UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 28, 2001

MEMORANDUM TO: Susan M. Frant, Deputy Director
Licensing and Inspection Directorate
Spent Fuel Project Office, NMSS

FROM: Nancy L. Osgood, Senior Project Manager
Licensing Section
Spent Fuel Project Office, NMSS

SUBJECT: SUMMARY OF THIRD MEETING WITH PACKAGING TECHNOLOGY, INC. REGARDING THE MIXED OXIDE (MOX) FRESH FUEL PACKAGE

Background

A meeting was held on March 21, 2001, in Rockville, Maryland, at the request of Packaging Technology, Inc. to discuss the design of a new package for the transport of fresh fuel assemblies containing mixed (uranium and plutonium) oxide fuel. The meeting was noticed on February 26, 2001. Attachment 1 to this memorandum is the list of meeting attendees. Attachment 2 is the meeting handout. No regulatory decisions were requested or made at the meeting. The discussion followed the attached meeting handout.

Introduction

The package is being developed for use by the Department of Energy (DOE) as part of the fissile disposition program. DOE will be the shipper and will be responsible for security and safeguards for the shipments.

Package Design Overview and Update

The package consists of a cylindrical, stainless-steel containment shell with foam impact limiters and will transport three MOX fresh fuel assemblies within a strongback. The package has been designed to minimize weight for compatibility with the DOE transportation system.

Criticality Analysis Results

The fuel assemblies are Mk-BW/MOX1 17x17 PWR fuel assemblies, with a plutonium enrichment of 6.0 weight percent. The uranium is depleted. The strongback incorporates borated steel plates with boron that is enriched in the boron-10 isotope. The transport index for criticality control will be 100. Criticality calculations have been performed and resulted in the maximum k-eff, including uncertainty and bias, of less than 0.95. Staff noted that benchmarking of the system will be important and that the application should show that the benchmarks are appropriate for the fuel material, the system, and the poison.

Thermal Analysis Results

The maximum decay heat is 80 watts per assembly and 240 watts per package. Calculations performed show that seals, impact limiter foam, and other components remain within their service temperatures under normal (hot and cold) conditions and fire test conditions.

Structural Evaluation

Results of engineering tests were discussed. Physical tests were performed using an engineering scale model that included the impact limiters. The certification testing of the package was discussed. Packaging Technology plans to do all testing at ambient conditions. The impact limiter foam will be modified to represent the package performance under cold-temperature conditions. Staff advised that Packaging Technology must evaluate the performance under hot and cold conditions, including the behavior of materials such as the brittle fracture of the borated steel poison plates. Drop and puncture test orientations were discussed.

Schedule

Packaging Technology plans to test the package in April 2002 and to submit an application for package approval in October 2002.

Docket No. 71-9295

Attachments: 1. Attendance List
2. Meeting Handout

MEETING ATTENDEES

Meeting with Packaging Technology
Regarding the MOX Fresh Fuel Package

March 21, 2001

Andrew Barto	NRC/NMSS/SFPO
Ken Erwin	NRC/NMSS/SFPO
Sue Gagner	NRC/OPA
Jack Guttmann	NRC/NMSS/SFPO
Daniel Huang	NRC/NMSS/SFPO
Tim Johnson	NRC/NMSS/FCSS
Bob Martin	NRC/NRR
Tim McGinty	NRC/NMSS/SFPO
Nancy Osgood	NRC/NMSS/SFPO
Dave Tiktinsky	NRC/NMSS/SFPO
Sheena Whaley	NRC/NMSS/SFPO
Bernie White	NRC/NMSS/SFPO
Gary L. Clark	Packaging Technology
Joe Nichols	Packaging Technology
Phil Noss	Packaging Technology
Toney Mathews	Duke Cogema Stone & Webster
Mike Klimes	U.S. DOE-CH
Patrick Rhoads	U.S. DOE-NNSA
Rick Michelhaugh	Oak Ridge National Laboratory
Andrea Genetta	WNC
Linda Gunter	Edlow International

ATTACHMENT 1

MOX Fresh Fuel Package
3rd NRC Meeting

NRC Docket No. 71-9295

March 21, 2001

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Agenda

- Introduction
- Packaging Design Overview & Update
- Criticality Analysis Results
- Thermal Analysis Results
- Structural Analysis Results
- Schedule

ATTACHMENT 2

Introduction

- Purpose
  - Update NRC SFPO
  - Present status of the MOX fresh fuel package (MFFP) design
  - Obtain NRC views of:
    - Design approach
    - Preliminary analysis & engineering test results
    - Certification test plan

Introduction

- Background
  - Excess plutonium (PU) from various DOE defense programs
  - Consortium of Duke, COGEMA, & Stone & Webster (DCS) awarded contract by DOE-MD (Materials Disposition) to design, license and build:
    - MOX fuel fabrication facility (MFFF)
    - MOX PWR fuel assemblies
    - Transportation packages (MFFP)
  - Fuel fabrication facility & transportation package to be NRC-licensed
  - Fuel to be transported between MFFF and mission reactors by DOE using Safeguards Transport (SGT) Vehicles

Packaging Design Overview & Update

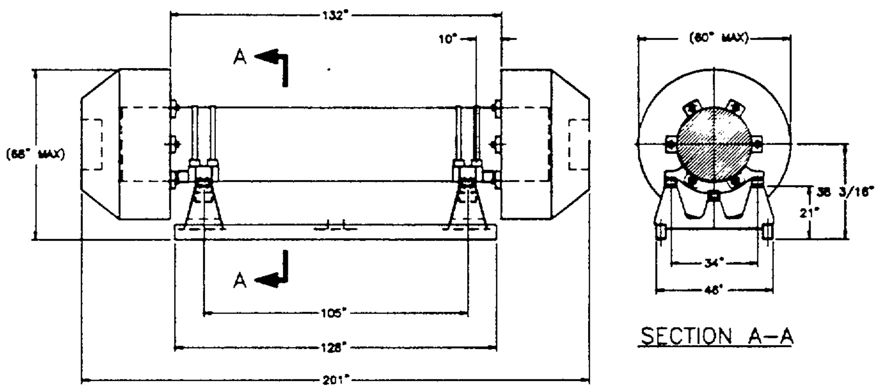
- Design Overview
  - System Overview
  - Containment Boundary & Impact Limiters
  - Strongback
  - Neutron Poison/Moderator

Packaging Design Overview & Update

- General Configuration:
  - Overall Envelope Parameters (Approx.)
    - Length: **171.1 inches** (w/o impact limiters)
    - Containment Shell Outer Diameter: **29⅝ inches**
    - Impact Limiter Outer Diameter: **60 inches**
    - Package Gross Weight: **14,500 pounds (15,000 Maximum)**
    - Weight of Internals (strongback, support discs, fuel assemblies): **7,300 pounds**

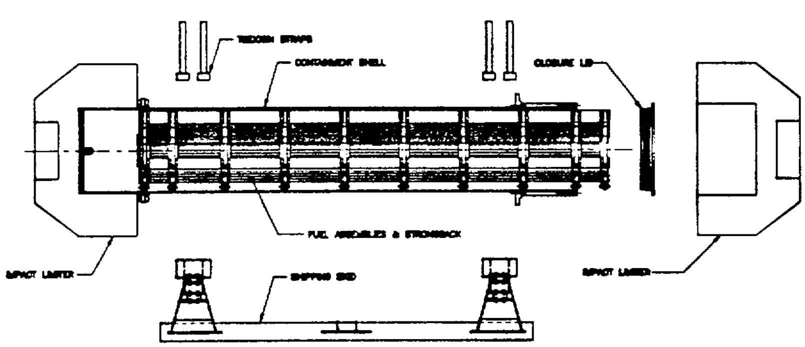
Packaging Design Overview & Update

- General Configuration:
  - Type B(U)F-85 packaging
  - Single containment boundary per 10 CFR §71.63(b)(1)



Packaging Design Overview & Update

- General Configuration:
  - Cylindrical containment shell with conventional, polyurethane foam filled impact limiters at each end

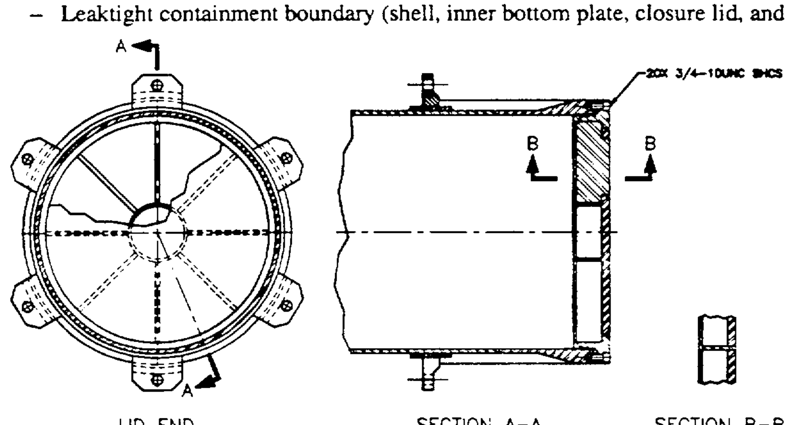


Packaging Design Overview & Update

- Payload
  - MOX Fresh Fuel Assemblies
  - MK-BW/MOX1 17 × 17 PWR Fuel Assemblies
    - Maximum total Pu enrichment: 6.0 weight percent (w/o)
    - Maximum assembly weight: 1,573 pounds
    - Heat Production, as supplied by fuel fabricator:
      - Initial = 62.0 Watts/assembly
      - After three year decay = 63.6 Watts/assembly
    - Heat Production, as used in the analyses: 80 Watts/assembly
    - MOX Fuel Material does not require specific radiation shielding

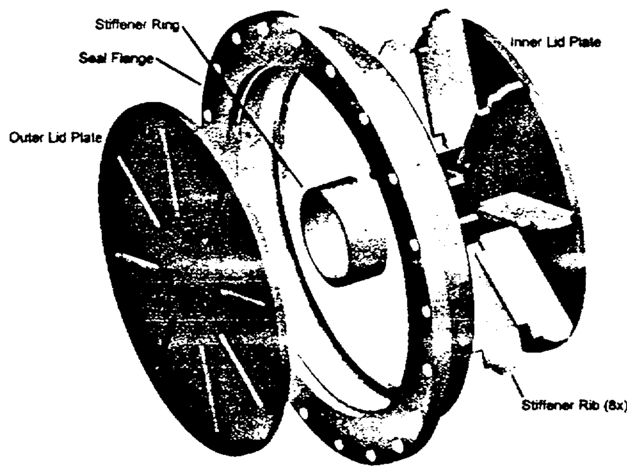
Packaging Design Overview & Update

- Containment Boundary:
  - Cylindrical, high strength stainless steel shell, flat ends, and a bolted closure lid at one end
  - Leaktight containment boundary (shell, inner bottom plate, closure lid, and seals)



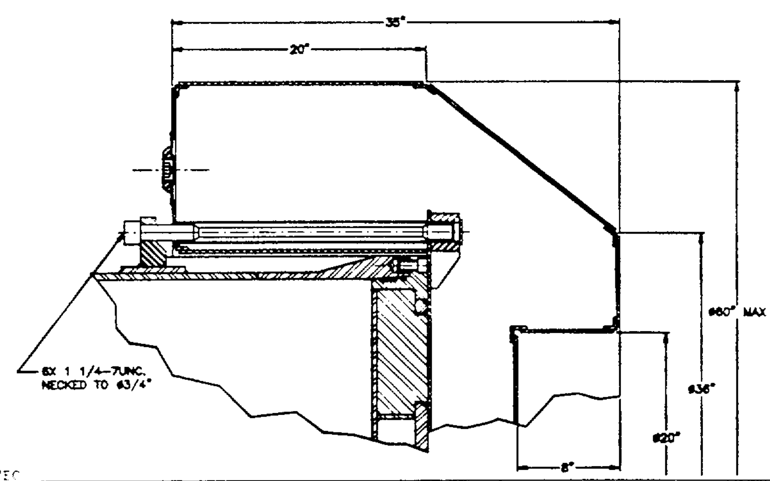
Packaging Design Overview & Update

- Containment Boundary: Lid



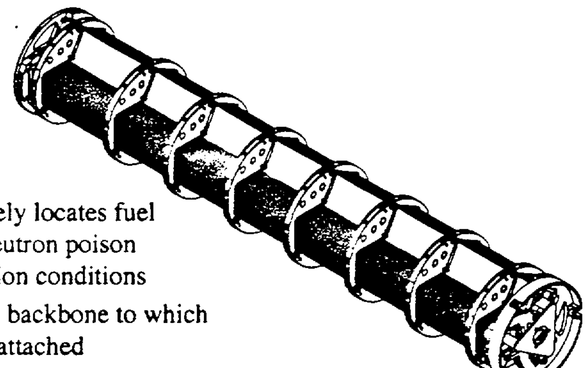
Packaging Design Overview & Update

- Impact Limiters - Top Impact Limiter
  - In addition to limiting impact forces, is designed to resist puncture



Packaging Design Overview & Update

- Strongback
  - Symmetric, triangular arrangement of assemblies
  - Support fuel assemblies for operations and for criticality control
  - Relatively low reactivity, triad design



  - Strongback securely locates fuel assemblies and neutron poison for all transportation conditions
  - Strongback forms backbone to which support discs are attached

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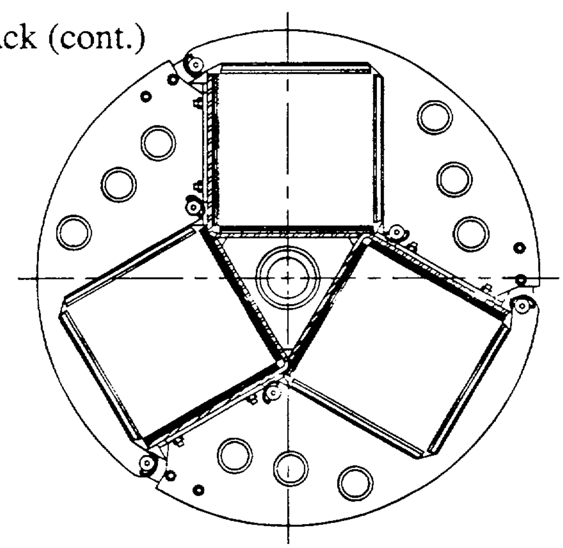
Packaging Design Overview & Update

- Strongback (cont.)



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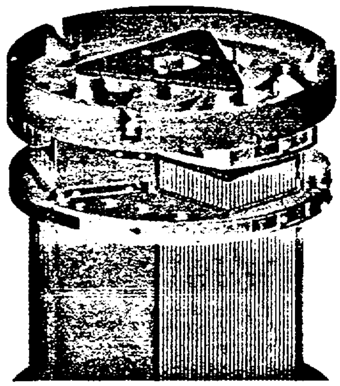
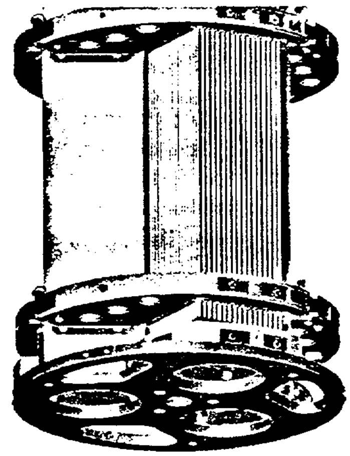
Packaging Design Overview & Update

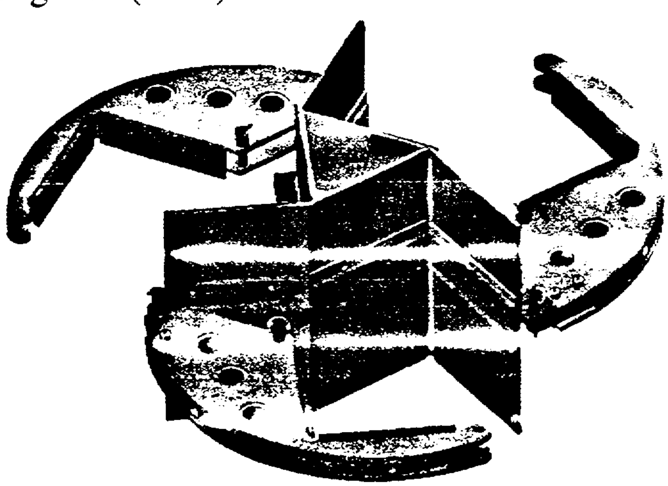
- Strongback (cont.)





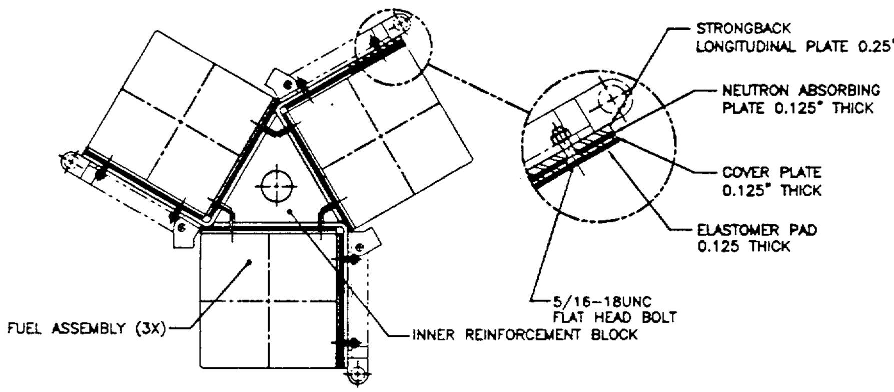
Packaging Design Overview & Update

- Strongback (cont.)



Packaging Design Overview & Update

- Strongback (cont.)



Packaging Design Overview & Update

- Neutron Poison
  - Borated Stainless: ASTM A887, Type 304B7
  - Design:
    - minimum 1.75% boron which is enriched to 45% ^{10}B
    - minimum density of 0.280 lb/in^3
    - minimum thickness of 0.115
    - minimum areal density of ^{10}B = 0.0164 g/cm^2
  - Analyses:
    - minimum 1.173% boron which is enriched to 50% ^{10}B
    - minimum density of 0.2853 lb/in^3
    - minimum thickness of 0.125
    - minimum areal density of ^{10}B = 0.0159 g/cm^2
  - Certification test unit poison is specified with minimum 1.75% boron, unenriched

Criticality Results

- Design Criteria
  - Exclusive Use ∴ Criticality Control Transport Index = 100 & 'N' = 0.5
  - The package must remain subcritical per 10 CFR 71
    - Subcriticality defined as $K_{eff} < 0.95$
      - Code bias added to calculated
      - 2σ added to calculated values
    - Single Undamaged Package Case (NCT)
      - Full water reflection
      - No Internal Flooding
      - No Damage
    - Single Damaged Package Case (HAC)
      - Optimum Internal Flooding
      - Full Water Reflection
      - HAC Damage
  - Analyses used the Effective Criticality Limit (ECL) method
    - $k_s = k_{eff} + \beta + 2(\sigma_{calc}^{\,2} + \sigma^2_{MCNP} + \sigma^2_{exp})^{0.5} \leq 0.95$

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Criticality Results

- Criticality Source Term
  - Criticality source term is based on:
    - A blend of depleted uranium and Weapons Grade plutonium
    - Plutonium "enrichment" up to 6.0 w/o of heavy metal
    - Depleted uranium assumed to contain 0.3% ^{235}U
    - MK-BW 17x17 PWR fuel assembly design

Isotope	Range of Concentration (w/o)	Criticality Basis Concentration (w/o)
Pu-239	90-95	95
Pu-240	5-9	5
Pu-241	<1	0
Pu-242	<0.1	0

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Criticality Results

- MOX Fuel Plutonium Enrichments

	MFFP Design Basis	
Enrichment Zone	**Number of Fuel Rods**	**w/o Pu***
Low (corners)	12	2.279
Medium (edges)	68	3.525
High (interior)	184	4.717
Total or Average	264	4.300

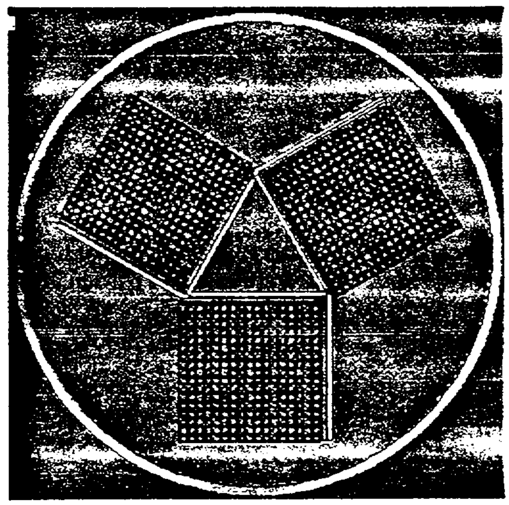
*The criticality analyses use an uniform enrichment of 6.0 w/o Pu

Criticality Results

- Criticality Models
  - Numerous MCNP calculations, including
    - Various poison configurations
    - Variations in internal water density
    - Variations in fuel assembly configuration
  - Benchmarking
    - MCNP calculations based on available benchmark data
    - MCNP code bias determined
  - Poison Design
    - Enriched borated stainless
    - Model includes attachment holes, which are treated as voids
    - Burnable poison rods ignored

Criticality Results

- Base Model



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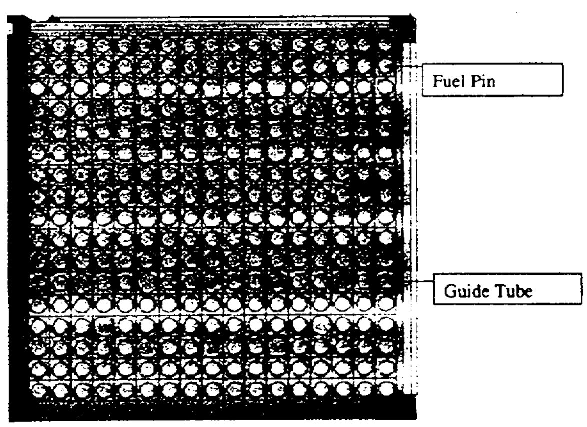
Criticality Results

- Base Model - Details



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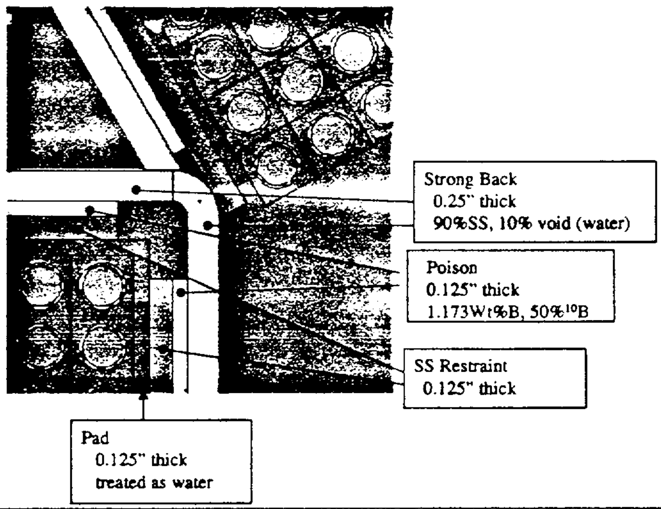
Criticality Results

- Base Model - Details



Criticality Results

- MFFP Preliminary Criticality Results

Case	K_{eff}	σ	$K_{eff} + 2\sigma$ + bias
Base NCT: No damage, nominal positioning, no moderation, 12" water reflector	0.2791	0.0014	0.2951
Base HAC: No damage, nominal positioning, optimum moderation, 12" water reflector	0.9102	0.0010	0.9260
HAC-1: Pin pitch decreased 1.2%	0.8992	0.0010	0.9149
HAC-2: Pin pitch increased 0.6%	0.9155	0.0011	0.9313
HAC-3: Pin pitch increased 1.2%	0.9215	0.0010	0.9372
HAC-4: All three assemblies moved inward	0.9104	0.0010	0.9261
HAC-5: One assembly moved horizontally	0.9092	0.0011	0.9250
HAC-6: Fuel density decreased by 1.1%	0.9107	0.0010	0.9264

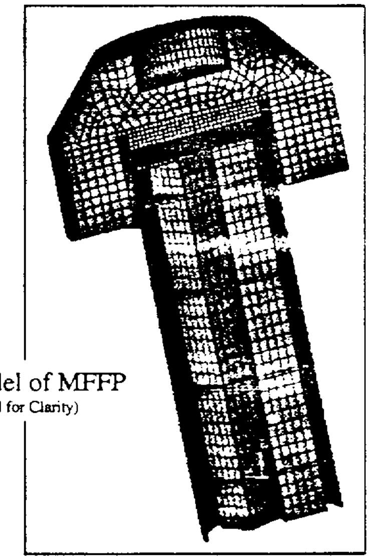
Thermal Analysis Results

- Thermal Model
  - ANSYS Finite Element Model
  - Quarter symmetry of closure end
  - Heat Source: 80W per assembly (240W total)
  - Fuel assumed to have properties of WE 17×17 standard fuel assemblies
  - Primary heat paths:
    - Conduction & radiation from fuel assemblies to inner surface of package (no convection in package cavity)
    - Convection & radiation from package surface
    - Axial conduction within package occurs primarily through shell, strongback and fuel

Thermal Analysis Results

- Thermal Model, cont.
  - NCT warm conditions, per regulations: 100 °F ambient, still air, defined insolation
  - HAC fire event conditions, per regulations: 1,475 °F environment, defined emissivities, forced convection
  - For HAC fire event, the model is altered to provide conservative representations of free drop and puncture damage (detail in later slide)
- Results
  - Due to relatively small payload heat generation, both NCT and HAC temperatures are governed by the regulatory environment

Thermal Analysis Results



FEA Thermal Model of MFFP
(Air Elements Removed for Clarity)

Thermal Analysis Results

Thermal Acceptance Criteria

	NCT	HAC
Seals (Butyl)	310 °F	400 °F for 8 hours
Limiter Foam	140 °F*	N/A
Fuel Cladding	392 °F	1,337 °F
Neutron Poison (ASTM A887, Type 304B)	800 °F	2,250 °F
Structural Members (Types 304 and XM-19)	800 °F	2,250 °F

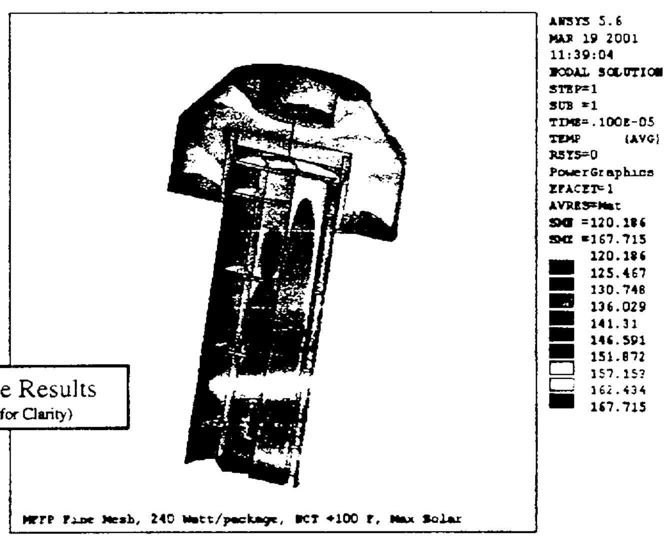
*Used to evaluate structural properties of foam but not an intrinsic foam limit.

Thermal Analysis Results

NCT Results

- Peak component temps (100 °F ambient, full solar)
  - Fuel Cladding: 168 °F (392 °F Limit)
  - Containment Seal: 146 °F (310 °F Limit)
  - Bulk Foam: 132 °F (140 °F Limit)
  - Neutron Poison: 164 °F (800 °F Limit)

Thermal Analysis Results

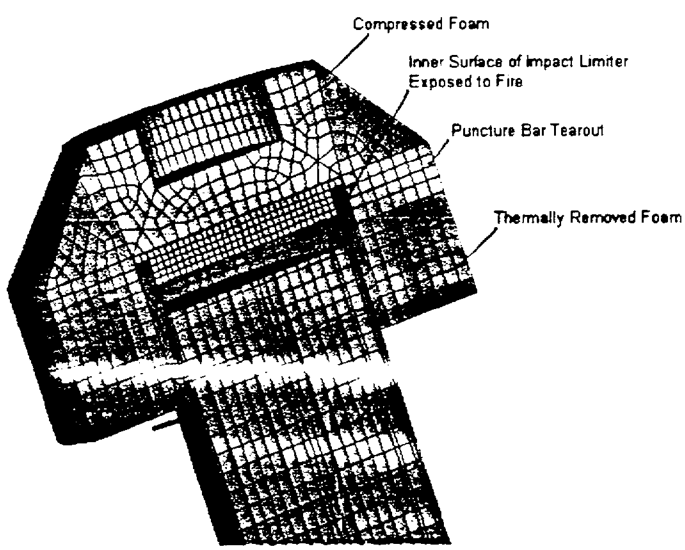


NCT Temperature Results
(Air Elements Removed for Clarity)

Thermal Analysis Results

- Conservative HAC Damage Assumptions
  - Impact limiter crushed by 80% over full circumference
    - Predicted maximum side drop crush <60%
    - Places maximum damage nearest containment seal
  - Two different puncture damage cases considered:
    - Primary case has no puncture perforation of limiter skin, based on engineering puncture test results
    - Added conservative case has puncture perforation, including foam tearout adjacent to containment seal
  - Heat paths to seal
    - Primary path via conduction through package walls and impact limiter skin, secondary path via conduction through fuel and strongback, radiated to seal area.

Thermal Analysis Results

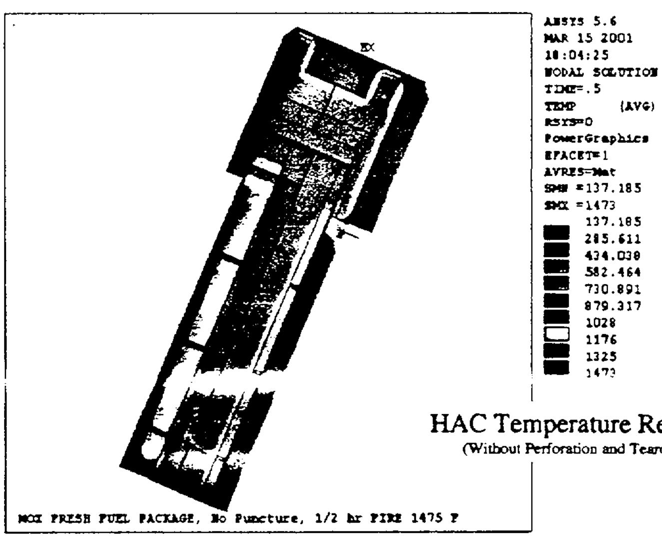


Thermal Analysis Results

HAC Results

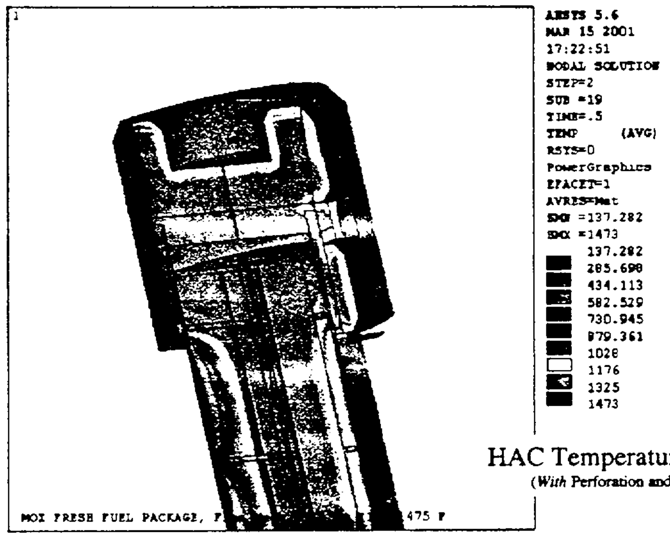
- Peak component temperatures due to fire event, assuming no perforation of the impact limiter skin by puncture bar:
  - Shell Wall: 1,380 °F (2,250 °F Limit)
  - Strongback: 1,017 °F (2,250 °F Limit)
  - Neutron Poison: 756 °F (2,250 °F Limit)
  - Fuel Cladding: 899 °F (1,337 °F Limit)
  - Containment Seal: 197 °F (400 °F / 8 hr Limit)
- Peak component temperatures, assuming perforation (conservative) and tearout adjacent to containment seal
  - Containment Seal: 363 °F (400 °F / 8 hr Limit)
  - All other temperatures remain the same

Thermal Analysis Results



HAC Temperature Results
(Without Perforation and Tearout)

Thermal Analysis Results



HAC Temperature Results
(*With* Perforation and Tearout)

Thermal Analysis Results

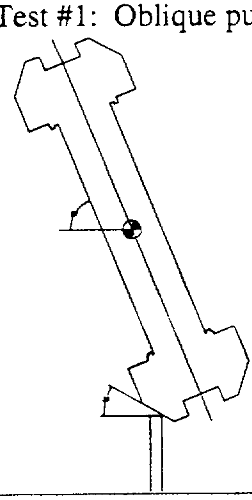
- Internal Pressure
  - NCT pressure, resulting from warming of air and 1% release of charge gas, is 2.4 psig. MNOP set at 10 psig
  - HAC pressure derived from: warming of internal air, release of all charge gas, and formation of combustion products from approximately 14 lbs. of polymer material
  - Resulting HAC pressure: 139 psig (170 psig conservatively used in analysis)

Thermal Analysis Results

- Conclusions
  - Conservative model yields temperatures well below limits (over 200 °F margin on containment seals)
  - MFFP design provides adequate thermal protection for the containment seals

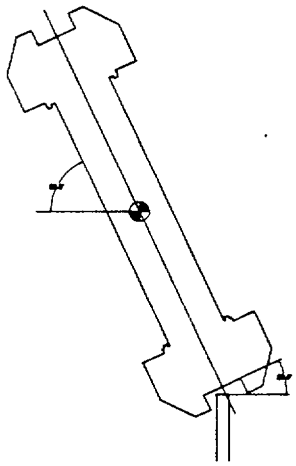
First Engineering Test - Review

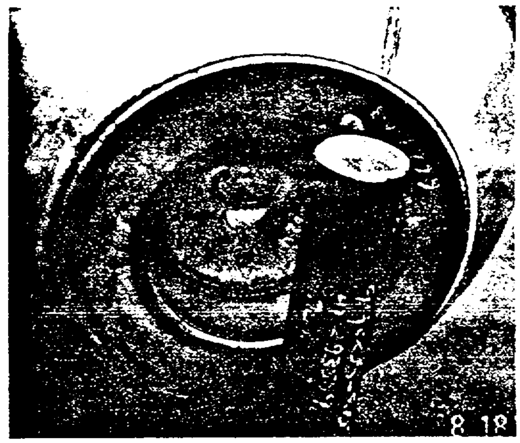
- Series of punctures on top end impact limiter
  - Test #1: Oblique puncture drop onto top end limiter



First Engineering Test - Review

- Test #3: Oblique puncture drop onto top end limiter





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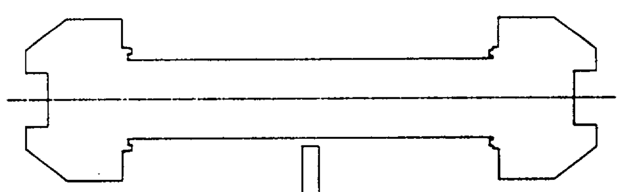
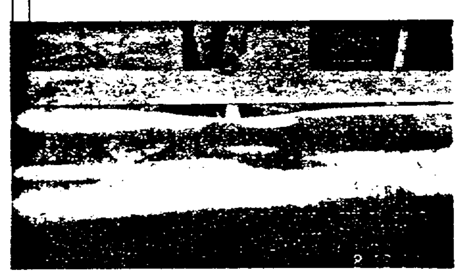
First Engineering Test - Review

- Test #7: Horizontal CG puncture drop





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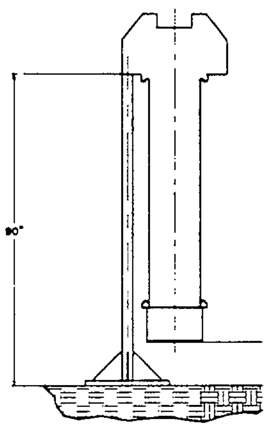
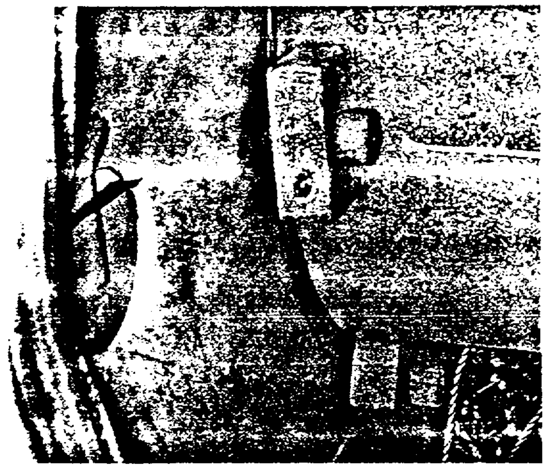
Additional Engineering Test Results

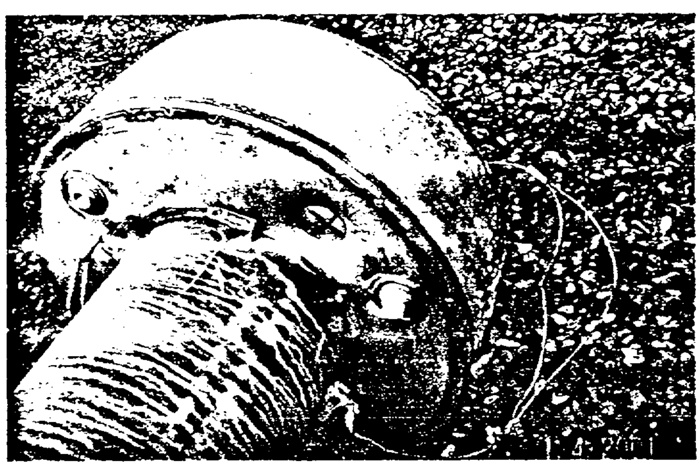
- Longitudinal Puncture to Remove Limiter (#1)



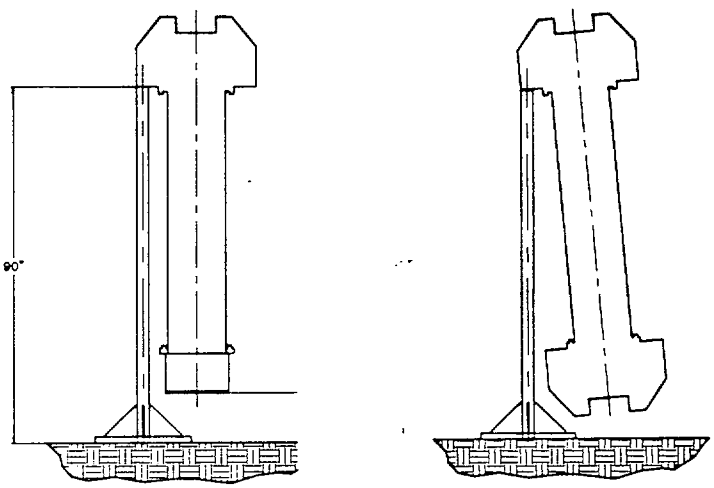


Additional Engineering Test Results

- Longitudinal Puncture to Remove Limiter (#2)



Additional Engineering Test Results



Engineering Test

Equivalent Certification Test

Additional Engineering Test Results

- Conclusions
  - Impact limiter attachments not affected by longitudinal puncture
  - Flat face of top end limiter shell not perforated by puncture
  - Due to the demonstrated robust nature of the design as demonstrated, no longitudinal puncture certification test is planned

Certification Testing

- Test Unit Configuration
  - Full scale, prototypic test article
  - Cask, strongback, and impact limiters to be completely prototypic in design, material, and fabrication
  - Prototypic weight and center of gravity
  - Components that are not exactly replicated:
    - Impact-absorbing polyurethane foam strength
    - Neutron poison (does not use enriched boron)
    - Payload fuel assemblies
      - prototypic
      - mock
      - simulated

Certification Testing

- Test Unit Impact Absorbing Foam
  - The governing temperature for impact is cold (-20 °F):

(Calculated Impacts)

Orientation	Cold g	Warm g
Side	132	110
End	87	78
C.G. corner	89	82
Slapdown 15°	208	176

  - Test foam should therefore be cold, **or** the effect of cold foam should be simulated
  - Maximum crush can be extrapolated from test results and strength properties of warm foam

Certification Testing

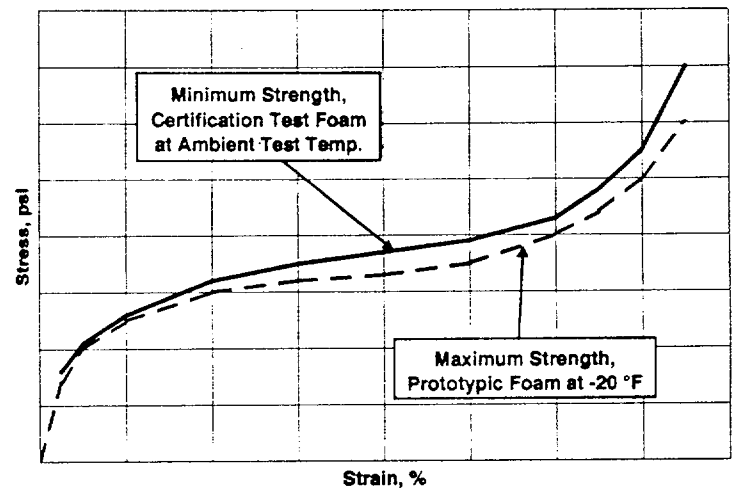
- Test Unit Impact Absorbing Foam, *cont.*
  - Test unit polyurethane foam strength will be adjusted to simulate the strength of cold (-20 °F) prototypic foam, but at ambient test temperature
  - Polyurethane foam can be "poured-to-order", i.e., it can be formulated to have any desired strength at the basis temperature
  - Crush strength of foam goes up with *decreasing* temperature; strength at -20 °F is higher than at ambient temperature
  - A denser foam can be formulated to have the same high strength at *ambient* temperature
  - Tolerances must be included

Certification Testing

- Test Unit Impact Absorbing Foam, *cont.*
  - Step 1: Establish the stress-strain curve of high-tolerance, minimum temperature prototypic foam. This is the strongest the prototypic foam will be under regulatory conditions
  - Step 2: Specify a foam for the certification test unit having a *minimum* strength at *ambient* temperature which is *at least as strong* as the stress-strain curve established in Step 1
  - Step 3: During certification drop and puncture testing at ambient temperature, the test impact limiter impact behavior will be the *same* as if the prototypic foam were tested at -20 °F

Certification Testing

- Test Unit Impact Absorbing Foam, *cont.*



Certification Testing

- Fuel Assemblies for Certification Testing:
  - Prototypic fuel assembly
    - Identical design, materials, and fabrication to actual MOX fuel
    - Same weight and weight distribution as actual MOX fuel
    - Tungsten carbide pellets replace MOX fuel pellets
    - Used to demonstrate actual fuel behavior in worst-case drop orientation
  - Mock fuel assemblies
    - Represent fuel assemblies, mounted prototypically in strongback
    - Same weight and weight distribution as real fuel
    - Applies drop loads to the strongback in a way similar to actual MOX fuel
    - Used when prototypic fuel assembly is not required

Certification Testing

- Fuel Assemblies for Certification Testing, *cont.*
  - Simulated payload (steel rods)
    - Conservative weight, uniform weight distribution
    - Conservatively low self-support
    - Used when actual payload configuration is of no importance to results of drop test

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Certification Testing

- Mock Fuel
  - Used to simulate a single MOX fuel assembly in certification testing when the internal behavior of the actual fuel assembly is not required
  - Interface to strongback same as actual fuel assembly
  - Designed to load the strongback in the same way as actual fuel
  - Primary design criteria
    - Bending stiffness
    - Weight
    - Weight distribution

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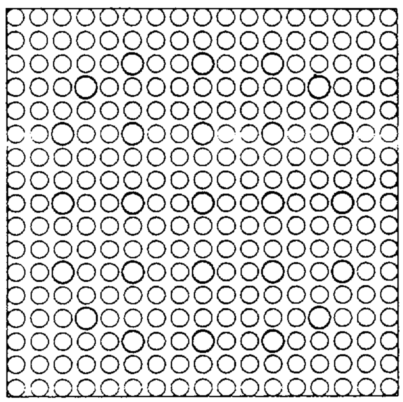
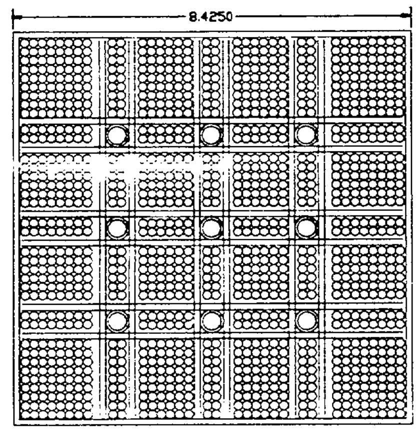
Certification Testing

- Cross-Section Comparisons

Actual Fuel

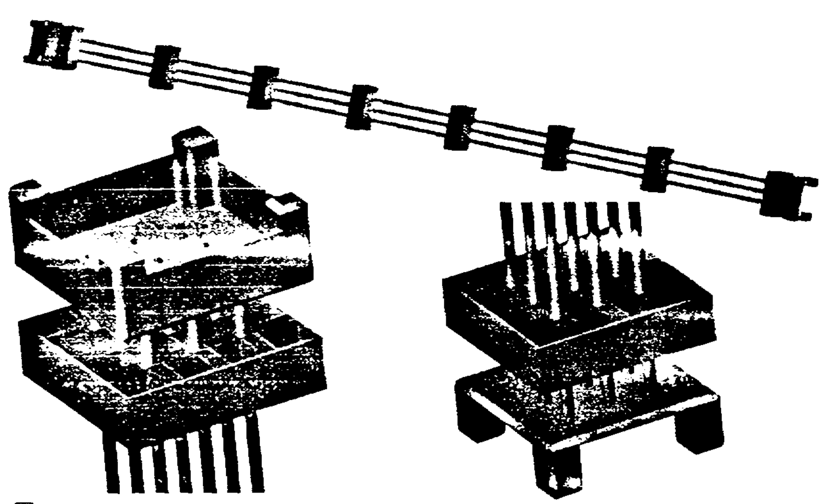


Mock Fuel



Certification Testing

- Mock Fuel Assembly (Steel rods removed for clarity)



Certification Test Plan

- Certification by Test, With Supporting Analysis
  - Test approach chosen since strongback and fuel are not amenable to detailed analysis
- Full-Scale Prototypic Test Article
- Test to Include Free Drop and Puncture
  - Tests include worst case orientations for containment shell, impact limiters, strongback, and fuel assembly
  - Each test focuses on specific aspect of package design
- HAC Thermal event, immersion event, and all NCT conditions by analysis

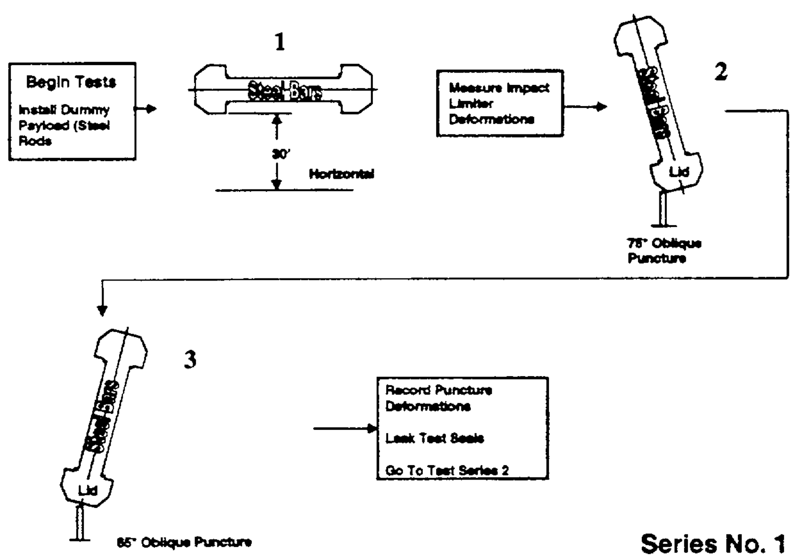
Certification Test Plan

- HAC Thermal Event Approach
  - Only the elastomer containment seals are sensitive to fire event temperatures
  - Detailed, conservative thermal model shows large temperature margins:
    - Peak fire seal temperature = 197 °F
    - Limit based on test = 400 °F for 8 hours (TRUPACT-II)
  - Large design margin afforded by:
    - Relatively thick polyurethane foam impact limiters (t ≅ 13")
    - Limiter skin thickness which resists puncture perforation
    - Even including severe puncture damage, maximum seal temperature (363 °F) is still well below the limit of 400 °F
  - Large design margins support analysis approach vs. test

Certification Test Plan

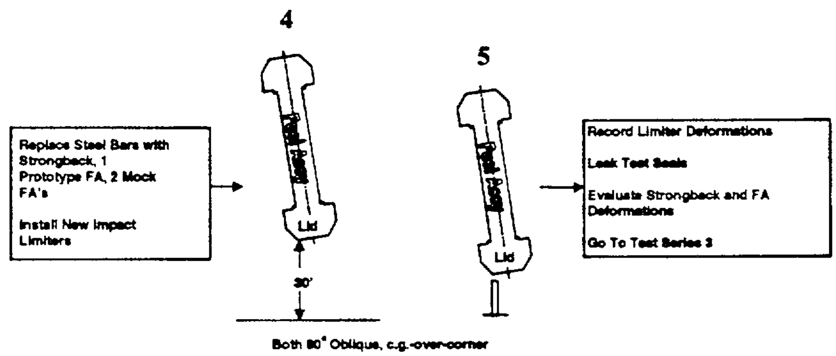
- Determination of Tests Performed
  - Containment Components:
    - evaluate **shell** for buckling under maximum moment **[Side Drop]**
    - evaluate **shell** for perforation under puncture **[Side Puncture]**
    - evaluate **closure** under maximum lateral loads **[Slapdown]**
    - evaluate **closure** under maximum axial loads **[Near-Vertical Drop]**
  - Strongback & Fuel Components:
    - evaluate **strongback** under maximum lateral loads in all potentially vulnerable orientations **[Slapdown]**
    - evaluate **fuel** response in drop **[Near-Vertical Drop]**
  - Impact Limiter Components:
    - evaluate **impact limiter** resistance to perforation **[Oblique Punctures]**
    - evaluate **impact limiter** retention **[Slapdown]**

Summary of Certification Tests



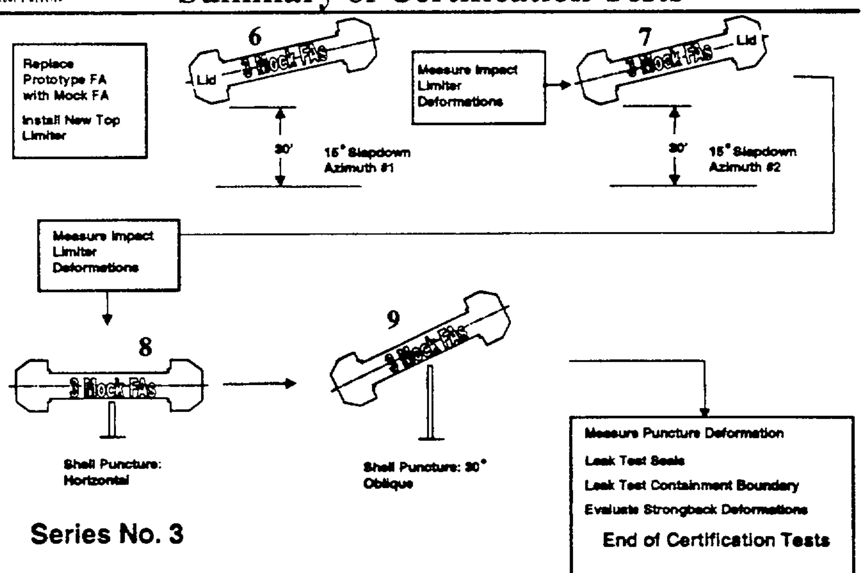
Series No. 1

Summary of Certification Tests



Series No. 2

Summary of Certification Tests

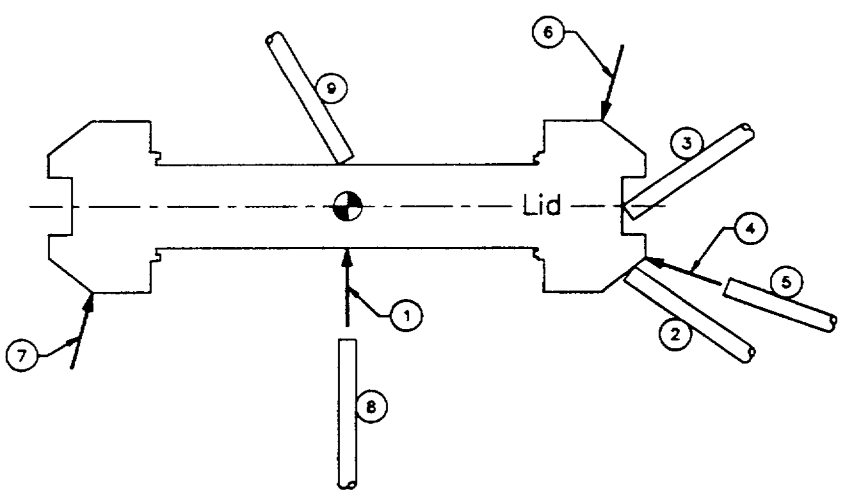


Series No. 3

Summary of Certification Tests

Test	Purpose	Acceptance
Horizontal Free Drop	✓ Apply maximum bending moment to the shell	• Shell remains structurally stable • Package leak tight
C.G. Over-Corner Free Drop	✓ Apply maximum vertical loads to closure ✓ Supply worst case fuel reconfiguration to criticality analysis	• Package remains leak tight • Fuel deformations within criticality assumption
Slapdown free drop, Azimuth #1	✓ Apply maximum loads to strongback	• Strongback deformations within criticality assumption • Package remains leak tight
Slapdown free drop, Azimuth #2	✓ Apply maximum loads to strongback ✓ Apply maximum horizontal loads to closure	• Strongback deformations within criticality assumption • Package remains leak tight
Puncture on top end limiter	✓ Demonstrate 'No Perforation' of limiter skin	• No perforation of limiter skin
Punctures on containment shell	✓ Demonstrate 'No Perforation' of shell	• No perforation of limiter skin • Package Leaktight

Certification Test - Summary of Tests



Certification Test Plan

- Instrumentation
  - High speed films will be used to record drop tests
  - As necessary, maximum deformation and acceleration can be calculated from films
  - Supplemental techniques may be used, such as crush gages

Planned Schedule

Activity	Previously Reported	Currently Expected
Certification Test	September 2001	April 2002
Application Submittal	March 2002	October 2002
Certificate of Compliance {Estimated}	June 2003	January 2004