CONF-950646--6

SAND95-0143C

A904

Research and Development Program for Transportation Packagings at Sandia National Laboratories*

Glenn F. Hohnstreiter
Transportation Systems Department 6642
Sandia National Laboratories
Albuquerque, NM 87185-0717

Ken B. Sorenson
Transportation Development Department 6643
Sandia National Laboratories
Albuquerque, NM 87185-0716

* This work was supported by the United States Department of Energy under Contract DE-AC04-76DP00789.

INTRODUCTION

The purpose of Research and Development (R&D) in transportation is to identify technical issues required to assure that the U. S. Department of Energy/ Office of Environmental Management (DOE/EM) transportation program will be able to provide safe and efficient transportation of radioactive materials and mixed wastes for the DOE complex in the 1990s and beyond. By its nature, R&D represent long term commitment to solve technical transportation problems, to evaluate new and novel technologies for their applicability to transportation efficiency and safety, and to provide convincing assurance to the public that a comprehensive understanding of the technology of radioactive material packagings and transportation is maintained. Because the U.S. demands utmost safety and reliability from radioactive material transportation operations, the R&D programs must demonstrate to regulators and the concerned public that DOE possesses an extremely high degree of proficiency in technical leadership and technical innovation. The public has a right to expect that DOE will provide this capability along with long-range technical commitment. The Transportation Assessment and Integration (TRAIN) Report[1], sponsored by the DOE provided a comprehensive evaluation of transportation operations within EM and throughout the DOE as a whole. This TRAIN report described that the task of an R&D Program Element was to ensure that the degree of technical capability be available, to provide long-term technical guidance for the DOE Transportation Management Division (TMD), and to serve TMD in applying technical capability in the solution of real problems.

Consistent with tasks identified in the TRAIN report, Sandia's Transportation Technology Programs develop innovative technology to solve transportation and packaging problems and needs for DOE and other federal agencies. Sandia National Laboratories' Transportation Technology Programs have been developed to provide Packaging R&D, Engineering, and Analysis capabilities. These activities provide the technology and know-how to support DOE in achieving safe, efficient, and economical packaging and transportation of nuclear and other hazardous waste materials. Below we summarize the principle areas of packaging research activities. A more detailed description of these activities is given in the Discussion Section of this paper.

Packaging Research and Development - Technology is developed and made available to solve DOE packaging problems and needs. Packaging research and development includes development of analytical methodologies and design codes, evaluation of packaging components, materials characterization, and development of creative packaging concepts.

Packaging Engineering and Analysis - This work involves engineering, design, analysis, and testing for packaging development. Under this program, new packaging concepts emerge to meet specific programmatic requirements.

BACKGROUND

New legislative requirements, regulatory changes, DOE policy changes focusing on site restoration and waste management, and level of public involvement all are forcing issues that have a common result: a dramatic increase in the need for new radioactive material transport packages that are safer and more efficient. This will require the ability to evaluate new technologies, including materials and package designs, that (1) provide specific enhancement in safety and (2) increase payload to enhance system efficiency and operational safety.

Regulatory drivers include the recent changes in Title 49 of the Code of Federal Regulations required by HM-181 and pending changes required by HM-169A that implement the requirements for performance evaluation of hazardous and radioactive material packages, respectively. These regulatory changes result in a dramatic shift from existing policy that provides package specification in lieu of performance criteria for approval of certain types of shipping packages. Requiring packages to meet performance-based criteria will force the assessment of existing packages with respect to their ability to meet the new requirements. It will result in the need for some redesign of existing packages, design and development of new packages for conventional and new payloads, and increased testing capabilities for the DOE complex.

The establishment of the Office of Environmental Restoration and Waste Management (EM) in 1989 represented a dramatic shift in DOE policy. The primary responsibility of EM is DOE site restoration and waste management. As DOE sites are characterized with respect to wastes and materials to be stored and/or disposed, it has become apparent that a major effort is required to manage these materials that will be focused on the storage, on-site and off-site transportation, and final disposal of DOE-owned hazardous (including radioactive) materials. Not only will new packages be required because there are not enough packages in the current DOE inventory due to sheer volume of material, new packages must be developed to achieve more efficient and safer designs realized through the use of new design methods, new materials, and new storage and disposal technologies. The goal of the Transportation Management Division is to support the necessary technological capabilities to allow for the development of these new more efficient and safer package designs.

The increased awareness of the public and oversight by other governmental agencies is creating a pressure on hazardous DOE shipments that results in an ever-increasing re-evaluation of the efficacy of the use of existing packagings. There is increasing institutional pressure to develop packaging systems that exceed regulatory compliance. A recent example of this type of influence is the Western Governor's Association's request to Congress to require that certain DOE radioactive material cargo's to meet the same requirements that are used for the shipment of transuranic wastes to the Waste Isolation Pilot Plant. These types of pressures result in the need to re-evaluate existing packages and to develop new packages.

In the next sections, detailed descriptions will be given of the work being performed and technologies being developed to ensure and demonstrate safe, efficient, and environmentally sound transportation of hazardous and radioactive materials and support for the development of new packages.

DISCUSSION

Packaging Research and Development

Development of Analytical Methodologies and Design Codes. Engineering analysis is a major tool used in transportation package design. It is also used for addressing various safety elements in a Safety Analysis Report for package certification and in determining package response for risk assessments. These safety elements include structural, thermal, criticality and shielding, and containment evaluations. Development of structural and thermal analysis methods is coordinated at Sandia National Laboratories (SNL). Criticality and shielding analysis are performed and containment evaluation is done with the output of the structural and thermal analyses combined with seal response.

Engineering analyses are performed using techniques that range from simple mathematical models to advanced computer codes. An analysis is developed to predict the behavior of the package when subjected to normal and accidental transport conditions. Finite element methods, for example, are state-of-the-art techniques developed specifically for performing sophisticated computer analyses of structural and thermal response. Figure 1 shows the analytical predictions of the response of a structural evaluation using a finite element analysis technique developed for this purpose.

Benchmarking is a vital part of engineering analysis that verifies analytic codes. Benchmarking may be accomplished by comparing numerical computer solutions with a theoretical or classical solution to a particular problem or by comparing the computer solution with actual experimental test results. In addition, because a number of similar computer codes typically exist, there is a need to ensure that these codes are consistent with one another. Benchmarking provides confidence to both the designer and the certifier that these codes are credible analytic tools. Figure 2 is a cross section showing the prediction from a finite element calculation of the stresses and deformed shape for a cylinder crushed by impact from a large weight along with a photograph of the test results

Finally, package designers must ensure that packages are designed efficiently while meeting all safety requirements. Computer methods for optimizing designs are being developed to ensure the highest efficiency possible in future designs and to accurately determine the safety factors by which certifiers can be assured of system integrity.

Evaluation of Packaging Components. The objective of the packaging components program is to determine the response of critical packaging components to the normal and accident environments they may be subjected to. Two of these critical components are the seals that provide part of the containment boundary at package closures and penetrations and the impact limiters that mitigate the effect of impact events.

Seals that provide the containment system interface between the packaging body and closure must function in both high- and low-temperature environments under dynamic- and static-loading conditions. A research and testing program for seal materials was initiated at SNL in 1988[2]. The mission of the program is to characterize the behavior of seal materials commonly used in radioactive material packages under normal and accident conditions as specified in Title 10 of the Code of Federal Regulations, Part 71[3] (10 CFR 71). The performance of the seals in undeformed closures at both high and low temperatures has been investigated. Work has begun on the response of seals to deformations in the closure region.

The response of O-ring seals to closure movements has been determined for gas leaks due to long-term deformations. A topic of interest to package designers is short-term closure movements that return to their initial configuration after a few milliseconds, resulting in the so called "burp" release. Methods for generating this type of response in a repeatable method have not been developed and standard leak detection equipment does not have a fast enough response time to measure these transient events. Also of interest for many package types is the release of particulate materials instead of gaseous materials. It is very difficult to derive a particulate-release rate from a standard gas-leak rate measurement. Investigation of these issues and methods of testing to overcome these problems are being developed.

This work has already provided data on impact limiting materials and screening methods but more work needs to be done. More definitive models need to be developed and the limiters need to be divided into two categories, namely wood and other materials such as hydrocarbon and metallic foams or honeycomb materials. The reason for this is the dependency of wood on moisture content and grain angle. Work is presently being done on redwood which appears to be the preferred limiter. A final report and a new constitutive model are being developed. Experiments will be conducted and the data used to complete a finite element or appropriate model which may be used to predict behavior of present limiters in case of an accident, and aid in the design of limiters for new containers.

To better predict the response of wood impact limiters, in particular redwood, a new constitutive plasticity model for wood stress through the crush range is being developed at SNL and the University of Wisconsin at Madison. Verification and refinement of a proposed crush failure theory for general triaxial stress states will be performed. This theory will allow definition of the crush plateau for general multi-axial stress conditions including those resulting from non-zero grain-to-load angles. Supplemental testing has been performed to help formulate theory. An alternative to Hooke's Law, which will be valid in the crush range, will be developed. Other impact limiters will be tested at load rates of 44 feet/second or the regulatory prescribed 9 meter drop test.

Materials Characterization. Materials characterization evaluates the physical response of materials in packaging construction to regulatory conditions as well as to package contents. This includes structural and thermal response to regulatory loading conditions as well as material compatibility between the payload and the package. Materials characterization also evaluates the suitability of promising candidate materials previously unused for radioactive material package construction. The drivers for this type of evaluation are often related to cost, safety, and system efficiency. The specific goal of the materials characterization work is to evaluate new candidate materials for suitability for various components of package construction. This includes structural, shielding, and thermal properties of the candidate materials. Compatibility of the materials used in package construction with each other and the intended payload is an important factor. For multipurpose packages, corrosion becomes an important factor. Also of concern is the chemical and radiation effect of payload materials on polymers used as packaging liners and seals. A study on polymer phenomenology has been recently initiated[4].

The Transportation Management Division has been a major sponsor of SNL work to establish the fracture mechanics methodology for ferritic materials. The fracture mechanics methodology accommodates the evaluation of a wide range of structural materials for package construction heretofore excluded from consideration due to the lack of adequate evaluation techniques. The success of this work has led to a significant amount of consensus standards development, both domestic and international. This is a high profile activity that puts the SNL in a leadership position with regard to materials issues. This activity blends standards work, materials testing, component testing, and analysis into an effort that supports packaging development for specific payloads and customers. The successful application of this technology can result in significant benefits to the packaging community.

Development of Creative Packaging Concepts. Designs of radioactive material shipping packages in the United States have historically been based on precedent from previously certified packages. Innovation (new designs incorporating advanced materials, seals, and impact limiter designs) has been limited in certified packages primarily because the market for new packages has been minimal. Proposing advanced designs for package certification has not been worth the cost of development and certification support due to limited requirements for new packages.

Since transportation is the key link to program functions for DOE waste management programs, a system engineering approach is also identifying new areas that require packaging development. For example, EM policy is to minimize transportation of waste. As site cleanup begins, site disposal facilities may not be ready to accept wastes. On-site storage may be required. In many instances, multi-purpose packagings may be used to provide on-site storage, transportation, and disposal of a given waste. This means that the transportation package must comply with all Environmental Protection Agency storage and disposal regulations as well as Department of Transportation regulations. However, the cost of meeting these extra conditions for certification will be offset by the savings resulting from reduction in the handling of the waste and in the number of packaging types required. Hardware concepts that will reduce payload transfers will thereby reduce operational exposures and system costs. Multipurpose packages may also prove beneficial for on-site storage and off-site transportation and disposal. Wastes identified for this potential application include Greater then Class C low level wastes, Vitrified High Level Waste, and spent fuel. Multipurpose package technology has the potential to save DOE a significant amount of money, as well as provide for a system that reduces operational exposure, enhances ALARA benefits, and provides a realistic opportunity to meet tight schedules.

Given these pressures on DOE's packaging capabilities, the existing inventory will not be sufficient to meet demand in the near future. New packages will have to be developed to provide enhanced safety, meet institutional policy directives, comply with a broad range of legislative and regulatory requirements that are not transportation related, and serve multipurpose roles that adopt a systems perspective. To address that need innovative new packaging systems are being developed.

One new design concept is a Type B transport packaging for plutonium and uranium[5]. The new design came about following review of current packagings, projected future transportation needs, and current and future regulatory requirements. One significant proposed requirement is the dynamic crush accident event. This event involves the impact of a 500 kg plate onto the package at a velocity of 44 ft/s. Most currently used plutonium and uranium transportation packages may not be able to withstand this test. The possible lack of available packagings caused the Transportation Management Division to charter Sandia National Laboratories to undertake a preliminary development program for a new Type B package that meets present and future regulatory environments. As a result of this program, Sandia developed a new design for a package that could transport similar quantities of plutonium and uranium as are currently transported. The new package design uses nested cylindrical containment vessels (double containment) with threaded closures and elastomeric seals. A composite overpack of metallic wire mesh and ceramic or quartz cloth insulation materials is provided for structural and thermal protection of the containment vessels in an accident environment. Figure 3 is a schematic of this new package.

Packaging Engineering and Analysis

Package Development. This activity focuses on development of transport and storage packagings. In particular, it concentrates on the development of payload-specific, externally approved [Nuclear regulatory Commission (NRC), the U.S. Department of Transportation (DOT), and the International Atomic Energy Agency (IAEA)] applications for the packaging of hazardous, mixed waste, and radioactive materials. Specific applications are identified mainly through integration of transportation into DOE program planning at Headquarters, DOE field offices, and DOE contractors. Development of specific packagings draws from the technical expertise that has been and is being developed under the support of the Transportation Management Division. This activity, while focusing on specific package development, also addresses basic technical issues associated with materials of construction and compatibility of packaging components with identified payload. The Beneficial Uses Shipping Systems (BUSS) cask, Figure 4, has been developed for the transportation of special form cesium chloride and strontium fluoride capsules. In addition, packages have been developed for on-site transportation of chemical weapons, Figure 5, and for protective shipments of treaty verification chemical samples.

Spent Fuel Reactor Packaging. There is need to identify a packaging for the shipment of spent fuel from either Material Test Reactors (MTR) or Training Research Isotope, General Atomics (TRIGA) type reactors. This package development program will enable the DOE complex to transport nuclear reactor spent fuel elements from their temporary storage at the reactor sites to permanent storage facilities. This program has been proposed in four phases. The first phase will concentrate on identifying an existing certified package that, in its current certified configuration, could transport the spent fuel elements. If there are no current package designs that will allow that transport of spent fuel elements. Phase two of this program will evaluate the modification of an existing package configuration to accept the fuel elements. This phase would include modification of the package design, retesting, and recertification of the modified package design. The third phase of the package development program will be initiated if no viable options are discovered in phase one or phase two. The latter phase will involve the design, development, proof of concept testing, and certification of a new package design for the shipment of the spent fuel elements. The final phase of the program would be undertaken at the direction of TMD and will involve SNL teaming with private industry for technology transfer of the developed package into certified transport packages.

Certification Support. The Transportation Management Division provides the foundation for packaging certification. With a centralized facility for collecting the technical knowledge, capabilities, and data developed by the program, the timely availability of certified Type B radioactive material packages to DOE is assured.

Activities that focus on evaluating specific packaging issues are ongoing efforts; the Transportation Management Division responds to support requests from other parts of DOE. One recent example of near-term technical support involves providing support for other organizations within DOE seeking NRC certification of BUSS cask for transportation of cesium chloride capsules in normal form. The BUSS is currently certified for special form shipments by DOE/EH and NRC. A strategy is being developed and implemented regarding normal form shipments and DOE and NRC certification.

Technical expertise required for this effort is derived from the other activities described in this paper. Development of analytical methodologies and design codes, evaluation of package components, materials characterization, package development, and testing, all provide meaningful input to the wide range of expertise required to successfully provide certification support.

Testing. The evaluation and certification of packages for transporting radioactive material can be performed by subjecting these containers to the normal and hypothetical accident test conditions defined in 10 CFR 71. Packages can be certified with the use of analyses, testing, or a combination of analyses and testing. In most cases, packages are developed using a combination of analyses and testing. Package designers use testing to substantiate assumptions used in analytical models as well as to demonstrate structural, thermal, and containment response. There is an institutional driver to favor validation via full scale testing due to higher public acceptance of this method. Testing facilities are used to simulate the required test conditions and provide response data. The hypothetical accident environments include impact, crush, puncture, thermal, and water immersion for certification of Type B packages. Figure 6 shows the capabilities and facilities for regulatory testing. Test facilities also provide environments and test conditions representing normal transport conditions. A major part of evaluating structural or thermal response is the collection of instrumentation measurement data. Development of state-of-the-art methods to simulate test conditions and development of improved instrumentation and data collection capabilities are ongoing activities.

CONCLUSIONS

The clean-up of the DOE weapons complex is a pressing national need. The DOE is addressing this need by the application of technology developed as part of the Sandia National Laboratories' Transportation Base Technology Program. Transportation is the critical link connecting the waste operations that are a major part of the cleanup and the disposal operations. The Transportation Base Technology Program has provided DOE with consistent leadership since 1978 to couple technology to meet this national need. The program will continue this leadership to meet the DOE's, and the country's, increasing transportation and packaging needs. It is imperative that the technology developed by this program be disseminated to other parts of DOE, other government agencies, and the foreign hazardous material transportation community. This is accomplished by technology transfer through presentations at technical meetings such as this, publication in technical journals, publication in contractor and DOE reports, and involvement in national and international committees. While we have attempted to provide an overview of the R&D Program in this paper, a more comprehensive discussion of some specific SNL R&D programs can be found in several companion papers given at this meeting.

ACKNOWLEDGMENTS

The author's gratefully acknowledge the contributions of their staff to the Transportation R&D Program. Particular thanks to Doug Ammerman, John Ludwigsen, Joe Koski, Jim Pierce, and Paul Nigrey for their help in the preparation of this paper.

REFERENCES

1. Transportation Assessment and Integration (TRAIN), U.S. Department of Energy, Transportation Management Program, Office of Technology Development, Final Report, Washington, DC, July 1992.
2. W. B. Leisher and D. R. Bronowski, "Performance Characteristics of O-Ring Seals for Radioactive Material Packages When Subjected to Extreme Temperatures", in Proceedings of the ASME Pressure Vessel & Piping Conference, Vol. 284, American Society of Mechanical Engineers, Minneapolis, 1994, pp. 13-17.
3. 10 Code of Federal Regulations Part 71, Packaging And Transportation Of Radioactive Material, Subpart E - Packaging Approval Standards, January 1, 1991 Revision.
4. P.J. Nigrey, M. Conroy, and L.B. Blalock, "Mixed Waste Chemical Compatibility with Packaging Components", in Proceedings of SPECTRUM '94, Nuclear and Hazardous Waste Management International Topical Meeting, Vol. 1, American Nuclear Society, La Grange Park, 1994, pp. 386-391.
5. J. D. Pierce, J. L. Moya, J. D. McClure, G. F. Hohnstreiter, and K. G. Golliher "Type B Plutonium Transport Package Development that Uses Metallic Filaments and Composite Materials", in Proceedings of PATRAM '92, the 10th International Symposium on the Packaging and Transportation of Radioactive Materials, Vol. 3, Japan Ministry of Transport, Yokohama, 1992, pp. 1011-1018.

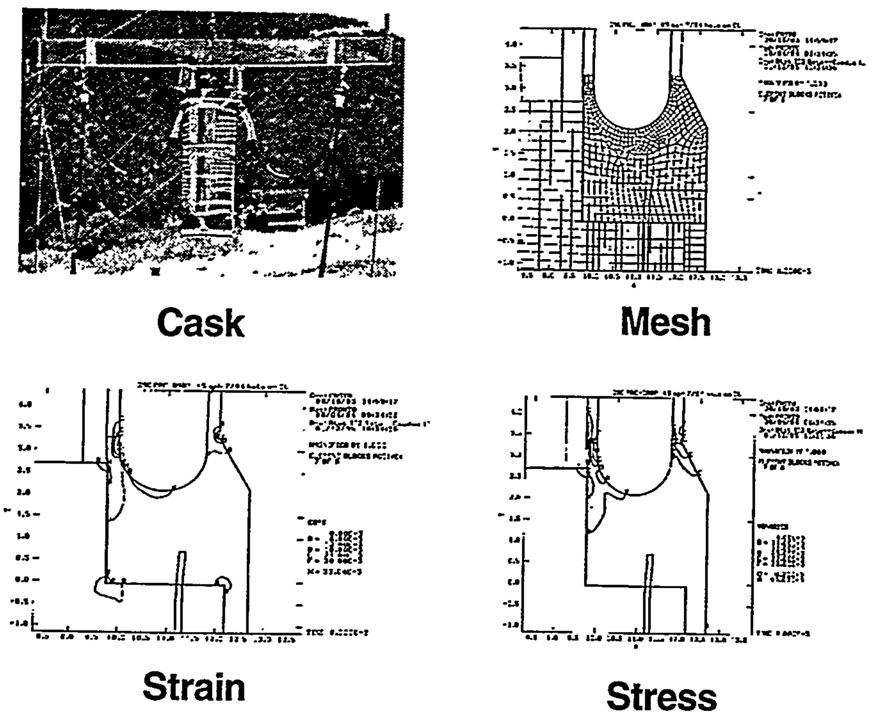

Figure 1 Analytical predictions of the response of the structural evaluation test unit to a 45 mph impact in an end-on orientation onto an unyielding target. The upper left figure shows the drop test configuration prior to the test. The upper right figure shows the displaced finite element mesh, and the lower figures show calculated strains and stresses.

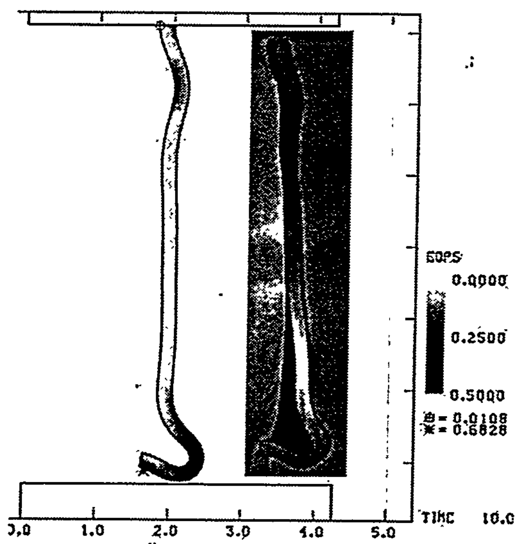

Figure 2 Cross section from a finite element calculation of stresses and deformed shape for a cylinder crushed by impact. Insert shows results of test while the figure represents the analytical prediction.

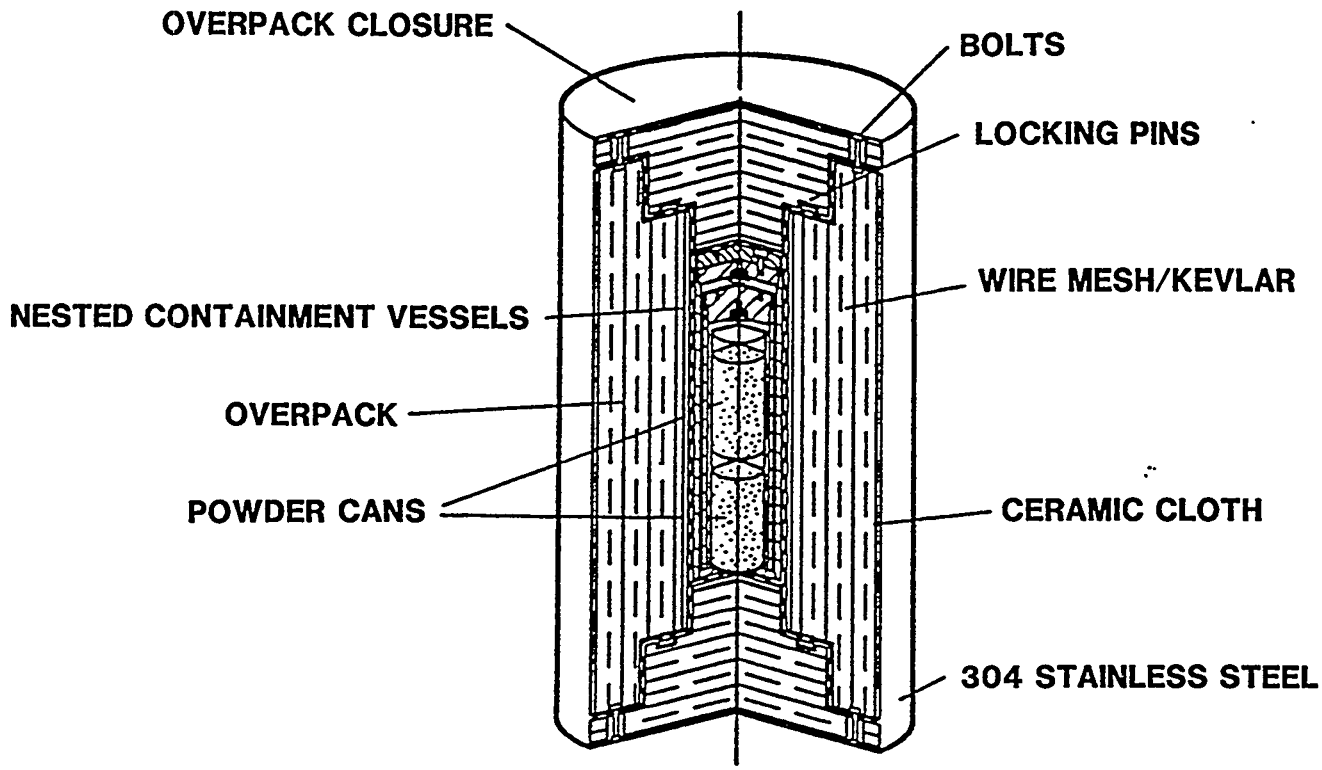

Figure 3 Innovative new design for a Type B plutonium and uranium transportation package using nested cylindrical containment vessels (double containment) with threaded closures and elastomeric seals.

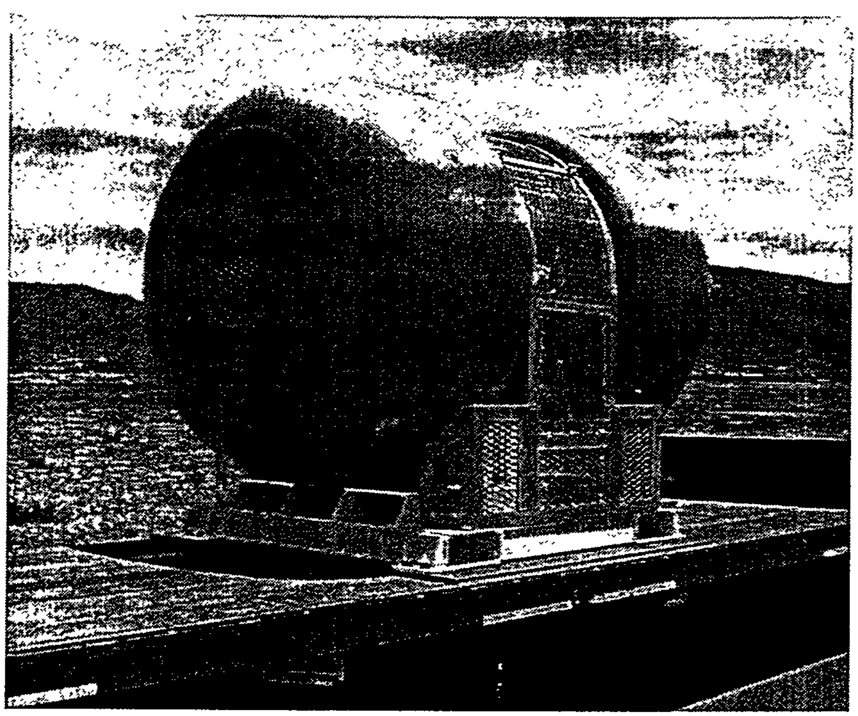

Figure 4 The Beneficial Uses Shipping System (BUSS) cask was recently certified by the DOE and the NRC to transport special form cesium chloride and strontium fluoride capsules.

Figure 5 Package developed for the on-site transportation of obsolete chemical.

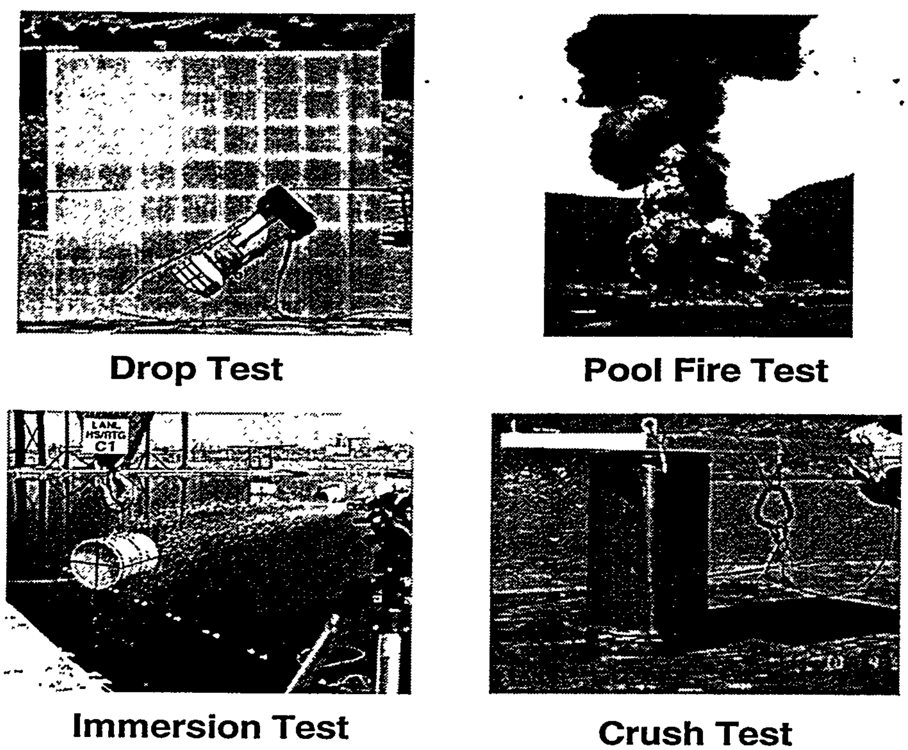

Figure 6 Facilities and capabilities to conduct a variety of regulatory tests. The upper left picture shows a hypothetical accident scenario tests for Type B packages include a 40 inch drop test, the upper right picture shows a 30 minute pool fire test, the lower left picture shows an immersion test in 50 feet of water, and the lower right picture shows a dynamic crush by a 1100 pound steel plate.