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Nondestructive Evaluation of LWR Spent Fuel Shipping Casks*

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NONDESTRUCTIVE EVALUATION OF LWR
SPENT FUEL SHIPPING CASKS*

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ABSTRACT

This report summarizes an analysis of nondestructive testing (NDT) methods currently being used to evaluate the integrity of Light Water Reactor (LWR) spent fuel shipping casks. An assessment of anticipated NDT needs related to breeder reactor cask requirements is included. Specific R&D approaches to probable NDT problem areas such as the evaluation of austenitic stainless steel weldments are outlined. A comprehensive bibliography of current NDT methods for cask evaluation in the USA, Great Britain, Japan and West Germany was compiled for this study.

TABLE OF CONTENTS

	Page
I. Introduction	2
II. Background	2
III. LWR Spent Fuel Cask Description	5
IV. Current QA Requirements - LWR Casks	6
V. Nondestructive Testing of LWR Casks	9
VI. Breeder Reactor Casks and NDT Projections	12
VII. Conclusions	15
VIII. References	16
IX. Appendices	
A. Acknowledgments and Key Organizational Contacts	17
B. Nondestructive Testing of Weldments	20
X. Distribution	22

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I. INTRODUCTION

This report was prepared to summarize the nondestructive testing (NDT) methods currently being used in the USA, Great Britain, Japan and West Germany to evaluate LWR spent fuel shipping casks. An assessment of their effectiveness on current casks was considered a necessary prerequisite to projections of NDT R&D needs to meet the more rigorous requirements to be imposed on future generation casks⁽¹⁾.

Conceptual breeder reactor cask designs from Sandia's materials and structures groups were reviewed for their inspectability using state-of-the-art NDT methods. Profitable development areas are indicated which could optimize specific NDT methods for Sandia's early conceptual designs of advanced technology casks.

II. BACKGROUND

Nondestructive testing has played an important role in the development of a safe nuclear power industry from its first introduction⁽²⁾. Nondestructive evaluation (NDE), which includes NDT but goes beyond testing to include interpretation and interdisciplinary decisions on effect of interpretation on a product's end usefulness, can be expected to play an even greater role in the 1980's through improvements and extension of the use of the basic NDT methods and a more complete understanding of their indications^(3,4). The causes for this greater dependence on NDE methods include increased structural performance requirements, the use of defect-sensitive materials, changes in design philosophy based on fracture mechanics, more rigorous construction and safety codes, and a recognition of the need to determine the conditions and degradation of critical structures during their service life⁽⁵⁾.

Spent fuel shipments, as are all radioactive material moves in the USA, are regulated by the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT). International shipments in most cases are made consistent with the standards of the International Atomic Energy Agency (IAEA) with DOT serving as the USA competent authority⁽⁶⁾.

Chapter 1 of Title 10 of the Code of Federal Regulations contains the rules related to transportation of radioactive materials. Specifically, Parts 20, 70, 71 and 73 of Chapter 1 deal with standards for protection against radiation, special nuclear materials, packaging of radioactive material for transport, transportation of radioactive material under certain

conditions, and physical protection of certain radioactive material. Spent fuel casks contain quantities of radioactive materials in excess of Type B limits of 49 CFR 173.393 which defines the general packaging requirements for radioactive material. Acceptable release fractions apply only to the gaseous and volatile components of the spent fuel. It is considered that the remaining fission products are retained within the fuel elements or shipping cask.

There is currently little LWR spent fuel being shipped in the USA because of a lack of operational fuel reprocessing plants. Only one private plant was ever licensed to operate, and it was shut down in 1972 for modifications. Its owner, Nuclear Fuel Services Inc. of West Valley, New York, has since withdrawn their application to reopen. In Barnwell County, South Carolina, Allied-General Nuclear Services has completed the separation facilities of a reprocessing plant with a capacity of 1500 tons per year. The owners are awaiting a Nuclear Regulatory Commission license, which hinges on a government decision on waste storage and on rules governing the utilization of recovered plutonium. President Carter's interim decision to forego spent fuel processing has essentially stalled the final development of the Barnwell Facility. As a result, the spent fuel from the nation's 62 operating LWR or fission power reactors (another 72 are under construction and 61 more are in the planning stages) have been piling up at reactor sites with a current inventory of about 2500 metric tons⁽⁷⁾. Britain, France, USSR and other countries reprocess spent fuels from their nuclear power reactors in government facilities, but that is not the current policy in the USA.

Part 71 of Title 10 CFR Chapter 1⁽⁸⁾ gives the following four basic safety requirements for transporting radioactive materials:

- . Adequate containment;
- . Adequate control of radiation;
- . Safe dissipation of heat generation;
- . Prevention of nuclear criticality.

Neither Part 71 or NRC/DOT regulations attempt to specify how these four basic safety requirements are to be met. This is left up to the cask designer who must qualify casks built to his design to a series of DOT/NRC-specified tests which represent the most credible accident conditions during the transportation cycle. In 1966 the Division of Reactor Development and Technology (RDT) requested that the Oak Ridge National Laboratory develop a Guide for good engineering standards of practice in the design, fabrication, testing, inspection, and

maintenance of irradiated fuel shipping casks⁽⁹⁾. It was decided that, initially, the information in the Guide would apply to lead-shielded spent fuel casks having steel inner and outer shells since this type of LWR cask is most widely used in the United States today.

The accident damage tests defined in 10 CFR 71 provide a means for reproducing in the laboratory or in the field the same general type and degree of damage a cask might reasonably be expected to sustain in a severe rail or truck accident. The damage test sequence includes: 1) a free fall from a height of 30 feet onto an unyielding surface with the cask landing in an orientation which should see the most damage; 2) a free fall from a height of 40 inches onto a 6-inch-diameter steel plunger long enough to do maximum damage; 3) heat input from exposure of 30 minutes to a fire or other radiant environment having a temperature of 1,475°F and an emissivity of 0.9; and 4) immersion of cask in water to a depth of 3 feet for 8 hours.

The designer must prepare a detailed Safety Analysis Report (SAR) prior to licensing. If his stress analysis and/or cask tests are adequate, an NRC-issued license will be granted before the cask can be used. Casks of varying sizes and mode of transportation have been licensed for either commercial transportation or on-site movement of LWR spent fuel elements or assemblies.

In addition to the damage test sequences required by 10 CFR 71, Sandia Laboratories has conducted over the past 18 months four full-scale crash tests of LWR casks for the Department of Energy⁽¹⁰⁾. These tests fell within the "extra-severe or extreme" accident categories and have been estimated in risk assessment studies of transportation environments to be events of very low probability; no such accidents involving nuclear materials have ever occurred.

In the first two impact tests, a 22-ton cask was mounted on the beds of tractor-trailers, which were slammed into the concrete wall weighing 690-tons and backed with more than 1740 tons of earthfill. Impact speeds were 60 and 84-mph. For the third test, a tractor-trailer rig with a 28-ton cask secured to its bed was struck broadside by a 120-ton locomotive traveling at a speed of 81.5 mph. The integrity of the casks was not breached in any of these crashes.

The final test in the series involved the 81.4-mph impact into a massive concrete wall of a special railcar carrying a 74-ton fuel cask. The impact demolished the front of the railcar, but the cask received only minor external damage. The

cask was subjected to a jet fuel fire (temperatures between 1800°F and 2100°F) for more than 90 minutes.

All crash results to date closely paralleled predicted results based on 1/8 scale model crashes and computerized mathematical analyses⁽¹¹⁾. The tests have helped confirm our ability to predict damage from extra-severe transportation accidents.

III. LWR SPENT FUEL CASK DESCRIPTION

Figures 1 and 2 show the general configurations of a typical spent fuel shipping cask for LWR fuels. The inner cavity containing the irradiated fuel is filled with water for cooling and shielding purposes. The inner and outer shells are usually made of stainless steel and the main shielding material for gamma radiation is lead or depleted uranium. The fins on the outer surface may provide some impact protection as well as adequate heat transfer. The cask travels on either a railcar or truck bed in a horizontal position resting on appropriate supports with tiedowns. To keep radiation doses and surface temperatures below the specified limits, a personnel shield may be used around the cask during transport.

Fig. 1. Typical Cross-Section of a Large Spent-Nuclear-Fuel Shipping Cask

Fig. 2. Above, the shipping casks for spent fuel are built to withstand even a major accident

The largest and latest LWR cask licensed for use in the USA to date by NRC was built by NL Industries and is designated as NL 10/24. Each cask, weighing approximately 87 metric tons and mounted on a railroad flatcar, can carry up to 10 pressurized water or 24 boiling water reactor spent fuel assemblies. The cask has a 4.5 ton capacity for uranium, measures 5.3 m (17 feet) in length and 2.4 m (9 feet) in diameter, and uses helium rather than water as a coolant during shipments.

Other commercial LWR fuel casks licensed or still in design are listed in Table I.

TABLE I

Some Current LWR Casks			
<u>Cask Designer/Fabricator</u>	<u>Designator</u>	<u>Capacity</u>	<u>Transport</u>
Nuclear Fuel Services	NFS 4	1 FWR or	Truck
		2 BWR	
	NFS 5	2 FWR or	Truck
Nuclear Assurance Corp.	NAC 1	4 BWR	
		1 FWR or	Truck
Transnuclear, Inc.	TN 8	2 BWR	
		3 FWR	Truck
General Electric	TN 9	7 BWR	Truck
		10 FWR or	Rail
		17 BWR	
Exxon Nuclear		2 FWR or	Truck
		4 BWR	
		12 FWR or	Rail
Excellor, Ltd. (12)	EX-3	26 BWR	
		15 BWR	Rail
NL Industries	NL 1/2	1 FWR/ 2 BWR	Truck
		NL 10/24	10FWR/24BWR Rail

Depending on the size and intended mode of transportation the weight fraction of fuel in a loaded LWR cask ranges from only 2 percent for small trucked casks (25 tons) to 6 percent for large railcar casks (100 tons). Lead shielding for gamma radiation is typically poured into an annulus around the fuel assemblies formed by two concentric shells of steel. Where necessary, hydrogenous material such as water is used for neutron shielding and heat transfer from the spent fuel assemblies. Some casks (i.e., TN 8/9) are shipped dry (no liquid coolants), while others use water or other coolants. Some casks (i.e., IF 300) substitute depleted uranium for lead in gamma shielding. Because of its high density (~ 19 g/cc), a cylindrical uranium shield weighs less than 75 percent of a lead shield and less than 50 percent of a steel shield having the same internal cavity dimensions and comparable radiation attenuation capabilities. Another variable is the cooling of the outside surface of the cask by using either natural convection (passive) or forced circulation (active). This cooling is required since a typical LWR rail cask may release as much as 70 KW of heat or 250,000 BTU/hr and DOT/NRC regulations require that accessible surfaces of LWR casks not exceed 180°F under normal operation conditions. (Breeder fuel assemblies will generate much higher heat fluxes and it may be necessary to raise allowable cask surface temperatures from 350 to 400°F , and to provide a separate personnel shield from the heated surfaces.)

IV. CURRENT QA REQUIREMENTS - LWR CASKS

The fabrication and inspection requirements for LWR shipping casks are not specifically covered by existing codes and standards. Experience to date indicates that LWR casks designed to meet IAEA and ASME Boiler and Pressure Vessel Codes (Class MC, Subsection NC) are more quickly and straightforwardly licensed than those built without resorting to code requirements. Nevertheless, general LWR cask design guides^(9,13) devote several sections to the quality assurance (QA) programs expected from the designer, fabricator and user of current casks. Moreover, specific cask design specifications for the latest of LWR casks are quite detailed from a quality assurance standpoint. The following paragraphs summarize the major QA requirements gleaned from typical LWR cask specifications.

Designer's QA Responsibilities. The cask designer must furnish, in addition to complete materials/process/dimensional callouts, a cask design report to the licensing authorities and to the potential user which lists all design assumptions, cask limitations, and operational/maintenance procedures. Weldments, gaskets, seals and tiedowns are recognized as critical design and fabrication elements of all LWR casks. They are potentially "critical" points that require special quality assurance attention during the design phase. One of the provisions of 10 CFR 71 requires that the shipping cask licensee establish and maintain operating procedures and periodic inspection procedures to assure that the performance of the cask is in compliance with the regulations at all times. These cask inspections are imposed on the cask prior to its first use and prior to and following its use for transporting irradiated fuel assemblies.

Manufacturer's QA Responsibilities. The nature of the materials being transported makes it imperative that the manufacture and inspection of LWR casks be in strict conformity with the design drawings and construction specifications. Further, a quality control program patterned after Appendix IX of Section III of the ASME Boiler and Pressure Vessel Code must be defined and carried out by the manufacturer covering such as the following:

- . Rigid material conformance including mill test reports and marking;
- . Rigorous control of critical fabrication processes such as heat treatment and welding;
- . Maintenance of a complete Fabrication Record indicating compliance (or authorized deviations) with the design and process drawings and covering reports of all inspections and tests (including nondestructive tests) at the component and assembly levels;

- Provide full access to representatives of the design agency, cask purchaser and licensing authority.

Cask Purchaser or User's QA Responsibilities. To ensure that the fabrication requirements are met, an inspector(s), as a representative of the cask purchaser, must audit the manufacturer's procurement, fabrication, inspection and tests to determine compliance. The inspector must have the authority to stop work on a cask at any time when he feels the assurance of quality is being jeopardized. An Inspector's Log must be maintained in which he records the dates of his visits to the manufacturer's plant, status of work on the cask(s) on those dates, notations of materials accepted, notations of inspections and tests witnessed, difficulties encountered in fabrication and authorized deviations from design details and specifications. On completion of the cask fabrication, the Inspector's Log(s) must be incorporated into the Fabrication Record maintained by the cask manufacturer.

V. NONDESTRUCTIVE TESTING OF LWR CASKS

This section summarizes the widely variant nondestructive testing programs that have been imposed on first and second generation LWR spent fuel shipping casks. The information was compiled following a comprehensive study comprised of the following elements, not necessarily in chronological order:

- Literature search and compilation of bibliography of pertinent documents, journal articles and symposium proceedings dealing with nondestructive evaluation methods and procedures for current LWR casks. This bibliography⁽¹⁴⁾ was distributed on December 17, 1976 and a reference file of hard copies or microfiche of this information is located in the NDT Information Center at Sandia Laboratories.
- Personal contacts with NDT and cask design and fabrication personnel involved in LWR shipping cask production. Both telephone and personal visits were used to secure up-to-date information from key installations on current cask evaluation techniques and their limitations. A listing of organizations and persons contacted is given in Appendix A.
- Attendance and participation in selected conferences and symposiums related to shipping cask evaluations. A list of these meetings attended during the period from July 1, 1975 to December 31, 1977 for this purpose is also given in Appendix A.
- Interdisciplinary discussions with Sandia Laboratories' members of the LMFBR Shipping Cask Technology Project

were held periodically during the past year. As straw-man or conceptional designs were derived^(15,16), we attempted to supply NDT input on methods, sensitivities and problems engendered by design/materials/fabrication considerations.

Nondestructive testing and evaluation practices vary widely on LWR casks. While there are some common denominators such as pressure and leak testing that are applicable to all casks, the degree of application of other NDT testing using such methods as radiography, ultrasonics, dye penetrants and radiation gauging varies widely. Commercial cask documentation of tests was quite thorough since the requirements for licensing by DOT/AEC (now NRC) impose such documentation.

The variation in NDT evaluation practices can be partially attributed to the lack of definitive NDT requirements on casks such as those imposed on pressure vessels and associated plumbing by ASME Codes and Standards. (Here again, we can expect this to change on next generation LWR Casks since both NRC and ANSI Cask Guides are expected to reference applicable NDT sections of the ASME Boiler and Pressure Vessel Code.)

It is difficult to understand the lack of imposition of state-of-the-art NDT methods on critical cask elements such as closure weldments and tie downs on some of the LWR casks. In most instances, the cask design agency and the cask fabricator had access to knowledgeable in-house NDT personnel and equipment that they used routinely to process ASME code vessels.

NDT methods are used most often as verification of basic construction requirements during cask fabrication. Application of the same methods on subsequent in-service or post-service examinations is understandably most difficult in view of the residual radioactivity on all inside cask surfaces and the excessive thickness of the overall cask assembly. Even so, good baseline ultrasonic data on critical weldments following initial fabrication does not exist on some of the current casks and would be difficult, if not impossible, to obtain at this time.

Our analysis of NDT capabilities versus current LWR requirements for NDT application revealed only one major limitation. Volumetric NDT of austenitic stainless steels being used on the interior and exterior surfaces of most LWR casks is exceedingly difficult. This limitation is being studied widely in the USA and other countries⁽¹⁷⁾ but results to date of "round robin tests"

have merely confirmed the extent of the evaluation problem. This subject and weldments in general deserve more discussion; hence, a summary is given in Appendix B.

NDT of A508 or A533 structural steel weldments is being successfully applied to one or more of the current LWR casks without major difficulty. Other NDT requirements such as radiography or radiation gaging for LWR shielding defects are well within the capabilities of current nondestructive testing equipment(18,19,20).

Visual inspection is given a high degree of importance in cask evaluation both during fabrication and after use. In fact, the total NDT in-service practice on several casks is to visually inspect for shipping damage and corrosion (using special mirrors and floodlights or borescopes for remote viewing of radioactively hot cask interiors) followed by a pressure drop or leak test. More sophisticated NDT methods are only applied if damage is detected or leaks are evident.

The following NDT test plan is a composite of several different practices used on LWR casks. It represents a workable and meaningful NDE program that should carry over to many of the future generation cask designs - with augmentation of additional methods as needed for more rigorous design requirements.

- A. During fabrication or prior to initial use:
 - . Certification of all materials;
 - . Ultrasonic scans of all precursor plate stock;
 - . Radiography and/or ultrasonics of all weldments on subassemblies and final assembly;
 - . Visual inspection of all surfaces;
 - . Dye penetrant checks of all ID surfaces and OD weldments plus tie downs and lifting trunnions;
 - . Radiation gauging of shielding integrity and uniformity;
 - . Leak test of all seals and entire cask;
 - . Radiography and/or ultrasonics of all lifting and handling members;
 - . Over pressure test ($1\frac{1}{2}$ x MAWP) of sealed cask.
- B. During use and periodic maintenance:
 - . Visual checks of all surfaces, trunnions, and tie downs for shipping damage and corrosion products;
 - . Leak test of entire cask before and after each use;
 - . Penetrant test of any damaged areas;
 - . Ultrasonic test of OD weldments if damage is visually indicated;
 - . Replacement and testing of seals if not designed for multiple closure.

VI. BREEDER REACTOR CASKS AND THEIR NDT PROJECTIONS

The cask for breeder reactor spent fuel must attenuate gamma rays by 8-9 orders of magnitude and neutrons by 4-5 orders. It must keep the outer surfaces of the cask below 350°F while rejecting as much as 100 kW of heat. It must provide the same structural and radiation containment as LWR casks after subjection to the damage tests specified in 10 CFR 71.

Several conceptual cask designs for shipping breeder reactor spent fuel have been generated to date based on the best trade-offs commensurate with the current knowledge of FFTF fuel and expected reactor operating practices. ORNL analyzed a conceptual railcar design in 1972 based on transporting 6 fuel assemblies (3000 pounds) of 30-day cooled fuel irradiated to 100,000 Mwd/MT (megawatt days/metric ton) or approximately three times as hot as LWR fuels. Their design⁽²¹⁾ incorporated sodium as the primary passive coolant, steel for gamma shielding, lithium hydroxide/sodium hydroxide for neutron shielding and triplicate sealing.

Aerojet Manufacturing Company described a conceptual rail-road car cask for FFTF fuel held for 180 days after removal from the reactor⁽²²⁾. Their cask would carry 9 breeder reactor fuel assemblies in a liquid filled cannister shielded in a steel/depleted uranium cylinder for gamma shielding plus an exterior neutron shield water jacket. The liquid coolant would be Dowtherm A (eutectic mixture of diphenyl and diphenyl oxide). Helium gas in a space between the cannister and shield would be provided to enhance heat transfer and to serve as a buffer between the two seals.

Figure 3 shows a cross-sectional view of a reference breeder reactor spent fuel reference cask with only 2 layers - the depleted uranium gamma shield and the neutron shield - as variable elements in the conceptual design. The thicknesses of these 2 layers were adjusted independently using computer code calculations until the dose rate 1.83 m (6 feet) from the outer surface was 5 mrem/hr, half of which would be attributable to neutrons and half to gamma rays.

Fig. 3. Trial Reference Cask Configuration

Figure 4 presents the results of these calculations diagrammatically. Five different neutron shielding materials were used in the analysis - lithium hydroxide (LiH_2O), didymium or misch metal hydride ($\text{DiH}_{2.5}$), beryllium, boron carbide (B_4C) and graphite (C). The latter three candidate neutron shield materials, although less efficient than the misch hydrides, are readily available, thermally stable and relatively chemically inoffensive.

Fig. 4. Radial Dimensions of a Trial Reference Spent-Fuel Shipping Cask for One 30-day Cooled CRBR Spent Fuel Subassembly

Nondestructive testing requirements over and above those currently being applied to LWR cask have not been defined for the conceptual breeder casks. However, the following incomplete projections of specialized NDT needs appear valid at this date:

- Improved weldment test methods for the austenetic steel structural members (SS 304). Focused and/or phased array ultrasonics may be necessary.

- NDT methods to ensure the uniformity and full density of the neutron shield and detect any crumbling before and after cask use. Radiation gaging and/or ultrasonics may be useful methods.
- Uniformity of depleted uranium castings and their 10 mil flame-sprayed copper cladding. LINAC high voltage radiography or ultrasonics plus eddy current scanning of cladding may be required.
- Quality and completeness of copper fin weldment to O.D. of SS 304 external structural member must be assured.
- Overall effectiveness of cask radiation and heat dissipation systems will be necessary. Autoradiography and/or radiation detector scans using actual cask loading or artificial fuel simulators (Co^{60} and Cf^{252}) and infrared scan with actual spent fuel loading or heat simulator are projected.
- Leak tightness of seals on cask closures and Graylok seals on primary coolant cannister must be assured⁽²⁵⁾. Worst case pressure rises of 10-30 atmospheres within the casks due to fuel element rupture have been estimated. Helium mass spectrographic and halogen leak detectors may be required rather than a PAV (differential pressure drop) as run on many LWR casks.
- Size/weight/thickness/processing considerations will make NDT checks during cask fabrication and prior to use of great importance. Tests of precursor materials before processing and after welding can be performed reliably and efficiently at subassembly stages, but may be impossible after final assembly.

VII. CONCLUSIONS

1. Nondestructive test methods are currently playing a major role in assuring the structural integrity and safety of LWR spent fuel shipping casks. However, NDT requirements vary considerably from cask to cask, but will become more definitive in the future.
2. Cask fabrication and users are not applying state-of-the-art NDT methods which are used on other parts of the nuclear fuel cycle (i.e., on pressure vessels, fuel rods, generator, tubing, valves, etc.). Lack of ASME code requirements^(26,27,28) on LWR casks undoubtedly contribute to this generalized shortcoming.
3. Some basic improvements in NDT methods are desirable for LWR casks and will be mandatory for breeder reactor casks. Austenetic stainless steel weldment testing is the most deficient of current and projected NDT requirements.

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IX. APPENDICES

A. Acknowledgments and Key Organizational Contracts

A grateful acknowledgment is made of information from all of the organizations and individuals who were contacted specifically for contributions to this report either in person or by phone. Most of the key contacts are listed below, but there were others, both inside Sandia Laboratories and DOE, who also provided useful input to this cask NDT report. The organizations

are listed below in alphabetical order, while the listing of conferences and symposiums attended is in chronological order and covers the period from July 1, 1975 through December 31, 1977.

Key Organizational Contacts.

- A. Aerojet-Nuclear, Idaho Falls, Idaho
 - W. Francis, Materials Engineering
 - L. Lott, NDT
- B. Babcock & Wilcox, Lynchburg, Virginia
 - A. Wehrmiester, NDT
 - A. Holt, NDT
 - J. R. Birchek, NDT
- C. Battelle/NW Lab, Richland, Washington
 - G. J. Posakony, Manager of NDT
 - L. Becker, NDT
- D. Boeing/Nuclear Power Division, Seattle, Washington
 - D. Martyr, Contract Administrator
 - W. R. Milne, Cask Design
- E. Combustion Engineering, Chattanooga, Tennessee
 - R. M. Stone, NDT
 - W. A. Young, Nuclear Quality Engineering
- F. DuPont/AE Division, Wilmington, Delaware
 - J. W. Langhaar, Cask Design
 - H. Brewer, Quality Control
 - J. Landrum, Quality Control
- G. DuPont/Savannah River
 - L. E. Weisner, NDT
 - W. Joseph, NDT
 - R. Middleburg, Cask Design
- H. Electric Power Research Institute, Palo Alto, California
 - G. T. Dau, Projects Manager for NDT
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 - I. Berman, NDT Liaison
 - R. Henschel, Solid Mechanics Department
 - M. F. Aiello, Solid Mechanics Department
- J. Nuclear Assurance Corporation, Atlanta, Georgia
 - J. Viebrock, Cask Design
 - J. Rollins, Cask Fabrication
- K. Nuclear Containers, Elizabethtown, Tennessee
 - W. R. Householder, Manager
 - N. L. Green, Vice President
- L. Nuclear Regulatory Commission, Washington, D. C.
 - W. F. Anderson, Division of Engineering Standards
 - J. Muscara, Division of Reactor Safety Research
 - E. J. Brown, Division of Engineering Standards
 - V. S. Goel, Division of Engineering Standards
- M. Oak Ridge National Laboratory, Oak Ridge, Tennessee
 - R. W. McClung, NDT R&D
 - J. N. Robinson, NDT Inspection
 - L. B. Shappert, Cask Technology
 - C. Brinkman, Reactor Metallurgy
 - J. Hammond, Technical Contact with Y-12

- N. Philadelphia Electric, Philadelphia, Pennsylvania
R. H. Zong, Quality Manager
- O. Southwest Research Institute, San Antonio, Texas
C. E. Lautzenheiser, Vice President
S. A. Wenk, NDT, R&D
- P. Union Carbide Y-12 Plant, Oak Ridge, Tennessee
V. C. Jackson, NDT Production
L. E. Burkhart, NDT R&D
J. L. Mason, NDT R&D
R. Oakes, Mechanical Properties
W. Moyer, Mechanical Properties
- Q. Westinghouse/Manford, Richland, Washington
J. C. Spanner, Materials Application
D. Green, NDT

Conference/Symposium Participation and/or Attendance.

- A. Materials/Design Forum, San Francisco, CA, July 9-11, 1975,
J. C. Bushnell
- B. Review of Quantitative NDE, Thousand Oaks, CA, July 15-17,
1975, A. G. Beattie
- C. Failure Prevention & Reliability Conf., Washington, D. C.,
September 17-19, 1975, D. W. Ballard
- D. Ultrasonics Symposium, Los Angeles, CA, September 22-24,
1975, A. G. Beattie
- E. Third Annual Boiling Water Reactor Mtg., Gaithersburg, MD,
September 29-30, 1975, O. J. Burchett
- F. Eddy Current Methods Group (ASME), Denver, CO, October 9-11,
1975, J. C. Bushnell
- G. Quality Testing Conference (ASNT), Atlanta, GA,
October 13-16, 1975, D. W. Ballard
- H. NDE in Nuclear Industry, Denver, CO, December 1-3, 1975,
J. H. Gieske and D. W. Ballard
- I. Acoustic Emission Working Group, Ft. Lauderdale, FL,
January 19-23, 1976, A. G. Beattie
- J. Critical Materials Availability Conf., Reston, VA
February 24-26, 1976, D. W. Ballard
- K. Spring ASNT Conference, Los Angeles, CA, March 9-13, 1976
- L. Review of ARPA-Sponsored NDT Programs, San Diego, CA,
July 8-10, 1976, D. W. Ballard and J. C. Bushnell
- M. Fourth Henniker Conference, Henniker, NH, August 9-13, 1976
- N. Second International Conference on Materials Behavior,
Boston, MA, August 16-20, 1976, D. W. Ballard
- O. Review of Quantitative NDE, Alsimar, CA, August 30-31, 1976,
O. J. Burchett
- P. Fall ASNT Conference, Houston, TX, September 27-30, 1976,
R. W. Mottern
- Q. IEEE Acoustical Imaging & Holography Symposium, September 29-
October 1, 1976, J. H. Gieske

- R. Acoustic Emission Working Group, Williamsburg, VA, October 17-20, 1976, A. G. Beattie
- S. WAMTO NDT Conference, Livermore, CA, December 6-9, 1976, D. W. Ballard, R. W. Mottern
- T. ASME Code Meeting, Ad Hoc Acoustic Emission Group, Ft. Lauderdale, FL, January 23-26, 1977, A. G. Beattie
- U. QUINTECH-77, Golden Gate Welding & Materials Conference, San Francisco, CA, January 26-28, 1977, D. W. Ballard and J. H. Gieske
- V. ASNT Spring Conference, Phoenix, AZ, March 26-April 1, 1977, D. W. Ballard
- W. ASME Code Meeting, Ad Hoc Acoustic Emission Group, Livermore, CA, June 15-17, 1977, A. G. Beattie
- X. ARPA/APML Review of Progress in Quantitative NDE, Ithaca, NY, June 13-17, 1977, D. W. Ballard
- Y. ASNT Conference on Innovative and Advanced Radiography, Wilmington, DE, August 1-3, 1977, F. A. Hasenkamp
- Z. Energy Technology Conference, Houston, TX, September 19-22, 1977, J. H. Gieske
- AA. Ninth National SAMPE Conference, Atlanta, GA, October 3-6, 1977, A. G. Beattie

B. Nondestructive Testing of Weldments

Welding is the specified method of joining that is common to all LWR shipping casks as well as most of the other components of LWR power plants. It is a highly reliable process that is well understood and produces consistently high strength joints when properly controlled. Weldment testing has been developed and refined over the past decade and a variety of useful NDT methods are available. Unfortunately, a combination of factors still make weld joints the weak links in most structures inside and outside the nuclear field.

Currently, the major problem that is plaguing LWR plants is the difficulty of testing, with a high degree of reliability, weldments in austenitic stainless steels (Type 300 series, commonly called 18:8 types). Austenitic steels are not heat treatable since they retain an essentially austenitic microstructure at all temperatures. Moreover, they have high ultimate strength, ductility and toughness, retaining notch-tough even at very low temperatures. At elevated temperatures they are relatively strong as compared to iron/chrome alloys, ferritic stainless and martensitic stainless (400 series). For these reasons, austenitic steels such as types 304, 308, and 316 are widely used for nuclear applications.

ASME Code Case 1594 requires double volumetric examination of critical weldments, allowing in some cases (i.e., in austenitic stainless steels because of problems with ultrasonics) two radiographic

techniques at different angles to satisfy this requirement. This two-view radiography is questionable as to its validity and efficiency when compared with ultrasonics which is successfully used on standard nuclear structural steels such as A508 and A533.

Coarse grained austenitic stainless steel weldments are difficult to interrogate with standard ultrasonic methods because of the large and variable attenuation and the high level of noise encountered during an examination. False defect indications and masking of real defects in the weldments and adjacent heat-affected zone have raised real doubts as to the credibility of an ultrasonic method for such weldments. The problem is being studied extensively in the USA and abroad^(5,17) and round-robin experiments are underway.

Potential solutions to excess noise from austenitic weldments include the use of focused transducers, use of frequency analysis, phased arrays of transducers, advanced data processing to improve the signal-to-noise ratios, artificial aperture scanning techniques similar to acoustic holography, and use of non-contact or electromagnetic transducers for ultrasonic testing. Acoustic emission monitoring during and following welding and electro-thermal methods have also been proposed as alternates to conventional ultrasonics.

As initially stated, weldments can be highly reliable and are the preferred method of joining in cask assemblies. Factors requiring close attention to consistently achieve joints as strong as the parent metal include:

1. Optimum weld joint design considering local applications, wall thicknesses, materials, etc.
2. Optimum welding process selection considering materials, dissimilar metals, filler rods or electrodes, number of passes required, pre-heat and post-heat treatments, etc.
3. Qualification of both welders and NDT personnel involved in weld examinations. Section IX of the ASME Code is the preferred guide for the qualification procedures.
4. Rigorous weld rejection and repair criteria must be documented and followed.
5. All weld external surfaces, including the heat and affected zone, must be inspected for cracks using either liquid penetrants per procedure A-2 or B-3 of ASTM E-165 or with magnetic particles using ASTM E-109.