

The Packaging Handbook - A Guide to Package Design

L. B. Shappert

Transportation Technology Group, Oak Ridge National Laboratory,\*  
Oak Ridge, Tennessee 37831

RECEIVED  
JAN 31 1995  
OSTI

To be presented at Packaging and Transportation of Radioactive Materials PATRAM '95  
Conference, Las Vegas, NV, Dec. 3-8, 1995.

"The submitted manuscript has been  
authored by a contractor of the U.S.  
Government under contract No. DE-  
AC05-84OR21400. Accordingly, the U.S.  
Government retains a nonexclusive,  
royalty-free license to publish or reproduce  
the published form of this contribution, or  
allow others to do so, for U.S. Government  
purposes."

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Oak Ridge National Laboratory  
Oak Ridge, Tennessee 37831-6495  
managed by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
for the  
U. S. DEPARTMENT OF ENERGY  
under contract  
DE-AC05-84OR21400

MASTER

\*Managed by Lockheed Martin Energy Systems, Inc., under contract DE-AC05-84OR21400 to the U.S. Department of Energy..

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED  
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

## INTRODUCTION

*The Packaging Handbook* is a compilation of 14 technical chapters and five appendices that address the life cycle of a packaging which is intended to transport radioactive material by any transport mode in normal commerce. Although many topics are discussed in depth, this document focuses on the design aspects of a packaging. The *Handbook*, which is being prepared under the direction of the U.S. Department of Energy (DOE) (EH-32), is intended to provide a wealth of technical guidance that will give designers a better understanding of the regulatory approval process, preferences of regulators on specific aspects of packaging design, and the types of analyses that should be seriously considered when developing the packaging design. Even though the *Handbook* is concerned with all packagings, most of the emphasis is placed on large packagings that are capable of transporting large radioactive sources that are also fissile (e.g., spent fuel). These are the types of packagings that must address the widest range of technical topics in order to meet domestic and international regulations.

The chapters are written by experts in their particular field, all of whom have considerable experience in one or more technical areas of package design, preparing a *Safety Analysis Report on a Package* (SARP) and certifying the design. Within their chapters, these experts provide much information and data taken from specific Safety Analysis Reports for Packaging (SARPs) prepared by the chapter authors and provide insights based on their interaction with regulators in the certification process. Included in the *Handbook* are technical chapters that address structural design, shielding, heat transfer, criticality, containment, and materials of construction. Many of the technical chapters also discuss the types of computer codes that have become useful for analyzing package behavior in their particular area.

Additional chapters address other topics that are critical to the package certification process and must be considered by the designer. These areas include packaging life cycle and certification, regulations and standards, quality assurance, and package testing. These chapters provide guidance on how a good package design can improve operability, maintainability, and safety (e.g., by reducing handling times and the dose commitment of operating personnel).

The *Handbook* has five appendices that provide additional information on very specific topics that may be of interest to a package designer. These topics include a survey of materials and procedures for the design of impact limiters in radioactive materials transport, thermal-code benchmark problems, a statistical

---

\* Managed by Lockheed Martin Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy.

technique for determining subcritical limits, a partial listing of isotopic source/shield design data that is referenced by the shielding chapter, and SCALE: a modular code system for performing standardized computer analyses for licensing evaluation. This latter appendix discusses the SCALE code that is often used by the Nuclear Regulatory Commission to evaluate the information that is provided to them in a SARP.

## STATUS OF HANDBOOK

Most of the chapters in the *Handbook* have been drafted and submitted to Oak Ridge National Laboratory (ORNL) for editing; the majority of these have been edited. Table 1 identifies the various chapters and appendices, their authors, and their status.

Table 1. Status of Chapters in the Packaging Handbook

Chapter/ appendix	Title	Authors and affiliations <sup>a</sup>	Status
1	Introduction	L. B. Shappert, ORNL	50% completed
2	Package Life Cycle and Certification	S. D. Moses, LMES	Completed, edited, in final format
3	Regulations and Standards	R. B. Pope and R. R. Rawl,* ORNL, and M. E. Wangler, DOE	Completed, edited, in final format
4	Package Testing	A. H. Wells, Consultant	Initial draft submitted
5	Structural Analysis	A. H. Wells, Consultant	Completed, undergoing edit
6	Structural Materials Considerations	R. A. Riddle, LLNL	Completed, edited, in final format
7	Thermal Analysis	R. W. Carlson and J. Hovingh, LLNL	Completed, edited, in final format
8	Containment	F. L. Danese, SAIC	Completed, undergoing edit
9	Shielding	B. L. Broadhead, H. Taniuchi,** and C. V. Parks, ORNL	Completed, edited, in final format
10	Criticality Safety	C. V. Parks, H. R. Dyer, and G. E. Whitesides, ORNL	Initial draft submitted
11	Quality Assurance	R. R. Fabian, T. R. Bump, and G. F. Popper, ANL and E. W. Russell, LLNL	Completed, edited, in final format
12	Package Operations	F. L. Danese, SAIC	Completed, edited, in final format

13	Package Fabrication and Acceptance Testing	R. H. Jones, Consultant	Completed, edited, in final format
14	Package Maintenance	F. L. Danese, SAIC	Completed, edited, in final format
A	A Survey of Materials and Procedures for Design of Impact Limiters	C. R. Hammond, LMES, and T. G. Carley, UT	Completed, edited, in final format
B	Thermal Code Benchmark Problems	R. E. Glass, SNL	Completed, edited, in final format
C	A Statistical Technique for Determining Subcritical Limits	M. D. DeHart and C. V. Parks, ORNL	Initial draft submitted
D	A Partial Listing of Isotopic Source/Shield Design Data	E. D. Arnold, ORNL	Completed, edited, in final format
E	The Standardized Computer Analysis for Licensing Evaluation (SCALE) Program	C. V. Parks and B. L. Broadhead, ORNL	Completed, edited, in final format

\* ORNL, Oak Ridge National Laboratory; LLNL, Lawrence Livermore National Laboratory; LMES, Lockheed Martin Energy Systems; DOE, the Department of Energy; SAIC, Science Applications International Corp.; ANL, Argonne National Laboratory; UT, University of Tennessee; SNL, Sandia National Laboratory

\* Currently with the International Atomic Energy Agency

\*\* Currently with Kobe Steel, Ltd.

The chapters range in length from 20 to 70 pages, with the average around 50 pages; as a result, the *Handbook* will be almost three times larger than the *Cask Designers Guide*<sup>1</sup> that was published in 1970.

## SUMMARY OF CONTAINED INFORMATION

Citations from a few of the chapters follow to provide an indication of the depth of coverage that most authors have provided. R. B. Pope, et. al., point out in Chapter 3 that the overall regulatory philosophy applied to radioactive material transport is to require that the packaging provide the primary protection with a minimal reliance on operational controls or human intervention. A graded approach has been applied to the required level of performance of radioactive material packages which is commensurate with the potential hazard presented by the contents. All radioactive materials packages must meet regulations which require appropriate measures to

1. contain the radioactive contents (containment);
2. limit radiation emanating from the contents (shielding);
3. prevent nuclear criticality (criticality safety); and
4. manage any decay heat generated by the contents.

All life-cycle phases of Type B and fissile materials packagings are tightly controlled by the regulations. Specific approval (or certification) is required of the package designs and many aspects of fabrication and use. A very high degree of quality assurance (QA) is mandated by the

regulations, including requiring formal QA programs and appropriate quality control (QC) measures for the use of the packagings.

Containment obviously has a close interaction with materials of construction, structural analysis, and protection of the package, possibly through the use of impact limiters. In the case of structural analysis, A. H. Wells notes that the structural evaluation of shipping packages requires special attention to two areas: the loads developed in impacts and the strength and stability of the structure that resists those loads. Two types of loads are developed in impacts: loads produced in the nine-meter drop scenario by deformation of impact limiters (shock absorbers) or by contact of the package with the ground, and loads produced in the pin puncture scenario. These loads cause stresses in the packaging body and closure lid, and the stresses must be calculated and shown by analysis to be less than the allowable stresses for the material of the structure. The allowable stress limits for package materials must be specified by code (such as the ASME Boiler and Pressure Vessel Code) or must be documented adequately with test results. Non-code materials may be used for structural components, but the material properties under all operating and hypothetical accident conditions must be known. Shielding materials also contribute to the weight (and stresses) of the packaging and may cause unusual loading upon the structural shells of multi-wall packages. For example, lead slump is an important phenomenon in lead-shielded packagings, since lead slump produces a dynamic pressure upon the packaging shells in an impact.

The materials which form the containment boundary of a packaging must be qualified by elastic analyses; that is, they may not yield in hypothetical accident scenarios. Non-containment components may function in the elastic/plastic regime. An example is impact limiter attachments, which may deform substantially in a nine-meter drop impact without losing their functionality. Ductile materials are preferred for structural components since they can absorb a significant quantity of strain energy in an impact without immediate failure of the component. Materials such as stainless steel can survive elongation of tensile test specimens of approximately 40 percent, while structural aluminum alloys may be capable of only 10-15 percent elongation before failure. Highly ductile materials add a measure of conservatism to package designs because a package subjected to impacts somewhat more severe than design values would yield without catastrophic failure.

With regard to containment, F. L. Danese points out that the regulatory provisions vary somewhat by package type, but usually, no loss or dispersal of contents is permitted in normal conditions of transport. Under accident conditions, the requirements vary much more widely. For some package types, loss of contents is permitted, while for others, such as the Type B package, only very small quantities of material may escape from the package, over time. Within the regulations, limits on the releasable materials are specified as a function of the contents, and the actual quantity of material that may be released is dependent upon its isotopic constituents. These requirements are established by both national and international regulations and are included in American National Standards Institute, Inc. (ANSI) N14.5, the standard entitled *Leakage Tests on Packages for Shipment of Radioactive Material*.<sup>2</sup>

Containment of the contents of a package during both normal conditions of transport and under accident conditions is important to the health and safety of the public and of the package operators and transporters. To assist the designer in developing a package design that provides adequate containment for the proposed contents, the regulators specify features that must be incorporated and also some that must not be incorporated into package design. The required

conditions or features include positive-fastening devices for closures (such as torqued bolts), protection of fasteners from inadvertent operation, enclosures at penetrations to retain leakage from valves, and use of adsorbents for liquids. Pressure-relief valves are excluded from the enclosure requirement. The regulations prohibit continuous venting devices, filters, and mechanical cooling of the package.

In the shielding chapter, B. L. Broadhead, et. al., note that a package must be designed to maintain radiation dose rates external to package surfaces below established regulatory limits under defined normal and accident conditions. These regulations can vary depending upon whether the package is transported with other goods in general freight or whether it has exclusive use of the vehicle that transports it. Two forms of radiation are of most concern in package design: gammas and neutrons. Gamma radiation requires dense material for efficient shielding (e.g., lead, steel, and depleted uranium). Neutrons, when present, require a light material often containing significant quantities of hydrogen in order to shield the source. Each type of radiation requires somewhat different techniques to determine the proper shielding thicknesses to reduce external dose rates to acceptable limits. This chapter discusses how the radiation source can be characterized, analysis methods that may result in a preliminary package design, and, finally, calculational techniques that may be applied to a package design in order to predict external dose rates.

The shielding chapter also points out that once the scoping work for preliminary package designs has been completed, a number of one-dimensional (1-D) transport methods are available for more detailed analysis. The ANISN and XSDRN 1-D discrete-ordinates codes are widely used for preliminary, and sometimes final (depending on the application) design work. These codes can utilize spent nuclear fuel source terms, if appropriate (typically generated from point-depletion codes such as ORIGEN2 or ORIGEN-S), as well as a number of multigroup cross-section libraries, including the SCALE 27-neutron, 18-gamma group library; the CASK 22-neutron, 18-gamma group library; and the BUGLE-80 47-neutron, 20-gamma group library. A number of excellent two-dimensional (2-D) and three-dimensional (3-D) methods are available for detailed final design calculations should they be needed. These include the 2-D discrete-ordinates code DORT and the 3-D Monte Carlo codes MORSE and MCNP. These codes and data are referenced and discussed in this chapter.

In the chapter on criticality safety, C. V. Parks, et. al., discuss the methodology of ensuring that adequate protection is provided against an accidental self-sustaining or divergent fission chain reaction by any package that carries fissile material. This protection is provided by using a design and safety assessment philosophy that effectively eliminates the possibility of a criticality event occurring under any credible scenario. Thus, the package design and allowable loading specifications must be such that the safety evaluation can demonstrate, under all transport conditions, that more neutrons are lost from the system (either a single package or an array of packages) than are produced; that is, the system must always be subcritical.

Whatever the control mechanism, an adequate margin of subcriticality must be demonstrated for both the single package in isolation and for arrays of packages. Undamaged and damaged packages must be considered using the credible fissile material configuration and the moderator and reflector conditions that provide the maximum reactivity. The evaluation of complex package designs under the prescribed conditions typically requires the use of sophisticated computer codes that incorporate either deterministic or statistical techniques to model neutron transport, taking into account the effect of biases and uncertainties, together with package design uncertainties and an acceptable safety margin, and predict the effective neutron multiplication factor of the system.

The chapter presents and discusses various issues related to the criticality safety of transportation packages containing fissile material.

With regard to heat transfer, R. W. Carlson and J. Hovingh point out that all packages that are designed to contain heat-producing radioactive materials must be evaluated to determine their expected normal operating temperatures and their responses to the accident conditions specified in the regulations. The amount of heat produced, the amount of radioactive material carried, and the package design itself may affect the type of analysis or testing that must be carried out to convince the designer (and the regulators) that the package is safe in the transport environment. This chapter contains a discussion of (a) thermal design considerations of a Type B packaging for normal conditions of transport as defined in 10 CFR 71.71 and (b) the hypothetical accident sequence as defined in 10 CFR 71.73. The major issue in the thermal design of a package involves the conflict between passively removing the radioactive decay heat from its contents (with a small temperature gradient through the package) while passively protecting its contents from external heat sources. Although elevated temperatures in a package are not necessarily harmful to the public, such temperatures must not compromise other functional requirements of the package, such as containment, shielding, or criticality control.

The thermal regulatory requirements can be satisfied by subjecting the package design to analysis, by physically testing a prototype packaging (containing appropriate surrogate material), or by use of a combination of the two. However, testing is often preferred for packagings that are built from components that are poorly characterized or that may exhibit a phase change or chemical decomposition under the regulatory hypothetical accident conditions.

The thermal chapter presents methods for analyzing the heat transfer requirements set forth in the regulations. These methods have been applied to the analyses of packagings in the past, follow good engineering practices, and should help the designer to avoid problems in the thermal analysis of any packaging.

## CONCLUSIONS

The above paragraphs demonstrate the interaction of the various chapters that are discussed in the *Handbook* in the design of radioactive material packagings. The other chapters and appendices in this document also show the interaction of each topic covered to package design.

The *Handbook* is currently undergoing final technical editing and many of the sections have already been electronically formatted for publication. All figures are being reviewed in detail. Once this is completed, a draft of the *Handbook* will be prepared for submittal both to the authors and to experts in a peer review process; this is expected to take place early in 1996. The authors will then have an opportunity to see how their section blends into the entire document.

It is planned to give reviewers several months for the peer review activity. Comments received will be returned to the senior author of each section to evaluate and make the appropriate corrections; the document will then be published.

## REFERENCES

1. L. B. Shappert, ed., *Cask Designers Guide*, ORNL-NSIC-68, Union Carbide Corporation-Nuclear Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 1970.
2. *American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment*, ANSI N14.5-1987, American National Standards Institute, Inc., New York, 1987.