COMPLETION OF THE RADIOACTIVE MATERIALS PACKAGING HANDBOOK

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SUMMARY

The *Radioactive Materials Packaging Handbook: Design, Operation and Maintenance*, which will serve as a replacement for the *Cask Designers Guide* (Shappert, 1970), has now been completed and submitted to the Oak Ridge National Laboratory (ORNL) electronics publishing group for layout and printing; it is scheduled to be printed in late spring 1998. The *Handbook*, written by experts in their particular fields, is a compilation of technical chapters that address the design aspects of a package intended for transporting radioactive material in normal commerce; it was prepared under the direction of M. E. Wangler of the U.S. Department of Energy (DOE) and 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 package design, and the types of analyses that should be considered when designing a package to carry radioactive materials. Even though the *Handbook* is concerned with both small and large packagings, most of the emphasis is placed on large packagings that are capable of transporting fissile, radioactive sources (e.g., spent fuel). The safety analysis reports for packagings (SARPs) must address the widest range of technical topics in order to meet United States and/or international regulations, all of which are covered in the *Handbook*.

In the summer of 1996, the final draft of the *Handbook* was circulated for peer review to all authors and additional independent reviewers. Comments were received and transmitted to the primary author of the appropriate chapter for his evaluation of the suggested changes. Revised chapters were due to the handbook editor in early spring of 1997, although some were not received until late summer. The peer review offered the authors the first opportunity to review their text in light of how other authors had treated the topics contained in their chapters. The following highlights key topics from each of the chapters.

One of the primary goals of the *Handbook* is to provide information which would guide designers of radioactive materials packages to make decisions that would most likely be acceptable to regulatory agencies during the approval process of the packaging. It was therefore important to find those authors who not only were experts in one or more of the areas that are addressed in a SARP, but who also had been exposed to the regulatory process or had operational experience dealing with a wide variety of package types. Twenty-five such people have contributed their time and talents to the development of this document, mostly on a volunteer basis. A summary of the chapters and appendixes that they produced is summarized in Table 1.

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Table 1. Chapters in the Radioactive Materials Packaging Handbook

Chapter/ appendix	Title	Authors and affiliations[a]
1	Introduction	L. B. Shappert, ORNL
2	Regulations and Standards	R. B. Pope and R. R. Rawl,[b] ORNL and M. E. Wangler, DOE
3	Package Life Cycle and Certification	S. D. Moses, LMES
4	Testing	A. H. Wells, Consultant
5	Structural Analysis	A. H. Wells, Consultant
6	Materials	R. A. Riddle, LLNL
7	Thermal Analysis	J. Hovingh and R. W. Carlson, LLNL
8	Containment	F. L. Danese, Consultant
9	Shielding	B. L. Broadhead, H. Taniuchi,[c] and C. V. Parks, ORNL
10	Criticality Safety	C. V. Parks, H. R. Dyer, and G. E. Whitesides, ORNL
11	Quality Assurance	R. R. Fabian, T. R. Bump, and G. F. Popper, ANL, and W. E. Russell, LLNL
12	Package Operations	F. L. Danese, Consultant
13	Package Fabrication and Acceptance Testing	R. H. Jones, Consultant
14	Package Maintenance	F. L. Danese, Consultant
A	A Survey of Materials and Proc. for Design of Impact Limiters	C. R. Hammond, LMES, and T. G. Carley, UT
B	Thermal Code Benchmark Prob.	R. E. Glass, SNL
C	A Statistical Technique for Determining Subcritical Limits	M. D. DeHart and C. V. Parks, ORNL
D	A Partial Listing of Isotopic Source/Shield Design Comp.	E. D. Arnold, LMES
E	The SCALE Program	C. V. Parks and B. L. Broadhead, ORNL

[a] ORNL, Oak Ridge National Laboratory; LLNL, Lawrence Livermore National Laboratory; LMES, Lockheed Martin Energy Systems; DOE, the U.S. Department of Energy; ANL, Argonne National Laboratory; UT, University of Tennessee; SNL, Sandia National Laboratory

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REGULATIONS AND STANDARDS

The primary regulations governing the design, manufacture, and use of certified radioactive materials packagings in the United States are those of the U.S. Department of Transportation (DOT) and the U.S. Nuclear Regulatory Commission (NRC). However, DOE also exercises jurisdiction over certified packaging activities that it or its contractors perform. The regulations produced by DOT and NRC are heavily influenced by the international regulations developed and promulgated by the International Atomic Energy Agency (IAEA). As an active participant in the IAEA regulatory development activities, the U.S. regulatory agencies work to ensure that the international and domestic requirements remain as consistent as possible. The nature and scope of all of these regulations are described in the chapter titled "Regulations and Standards," and a description of their relationships with one another is presented.

PACKAGING LIFE-CYCLE AND CERTIFICATION

Packaging life-cycle and certification (Chapter 3 in the *Handbook*) are two topics that are paramount to designers. Chapter 2, covering the regulations, instructs the designer, owner, or user on what requirements must be met to obtain package certification, while Chapter 3 provides an understanding of how to achieve these requirements. The life-cycle phases, as applied to the development of a packaging, are as follows: concept (development), definition (design, SARP preparation, certification), production (package fabrication and acceptance), operations (shipping, maintenance, modifications, certification renewal), and shutdown (decommissioning, decertification, and disposal). The division of these phases may differ somewhat from package to package, but the phases given are considered basic. It must be realized that these phases are not strictly sequential and that there may be considerable overlap, particularly with packagings requiring regulatory certification.

The U.S. Federal Regulations contained in 10 CFR 71 state that a new package design may be certified via analysis or testing, and a combination of both analysis and testing is often used. Analysis methodologies provide the means to evaluate package performance in a wide variety of conditions by adjusting modeling parameters. Testing is somewhat more limited since evaluation of even small variations in conditions may require multiple tests. Testing is preferred for conditions which are difficult to analyze, such as dynamic impact behavior and leakage of seals. Confirmatory tests are often used to validate analyses. Each package design may require a different strategy of testing combined with analyses to obtain the optimum combination.

TESTING

Tests (e.g., engineering tests, certification tests, package acceptance tests, and maintenance tests) may be used to serve a variety of purposes:

- Engineering tests are performed to gather knowledge of the behavior of a system or component. Engineering tests may be exploratory (e.g., when a component's behavior is not known prior to the test), or confirmatory (e.g., when verification measurements of expected behavior are sought).

- Certification tests are performed with the express purpose of obtaining data which will be included or referenced in a SARP. Certification tests should be performed under a 10 CFR 71-approved quality assurance (QA) program or DOE equivalent.

- Acceptance tests are performed prior to placing a package into service and are usually described in the SARP.

- Maintenance tests are scheduled for annual or other periodic maintenance of packages.

STRUCTURAL ANALYSES

With regard to structural analysis, the regulations which govern shipping casks for radioactive material or spent fuel permit a variety of approaches to the task of demonstrating the structural adequacy of the shipping package. The most straightforward method is to generate a series of structural calculations to evaluate the performance of the package under regulatory transport scenarios, which involve normal operating conditions and a set of hypothetical accident conditions consisting primarily of a 9-m drop impact and a 1-m puncture drop impact. These scenarios must not result in excessive stresses under a range of hot- and cold-temperature conditions.

The structural analysis of irradiated fuel shipping casks requires special attention to two areas: (1) the loads developed in impacts and (2) the strength and stability of the structure that resists those loads. Two types of loads are developed in impacts: loads imparted to the cask through sacrificial impact limiters (shock absorbers) or by contact of the cask with the ground in the 9-m drop, and loads produced in the pin puncture scenario. These loads cause stresses in the cask 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 cask materials must be specified by code (such as the American Society of Mechanical Engineers Boiler and Pressure Vessel Code) or must be documented adequately with test results. Noncode 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 cask and may cause unusual loading upon the structural shells of multiwall casks. For example, lead slump is an important phenomenon in lead-shielded casks because lead slump produces a dynamic pressure upon the cask shells during an impact.

MATERIALS

The choice of materials selected for the construction of a packaging is influenced by their ability to shield and contain. The internal structure of the package also maintains a spatial distribution of fissile nuclear material so as to prevent criticality. Chapter 6 concerns itself with the choice of materials for structural containment of the hazardous material. The chosen materials must be shown to be adequate for containment of the radioactive material; this can be demonstrated by design and testing and supported with material certification and structural analysis.

Material manufacture, certification, and fabrication are presented as standardized procedures by a substantial number of international organizations which are identified in Chapter 6. While following these procedures will take advantage of a large amount of experience developed and recorded in working with these materials, the responsibility for the choice of cask material and the related fabrication processes remain with the designer.

THERMAL ANALYSES

All packages that contain heat-producing radioactive materials must be evaluated to determine their expected normal operating temperatures and their thermal response to the accident conditions specified in the regulations. The amount of heat produced by the radioactive material carried, and the package design itself may affect the type of analysis and/or testing that must be carried out to convince the designer (and the regulators) that the package is safe in the transport environment. In Chapter 7, thermal design considerations of a Type B packaging for normal conditions of transport as well as for the hypothetical accident sequence are discussed. The major issue in the thermal design of a packaging involves the conflict between passively removing the radioactive decay heat from the contents, with a small temperature gradient through the package, while passively protecting its internals 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.

CONTAINMENT

Containment of the contents of a package under both normal conditions of transport and accident conditions is important to the health and safety of the public and to the package operators. To assist the designer in developing a package that provides adequate containment for the proposed contents, regulators specify features that must be incorporated in the design of a package and also some features that are prohibited. The required 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 the use of absorbents for liquids. The prohibited features include pressure-relief valves, continuous venting devices, filters, and mechanical cooling equipment for the package.

The designer may elect (a) to show by analysis that leakage, which might occur under normal and defined accident conditions, is below the limits specified in the regulations or (b) to show that the package is "leak tight," [defined as having a leak rate equal to, or less than, 10^{-7} std cm^3/s (air)].

SHIELDING

The shielding for a shipping 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: gamma rays and neutrons. Gamma radiation requires dense material for efficient shielding (e.g.,

lead, steel, and depleted uranium). Neutrons 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. Chapter 9 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.

While this chapter discusses shielding topics that will be applicable to any package design, one of the more challenging problems is the shield design for a spent fuel cask. Modern trends toward high burnup in spent nuclear fuel (SNF) and the corresponding high initial enrichments tend to complicate today's cask design efforts and have driven the cask designer away from hand calculations toward more sophisticated cask design tools.

CRITICALITY SAFETY

Criticality safety is the practice of ensuring that adequate protection is provided against an accidental, self-sustaining, or divergent fission chain reaction. For packages that transport fissile material, this "adequate 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 credible transport conditions, that the system must always be subcritical.

Chapter 10 presents and discusses the issues related to the criticality safety of packages containing fissile material and provides a discussion of the regulatory requirements specific to the criticality safety of packages. It also reviews the principles of criticality safety, applicable analysis methods and their validation and use in the criticality safety evaluation of a package, and computational modeling considerations. The chapter also deals with specific issues that include design considerations relative to packaging certification, allowance for reactivity loss resulting from fissile material irradiation (the burnup credit issue), and in-situ measurement techniques to demonstrate criticality safety.

QUALITY ASSURANCE

In order to have a well-coordinated design, fabrication, and testing program and also to be able to develop an effective QA chapter for the SARP, the package design project should develop and implement a packaging-specific QA plan at the earliest possible stage of the design phase. The QA plan is intended to provided control of the various activities with a graded approach. A graded approach means that the QA requirements should be consistent with the importance to safety of the item or activity.

PACKAGE OPERATIONS

Planned operations should play a key role in the design of a package. Perhaps the two most important aspects of the concept of repetitive operations with a fixed design, aside from the actual steps required, are operator dose and operator performance. To address these concerns effectively, the designer must consider specifically how the package must be handled in the user-operating environment. The designer should consider how operator

exposure could be reduced, above that achieved by the package shielding, from placement of components or process efficiencies. Package operational requirements (e.g., draining) and package fixtures (e.g., penetration valves) should be designed so as to reduce the potential for the operator to make an error when opening, closing, venting, draining, or otherwise using the package.

Efficient use of the package sometimes requires using other equipment, such as a lifting fixture or special tools, specified by the package designer. To the greatest extent possible, the package should be designed so that reliance on special tools or equipment is not required. As the number of special tools or the amount of equipment increases, the total system reliability decreases (since the package system must have all of the special items for use); operational complexity increases; and the transportation, handling, packaging, and decontamination requirements increase. Reducing, or eliminating, reliance on unique equipment, tools, fixtures, or fasteners, reduces the burden on the future package user. Nevertheless, the designer may need to identify unique equipment that reduces package turnaround time or decreases operator dose and potential for operator error. Such items merit consideration for inclusion in the ancillary equipment provided to the package user.

FABRICATION AND ACCEPTANCE TESTING

Chapter 13 outlines some of the fundamental considerations of packaging fabrication and acceptance testing. It identifies those that are extremely important for a successful project, and it offers some suggestions based on experiences which have been shown to facilitate project execution. The chapter also provides some fundamental guidance concerning selected manufacturing processes.

MAINTENANCE

Package maintenance, discussed in Chapter 14, can be either planned or unplanned. Planned package maintenance is performed on some periodic basis that is established by the designer and/or specified in the Certificate of Compliance. It usually consists of a series of inspections and tests that are intended to demonstrate that the package retains the capability specified in the package SARP for safely containing and transporting the authorized contents. Periodic maintenance requirements occur on some cyclical basis specified by the designer. In the United States the cyclical basis is typically the calendar year, and the periodic maintenance is called an "annual."

Unplanned maintenance occurs when a defect is found during inspection of a package before or during use, or when handling or transport conditions cause the package to be impaired or otherwise not in conformance with its licensed configuration. This unplanned maintenance is often referred to as "Repair."

Some actions that could be considered maintenance may be required on a package per-use basis, such as seal or O-ring replacements, or specific inspections and tests. The requirements for these routine tasks are contained in the package operating procedure(s) and are specified by the package designer.

IMPACT LIMITER DESIGN

Appendix A provides a survey of shock-absorbing materials and procedures for the design of impact limiters. In it are discussed general analytical methods followed by information on foamed materials; either polymer, ceramic, or metal; wood impact absorbers; honeycomb absorbers, constructed of either aluminum or stainless steel; and a wide variety of configurations of metallic energy absorbers, including fins, tubes, and frames. Each of the sections in Appendix A is divided into four areas: material characteristics, examples of successful use, sources for design data, and specific design procedures.

THERMAL CODE BENCHMARK PROBLEMS

Appendix B presents a series of thermal condition scenarios (or problems) that have been defined to evaluate thermal codes. These problems were designed to simulate the hypothetical accident conditions given in 10 CFR 71 while retaining simple geometries. This produced a problem set that exercises the capability of the codes to model pertinent physical phenomena without requiring extensive use of computer resources. The solutions presented are consensus solutions based on computer analyses done by both national laboratories and industry in the United States, United Kingdom, France, Italy, Sweden, and Japan. The intent of this appendix is to provide code users with a set of standard thermal problems and solutions which can be used to evaluate, or benchmark, individual codes.

DESIGN SUPPORT INFORMATION

Other appendixes provide additional information dealing with criticality and other design attributes in packages. One discusses a statistical technique for determining subcritical limits and the criteria for establishing those limits. Another provides background information on the **S**tandardized **C**omputer **A**nalyses for **L**icensing **E**valuation (SCALE) code and an overview of the system. The SCALE code is important because its development has been supported by NRC and the fact that it considers not only criticality of a package, but also shielding and heat transfer.

CONCLUSION

In conclusion, the *Radioactive Materials Packaging Handbook* provides technical chapters that address materials of construction, structural design, heat transfer, shielding, criticality, and containment. Other important topics are covered, including quality assurance, package operations, package maintenance, and fabrication and acceptance testing. Several important topics were selected for more detailed treatment in appendices, including a survey of materials and procedures for the design of impact limiters and thermal-code benchmarking problems.

REFERENCE

L. B. Shappert, ed., *Cask Designers Guide*, ORNL-NSIC-68, Union Carbide Corporation-Nuclear Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 1970.