Presentation To

THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

Subject: **Transportable Storage Cask: Interim Storage Effects on Transport Reliability**

Presenter: **Dr. Thomas L. Sanders**

Presenter's Title and Organization: **Manager, Transportation Systems Development Department, Sandia National Laboratories, Albuquerque, New Mexico**

Presenter's Telephone Number: **(505) 845-8542**

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TRANSPORTABLE STORAGE CASK (TSC) CONCEPT
WHAT IS IT?

A Cask is Used for Interim Storage of Spent Fuel (or HLW) Until a Federal Storage or Disposal Facility is Available at Which Time the Cask is Shipped to the Facility.

BACKGROUND

- There is No Historical Precedent in the United States for Transporting a Spent-Fuel Shipping Cask Following a Long-Term Storage Cycle in the Loaded Condition
- There are No Specific Regulations or Guidelines in Place for the Concept

MISSION OF TRANSPORTABLE STORAGE CASK

- **Cask Licensed for Both Storage and Transport**
- **Transportable Storage Cask Would Be Shipped From Reactor Site Without First Opening Cask to Inspect Spent Fuel**

WHAT IS THE ISSUE?

- If Preshipment Inspections of a Loaded TSC Require Unloading and Inspection of the Cask Cavity and Contents, the Mission and Advantages of the Concept are Lost

TRANSPORTABLE STORAGE CASK REQUIRES IN-SERVICE MONITORING AND PRESHIPMENT INSPECTIONS

- **Assess the Effects of a "Normal Storage Cycle Environment" on the In-Transport Reliability of a Spent-Fuel Shipping Cask**

- **Determine Sufficient Combination of Design Compensation for Environmental Effects and Storage Cycle Environmental Monitoring Requirements to Preclude Having to Unload and Inspect a TSC Prior to Shipment**

TRANSPORT-ONLY CASK (TOC) ANALOGY

- The Issue of Concern is Analogous to the Philosophical Basis for Transport Evaluations
  - TOCs are Designed to Envelop Potential Handling and Transport Environmental Factors That May Affect a Cask's Functional and Accident Response Capabilities
  - Annual Maintenance Tests are Designed to Monitor and Ensure Continued Functional Capabilities

TSC/TOC ANALOGY

- Need to Define a "Normal Conditions of Storage Evaluation" That Envelops Potential Storage Cycle Degradative Environmental Uncertainties
  - Corrosion
  - Radiation
  - Temperature
  - Etc.
- Need to Define In-Service Environmental and Functional Monitoring Requirements that Ensure
  - Design Basis Environmental Assumptions are Not Exceeded
  - Functional Capabilities of the Cask Have Not Degraded

TO ENSURE CASK AND FUEL ARE TRANSPORTABLE AFTER A PERIOD OF ≤40 YEARS REQUIRES:

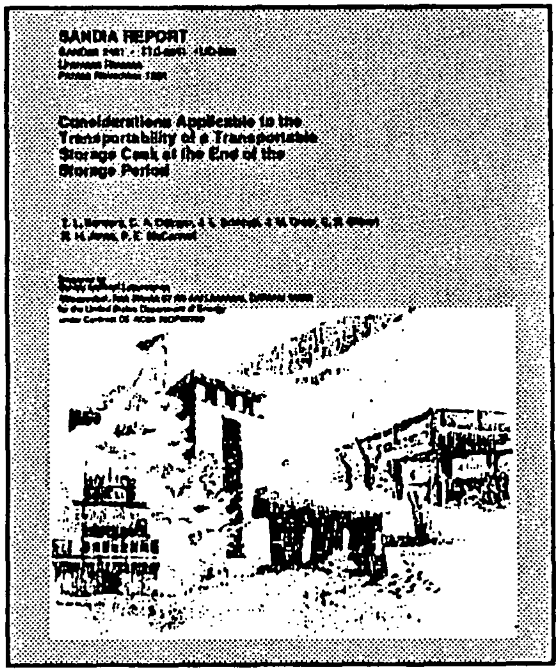
- Definition of Storage Conditions
  - Dry, Inert Environment
  - Temperature Limitations

- Assessment of the Impact of Storage Conditions on Transport Functions of Cask

- Development of TSC System and Operational Strategy
  - Design Features
  - Inspections
  - Fuel and Cask Monitoring

PRESENTATION BASED ON STUDY DOCUMENTED IN:

"Considerations Applicable to the Transportability of a Transportable Storage Cask at the End of the Storage Period," SAND88-2481, Sanders et al.



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OBJECTIVES OF TSC ANALYSIS WERE TO EVALUATE:

- Impact of Long-Term Dry Storage Environment on Expected Condition of Spent Fuel
- Impact of Dry Storage Environment on Condition of Cask Components
- Poststorage Condition of System in Terms of Transport Reliability

REGULATORY GUIDANCE/PHILOSOPHY EXIST FOR:

- Dry Storage
- Transport
- Minimizing Radiation Exposure

No Guidance for Dual-Purpose Role of Storage and Transport

TRANSPORT REGULATIONS AND REGULATORY GUIDES THAT AFFECT THE FEASIBILITY OF THE CONCEPT

- 10 CFR 71
  - All
  - Subpart G
    - ~ 71.85 - Acceptance Tests
    - ~ 71.87 - Routine Determinations

- Regulatory Guide 7.9
  - Maintenance Requirements
  - Acceptance Tests

- Packaging Review Guide
  - Expands Definition of Maintenance Tests

TO MEET REGULATORY REQUIREMENTS:

- Define Normal Condition of Storage Environment, i.e., Expected Condition of Spent Fuel and Cask Materials at End of Storage Period

- Identify Effects of That Environment on Integrity of Spent Fuel and Reliability of TSC in Terms of
  - Criticality Control
  - Shielding
  - Containment
  - Heat Transfer

SANDIA STUDY BASED ON A RELIABILITY COMPARISON OF TSCs AND TOCs

- Comparative Risk Approach: Components and Operations that Ensure Transportability of Either Cask Defined/Compared
- Strategy for TOC Reliability Defined
- Operational/Design Considerations Needed to Maintain Comparable TSC Reliability Identified

TSC/TOC FUNCTIONAL RELIABILITY COMPARISON

Source of Potential Degradation	Applicability (TSC or TOC)	Uncertainty Reducing Measures
Defective Fabrication	Both	Acceptance Tests Quality Control
Defective Designs		
Design Basis Transport Environment Exceeded	Both	Removed From Service Design Conservatism
Design Basis Storage Environment Exceeded	Both (External) TSC (Internal)	Monitor Environment Design Conservatism
Operational Errors	Both	Quality Assurance
Environmental Degradation		
Transport Induced	TOC	Periodic Evaluations
Handling Induced	TOC/TSC	Preshipment Inspections and Monitoring
Storage	TSC	Design Compensation and Monitoring

IMPORTANCE RANKING ASSIGNED TO EACH TSC FAILURE/ERROR MODE

Ranking Function of:

- Failure Mode's Potential Effect on Transport Reliability
- Importance Assigned to Similar Effects on TOC System
- How TSC Failure or Error Mode Differs From Similar TOC Modes

IMPORTANT TECHNICAL ISSUES FOR TSC

Functional Category	Technical Issue
Containment	Spent Fuel Integrity After Storage Seal Reliability After Storage Corrosion of Welds During Storage Effects on Structural Properties of Containment Materials
Criticality Control	Corrosion of Welds During Storage Poison Burnout or Depletion Material Property Effects on Structural Properties of Basket Materials
Heat Transfer	In-Service Deterioration of Heat Transfer Paths
Shielding	Environmental Degradation of Neutron Shield
All	Definition of Design Basis Internal Environment Standardization of Procedures for Record Keeping and Data Processing

SPENT FUEL INTEGRITY

- Fuel Degradation During Dry Storage
  - Controlling Parameters
    - ~ Temperature
    - ~ Stress
    - ~ Atmosphere
    - ~ Time

EXPECTED CONDITION OF SPENT-FUEL CLADDING AFTER LONG-TERM DRY STORAGE

Cladding Degradation/Failure Mechanisms:

- Creep Rupture - Not Credible at 300°-400°C Interim Storage Temperatures
- Stress Corrosion Cracking - Stress Levels, Iodine Concentrations, Temperatures Too Low
- Cladding Oxidation - Not Credible in Inert Environment at 300°-400°C
- UO_2 Oxidation - Not Credible in Inert Atmosphere
- Hydride Formation Cracking - Hydride Reorientation May Reduce Ductility Which May Affect Transport Response

Conclusions:

- Spent Fuel Should Be in Transportable Condition After Long-Term Storage
- All Mechanisms, Except Oxidation, Produce Pinhole Defects of Low Probability
- Gross Ruptures Not Predicted for Dry Storage Conditions
- Even With Large Flaws, Cladding Can Survive Normal Transport Loads

EXPECTED CONDITION OF CASK MATERIALS/ COMPONENTS AFTER LONG-TERM DRY STORAGE

- Radiation Effects
  - Cask Materials
  - Basket Absorbers
  - Seals

- Long-Term Storage Effects (Time, Temperature)
  - Solid Neutron Absorbers
  - Cask Heat Transfer
  - Aging of Cask Materials

MAXIMUM PREDICTED EXPOSURE AFTER FORTY-YEAR STORAGE 7 X 10^{16} n/cm^2:

- No Adverse Radiation Effects Expected for Iron, Copper, or Aluminum Alloys
- No Adverse Effects Expected for Borated Stainless Steel Baskets Nor Any Boron Depletion
- No Degradation of Gamma-Shield Materials (DU, lead)

HEAT TRANSFER EFFECTIVENESS NOT DIMINISHED

- Heat Transfer Characteristics of Casks Should Not Decrease with Storage Time
  - May Slightly Increase
- Decay Heat Generation Will Significantly Decrease With Storage Time
  - Fuel and Cask Temperatures Will Also Decrease
- Inert Environment
  - No Change in Convective, Conductive, or Radiative Properties

FUEL-TO-BASKET HEAT TRANSFER IN AN OXIDIZING ENVIRONMENT

- Oxide Layer Formation
  - Conduction Resistance Increase
  - Negligible Convection Effects
  - Four-Fold Emissivity Increase
    - ~ Benefit in Normal Transport

      Increase Radiation Heat Transfer

CRITICALITY CONTROL FEATURES

- Structural Integrity of the "Basket"
  - Flux Traps Probably Should Not Be Used
  - "Aging" Effects on Aluminum Should Be Evaluated
  - Corrosive Effects on Welds is Uncertain

- Neutron Absorbers
  - Poison "Burnout" is Negligible Whether Cask is Dry or Flooded

CONTAINMENT

- Structural Response of Welds is a Major Uncertainty
- Dual Closure Concept With Installation of a Separate Transport Closure Prior to Shipment is Recommended
  - Questionable Seal Reliability
- Confinement Capabilities of Fuel Should Be Maintained

SEALS MAY REQUIRE SPECIAL CONSIDERATION

- Elastomeric Seals Exposed to Elevated Temperatures and/or Gamma Irradiation May Lose Resilience
- Gamma-Induced Chemical Decomposition May Release Reactive HCl of HF Gases, Which May Degrade Seal Surfaces
- TSC May Require Metal Seals (Long-Term Information Limited) and/or Installation of Separate Transport Closure

LONG-TERM AGING (TIME AND TEMPERATURE) OF METALLIC CASK COMPONENTS

- **Ferritics and Copper Alloys Not Expected to Be Adversely Affected**

- **Aluminum Alloys Should Be Thoroughly Evaluated for Load-Bearing Applications--Significant Microstructural/Property Changes Could Occur**

- **Aging Effects on Depleted Uranium or Lead Uncertain**

DATA ON EFFECTS OF LONG-TERM STORAGE ON SOLID NEUTRON ABSORBERS* LIMITED

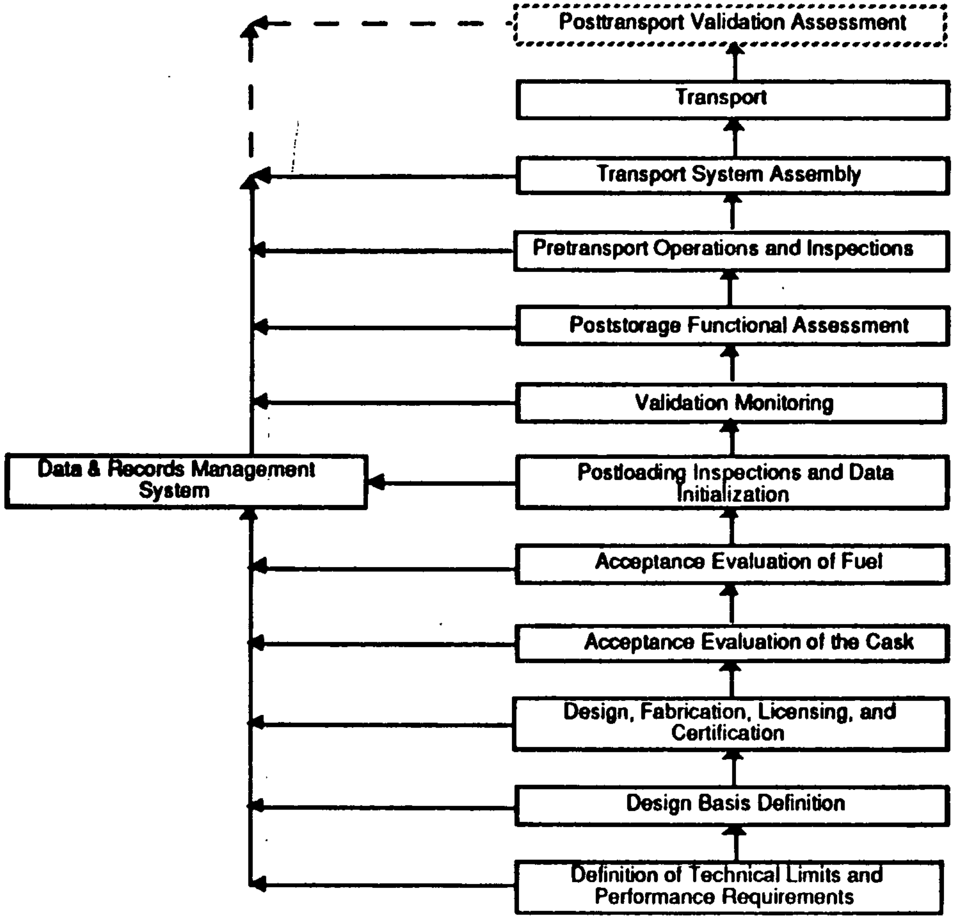
- Long-Term Exposure to Elevated Temperatures and Gamma Irradiation
  - May Degrade (Crack) Absorbers
  - May Require Evaluation of Surveillance Samples or Replacement of Neutron Shield
  - Poison "Burnout" Negligible

*e.g., borated silicone or polyethylene

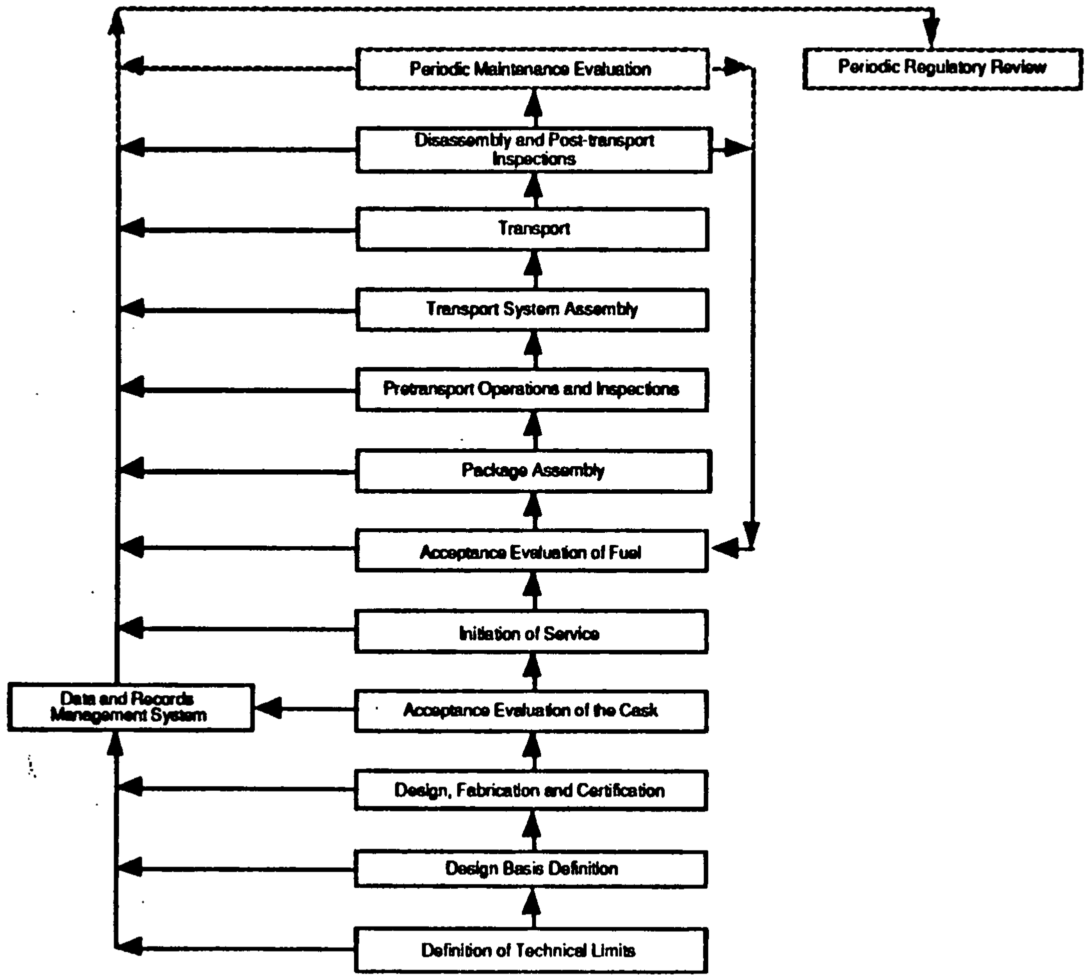
LIFE CYCLE EXPOSURE (LCE) COMPARISON

- Completed Bounding Case
  - TSC/Concrete Storage Only Cask (SOC) Comparison
  - Monitoring Beyond Requirements or 10 CFR 72
  - Conclusion
    - ~ LCE of SOC is About 45,000 Person-REM Over 40 Years
    - ~ If No Additional Monitoring is Required, the LCE of the TSC Reference Could Be as Low as 25% of That for the Same Capacity Concrete SOC
    - ~ Additional Monitoring of Up to 100% of TSCs Can Be Accommodated and Still Have Reduced Exposures

PROPOSED FEATURES OF A TSC SYSTEM



FEATURES OF A TRANSPORT-ONLY CASK SYSTEM



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CONCLUSIONS

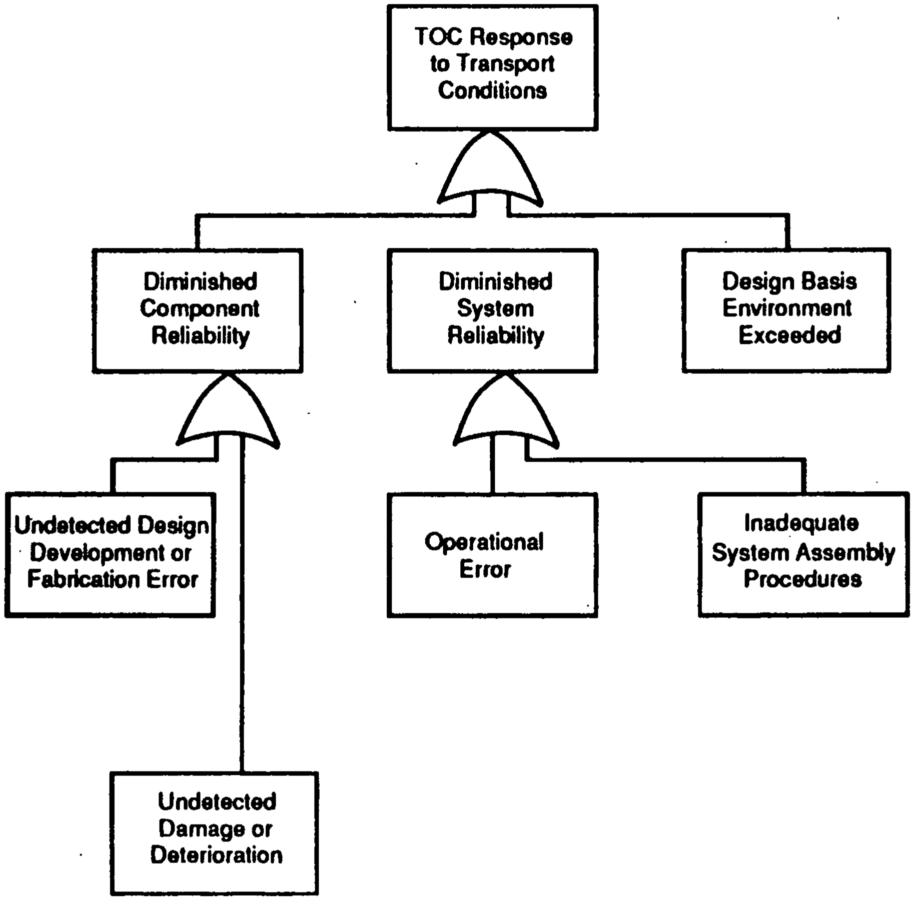
- Transport Function of TSC System May Be Comparable or Superior to That of TOC
- Most Error Sources and Failure Modes Identical for TSC and TOC Systems
- Many Accepted SOC and TOC Practices Readily Applicable to TSC System
- Concerns Include
  - In-Storage Deterioration
  - Unanticipated Storage Conditions
  - Extent of Current Materials Data on Long-Term Aging and Exposure
- No Adverse Effects Expected for Many Materials and Components; Some Significant Adverse Effects Probable for Certain Identifiable Materials

CONCLUSIONS
Continued

Provisos:

- No Assessment of Deterioration of Mechanically or Metallurgically Joined Components Made
- Expected Storage Conditions Must Prevail
- Monitoring of All Casks and Evaluation of Control Casks Desirable
- Long-Term Record Keeping Necessary
- Pretransport Functional Evaluations Necessary
  - Criticality
  - Shielding
  - Containment
  - Heat Transfer

MAJOR FAILURE MODES THAT AFFECT THE IN-TRANSPORT RELIABILITY OF A TRANSPORT-ONLY CASK (TOC)



PRELIMINARY IMPLEMENTATION GUIDELINES FOR A TRANSPORTABLE STORAGE CASK SYSTEM

Design Basis

- Use the Normal Conditions of Transport Definition to Define the External Environment
- Determine a Maximum Heat Load Based on Burnups and Ages of Fuel Expected to Require Dry Storage
- Limit the Internal Environment to Maintain Spent Fuel and Material Integrities
- Determine, Where Necessary, a Procedure for Validation Monitoring of Potentially Consumable Components and Materials
- Limit the Use of Internal Welds and Materials That Exhibit Adverse Aging Effects, Such as Some Aluminum Alloys
- Perform Degradation Analyses of All Functional Components
- Define Design Alternatives, Such as a Transport-Only Closure, and Identify Possible Replaceable Components Such as Neutron Shielding

PRELIMINARY IMPLEMENTATION GUIDELINES FOR A TRANSPORTABLE STORAGE CASK SYSTEM

Continued

Cask Performance

- Demonstrate the Adequacy of Pretransport Functional Assessments in Determining Reliability
- Demonstrate the Adequacy of Validation, Component, Material, and/or Environmental Monitoring for Ensuring Reliability
- Develop a Methodology That Integrates the Monitoring and Pretransport Assessments to Determine a Cask's Fitness for Shipment
- Develop a Strategy for Ensuring That the Safety Features of Auxiliary Systems, Such as Impact Limiters, Are Available for Future Use

PRELIMINARY IMPLEMENTATION GUIDELINES FOR A TRANSPORTABLE STORAGE CASK SYSTEM
Continued

Operational Considerations

- **Develop Uniform Procedures for the Following:**
  - **Postloading, Initialization of System Data and Confirmatory Analyses**
  - **Validation Monitoring of Control or Consumable Components**
  - **Pretransport Functional Reliability Assessments**
  - **Record Keeping and Data Analyses**
  - **Recognition of and Responses to Unanticipated Service Conditions**
- **Develop a Strategy for Controlling the Transport Environment During a Single Shipment**