid handling and instrumentation components are attached to flanges which are located within three service wells. Self sealing connectors are provided for the loading and unloading lines. These disconnects, developed from aircraft fuel systems, are provided to minimize release of radioactive liquids when the connections are made and broken and to minimize exposure of personnel. Level measurement and high and low level indicators are also provided.

The system is installed on a dedicated semi-trailer which conforms to US DOT requirements. The cask is secured to the trailer on cradles which are welded to the trailer frame. The cask is retained by shackles and front and rear stops.

The LR-56 system includes an air pump, filter system, instrumentation and controls to enable loading and unloading of the package. A crane for handling the access closures is also provided. With the exception of electrical power, the system is self contained and can perform all liquid handling operations without external assistance. French units are fitted with an internal combustion engine, making them independent of the electrical power requirement.

The units procured for use at the DOE sites incorporate additional features, in response to their particular applications. These include additional instrumentation and an internal spray-wash system for removal of residual material.

The Hanford and Oak Ridge units will be used to move waste materials similar to those for which the LR-56 is used in France. The SRS unit has been evaluated to move fissile material, including Plutonium solutions in excess of the regulatory amount for Plutonium bearing solutions. These are beyond the experience and design basis for the unit. Consequently, a thorough re-evaluation of the certification basis has been performed.

REGULATORY REQUIREMENTS

The regulatory requirements of 10 CFR 71 establish the criteria for Type B radioactive materials packages. These regulations are concerned with the containment, shielding and subcriticality of contents, rather than the phase of the contents. These regulations impose no special restriction on liquid contents, as distinct from solid contents, except for limiting Plutonium solutions to less than 20 Ci.

The LR-56 packages which have been purchased for use in the US are all intended for on site use at DOE facilities. Since the DOE applications are on-site moves, an exemption to the requirements of 10 CFR 71 may be employed, under the condition that equivalent safety (to public, workers and environment) is provided. To show equivalence, the performance of the package with its liquid contents must be evaluated against the standards of 10 CFR 71 for protection of public, workers and environment.

TECHNICAL ISSUES ASSOCIATED WITH LIQUID PACKAGES

CONTENTS DEFINITION

The definition of the contents may be more difficult for liquid than for solid contents. The reason for this is the ability to alter liquid contents, by valve misalignment during handling or loading. An incorrect valve alignment could allow incorrect contents to be loaded into the package or mixed with the intended contents. Such an event could directly change the contents, or result in a chemical reaction.

For liquids which are mixtures rather than solutions or solutions whose constituents are near phase saturation limits, separation of constituents may occur, with consequent stratification of phases. If the liquid contains suspended particles, these may settle during transport, forming a sedimentation layer which may subsequently be difficult to remove.

Some free volume is needed to allow for thermal expansion and gas generation in a liquid package. The presence of the free liquid surface permits surging and wave motion which can result in hydrodynamic loading on interior components.

Radioactive liquids characteristically produce hydrogen gas by radiolysis. In addition to its contribution to increasing the pressure within the package, the presence of hydrogen creates a flammability hazard.

Because the corrosion processes occur more rapidly in liquid environments than in dry conditions, materials compatibility concerns are more critical for liquid packages.

For the Savannah River application, the requirement of rigorous contents definition is met by analysis of the contents, provision of a dedicated tank in the loading facility and physical controls on the liquid transfer systems, for the LR-56. For the application of the LR-56 at the Savannah River Site, the time limit for shipment, from closure of the vessel, is a function of the vapor volume available in the vessel. The time to the lower flammability limit, due the increase in hydrogen concentration from radiolysis, is also proportional to the vapor volume available. For this reason, the volume loaded into the cask and the time for transfer must be closely controlled and the vapor space must be purged with nitrogen to provide an inert atmosphere. In the event of an unforeseen interruption in the shipment, the LR-56 onboard systems would permit venting and re-purging of the vapor space at an intermediate stage of the shipment.

STRUCTURAL ISSUES

Packaging design for liquids addresses a number of structural considerations which differ from the issues associated with solid contents. Motion of the fluid under both NCT and HAC conditions impose loadings on the package, that do not occur with solid contents. Under NCT, the motion of the fluid results in hydrodynamic loading of baffles, and internal components. It also results in a shifting center of gravity and dynamic loading of the components securing the package to the vehicle. Under HAC, the liquid transmits internal pressure loads during impacts to all interior surfaces with which it is in contact. Consequently, closures must be designed to withstand transient pressure loads during NCT and HAC events. Such loads are not experienced in dry contents packages.

The presence of contents handling equipment is unique and requires special attention, structurally. The regulations require the employment of a dip-tube to remove liquid from the containment vessel (rather than a drain point in the bottom of the vessel), for containment reasons. This dip tube must be adequately supported so that it is able to withstand the HAC drop test accelerations, and vibrations experienced in NCT. In addition it must be able to withstand forces produced by bulk motion of the liquid during transport.

Finally, the tube must be designed so that it does not act as a spear and puncture the containment vessel, if the vessel deforms during the drop test.

For the LR-56, the liquid handling features are supported so that they are able to withstand drop and hydrodynamic loads. In addition. they are designed so that they will not penetrate the containment vessel under the loads and deformations experienced during drop tests. Finally, in most cases, they are designed with bends, so that they would buckle, rather that transmit full loads to the containment vessel.

An additional issue, particular to packages fabricated outside of the United States, but used in the US, is that of design codes and standards. Nuclear Regulatory Commission Regulatory Guide 7.6 requires that packages be designed to the ASME Boiler and Pressure Vessel Code. Use of other codes and standards requires review on a case basis. In the case of the LR-56, which was designed to the CODAP pressure vessel code, sufficient re-evaluation was performed to show that the ASME Code requirements were met. The CODAP methodologies are comparable to Section VIII of the ASME Code.

In addition, the NRC regulations (e.g. NUREG/CR-3854) invokes ASME code fabrication criteria for the fabrication of shipping containers. A thorough review of fabrication methodologies employed for the LR-56 was conducted to confirm that these requirements were satisfied, as part of the safety analysis of the Savannah River unit.

THERMAL ISSUES

Liquids requiring a Type B package generally have significant heat generation. To prevent boiling, the package must be able to dissipate this heat. Liquids achieve good thermal contact with the containment vessel. As a result, the contents-to-containment-boundary thermal resistance, which is typically a source of difficulty in packages for heat generating solid materials, is minimized.

The heat release by and temperature rise of the contents also has structural implications. By regulation, all packages must be sealed during transport. The vapor pressure increase with temperature, for heat generating liquids, results in increasing internal pressure for liquid packages.

In the case of the LR-56 applications, some of the proposed contents have sufficient heat generation that the duration of shipment must be closely controlled administratively. This is achievable for on-site movements at a controlled facility, but would not be acceptable for moves in commerce.

CONTAINMENT ISSUES

The ASME Code design practice provides assurance of structural adequacy. However, packaging applications are also concerned with maintaining containment of the contents. In consequence, in addition to preventing catastrophic structural failure, the displacement or deformation of all closures must be minimal.

In some respects, containment of liquids is more challenging than for solids. For example, liquids can flow from any breach in the containment, which might be located below the free surface. For packages containing large volumes, such as the LR-56, the volume of liquid present may represent thousands of A_2 quantities. However, unless a dispersion mechanism is present, such as flowing water or fire, the contents will either remain as puddle, or soak into the soil in the event of a spill. In this respect, liquids are much less dispersible that powdered solids, which can easily become airborne, or gases.

A significant modification for the Savannah River LR-56 was upgrading the secondary vessel to provide containment. The modifications included changes in materials and secondary closure design to provide a testable leak tight closure design and corrosion resistant material for the containment boundary. The presence of hermetically sealed electrical connectors in the containment boundary follows the practice of the Radioisotope Thermoelectric Generators, Ref. 2. The electrical connectors were qualified by subjecting them to rigorous shock testing. After being subjected to shock accelerations exceeding those predicted for the LR-56 under HAC, by bounding analysis, the connectors were leak tested to confirm that they met the leak tightness requirements.

SHIELDING ISSUES

Because of their geometry, liquid packages allow efficient shielding. Liquid containers are typically cylindrical so that protection provided by a given mass of the shielding material is optimal. In addition, the relatively small openings needed for filling and emptying the package simplifies shielding.

The biological shielding for the LR-56 is obtained from the combination of the containment vessels, the 35 mm of lead and the 30 mm steel strength vessel. The Wood layer contributes to neutron shielding, and because of its thickness, increases the distance between the contents and accessible surfaces.

CRITICALITY ISSUES

Insuring subcriticality in liquid packages is accomplished in the same manner as in packages for solid contents. First, the quantity of fissile material can be kept below the critical mass. Secondly, the geometry of the fissile material can be controlled so that the material remains subcritical. And third, sufficient poison can be employed to insure sub criticality. The forth means, eliminating moderation, is not an option for aqueous solutions. In keeping with packaging practice, redundant independent means of insuring sub criticality must be employed. This may be accomplished by controlling amounts, geometry or introducing liquid or solid poison into the vessel.

The LR-56 was designed to transport wastes in which the quantities of fissile material are insufficient for criticality to be a concern. Some of the proposed Savannah River contents, however, could contain fissile material in excess of the critical mass. However, the fissile material is in solution and, like salt in sea water, will remain in solution unless a chemical addition is made, or a change in state, such as freezing, occurs. While in solution, the material is dispersed geometrically, so that criticality is prevented by geometry. For the Savannah River application, a Double Contingency Analysis (DCA) was performed to confirm the effectiveness of the controls being designed to ensure that the solution chemistry is maintained within the required limits. The DCA identified no mechanism which could adversely affect solution chemistry within the package after closure. Nevertheless, in order to provide a redundant means of insuring subcriticality, liquid poison will be employed for the Savannah River contents.

OPERATIONS ISSUES

In keeping with DOE orders, the DOE sites must prepare safety assessments for their application of the LR-56. Administrative controls on the loading, transport, and unloading will be included in the safety assessments. The Transportation Plan, which is part of the administrative controls, will specify the route which will be followed, speed of movement, roads which will be closed to other traffic, and escorts required for the movement of the package. The speed and traffic controls will eliminate the possibility of a traffic accident. The route will be selected to avoid crossing streams to eliminate the possibility of immersion and contaminant dispersion. The amount of fuel on the tractor will be minimized to minimize the duration of any fire which might occur.

Loading and unloading operations for liquid packages are fundamentally different from packages for solids. The contents can be loaded into the vessel, or removed from the vessel through relatively small openings. Once the connections are made, the transfer can be made completely by remote operation. Transfer by siphon is recommended, since under these conditions the transfer lines are at sub-atmospheric pressure. Following transfer, the lines must be flushed to minimize the amount of residual radioactive material, before being disconnected.

The provision of internal instrumentation in the package, such as level indication and high and low level limit detectors, interseal pressure indication, intervessel leak detection and cask temperature indication is needed for the remote loading and unloading operations. The presence of such instrumentation, while not common in packages, is similar to the instrumentation installation in the packages for the Radioisotope Thermoelectric Generators. Provision is made to monitor key parameters during transport.

As noted, hydrogen gas is likely to be present as a result of radiolysis. Accordingly, measures must be taken to analyze for the presence of hydrogen and provision made for purging the vessel with inert gas to reduce the hydrogen concentration to a safe level.

The LR-56 is provided with Zenith® quick disconnect couplings, adapted from aircraft refueling practice. These couplings, in addition to being self sealing and containing mechanical interlocks, provide minimal residual liquid at the coupling interface after the connection is broken. The LR-56 remote operating system helps maintain personnel exposure as low as reasonably achievable.

CONCLUSIONS

The design and certification of packages capable of carrying large volumes of radioactive liquids, well in excess of a Type B quantity, requires addressing a different set of issues from those commonly encountered in design of packages for solid contents. With effective design, these issues can be resolved so that the regulatory requirements of 10 CFR 71 are satisfied. The experience of the CEA demonstrates the feasibility of employment of Type B liquid packages in management of radioactive liquid wastes.

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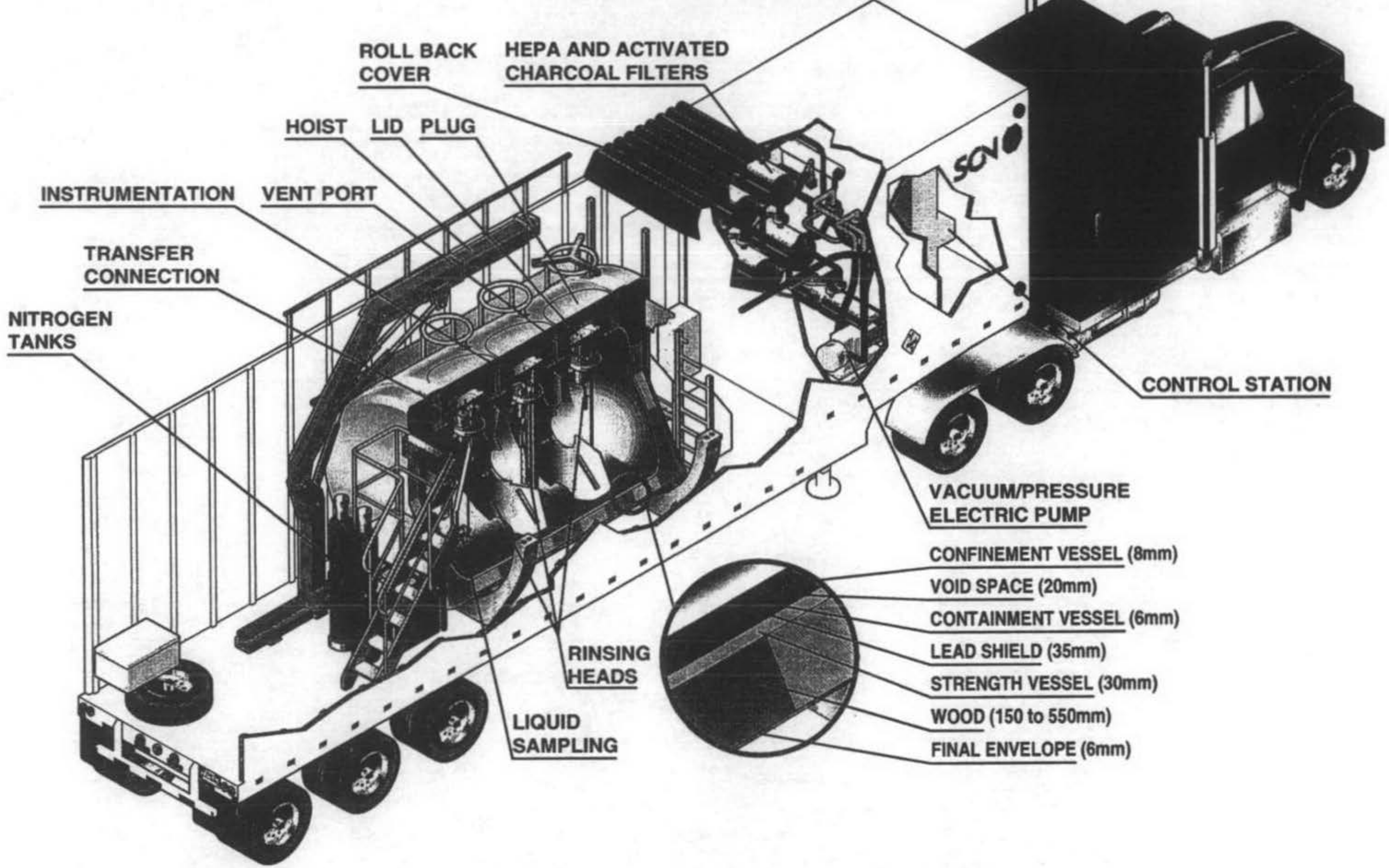
HIGH LEVEL RADIOACTIVE LIQUID WASTE TRANSPORTATION SYSTEM



SESSION 5.2

Container Design