MIDUS Transportation Package
Pre-Submittal Meeting

November 3, 2005

Rockville, MD

Agenda

- **Design Update**
- **Confirmatory Test Plan**
- **Gas Generation**
  - Experiments
  - MIDUS Package Design
- **Safety Analyses**
  - Structural
  - Shielding
  - Thermal
- **Licensing & Fabrication Schedule**

MIDUS Design Update

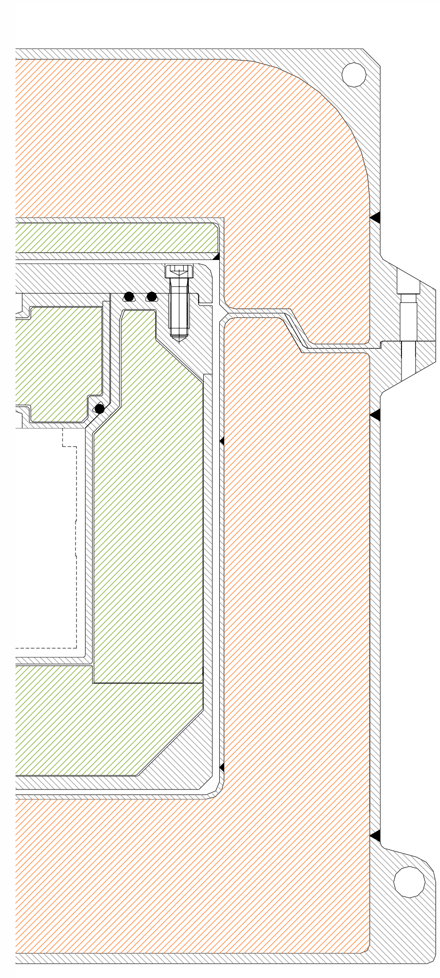
- **MIDUS Program Refresher**
- **Design Overview Refresher**
- **What's Changed Since July Meeting?**
  - Shielding-related changes
  - Structural-related changes
  - Thermal-related changes
  - Fabrication enhancements

MIDUS Program Overview

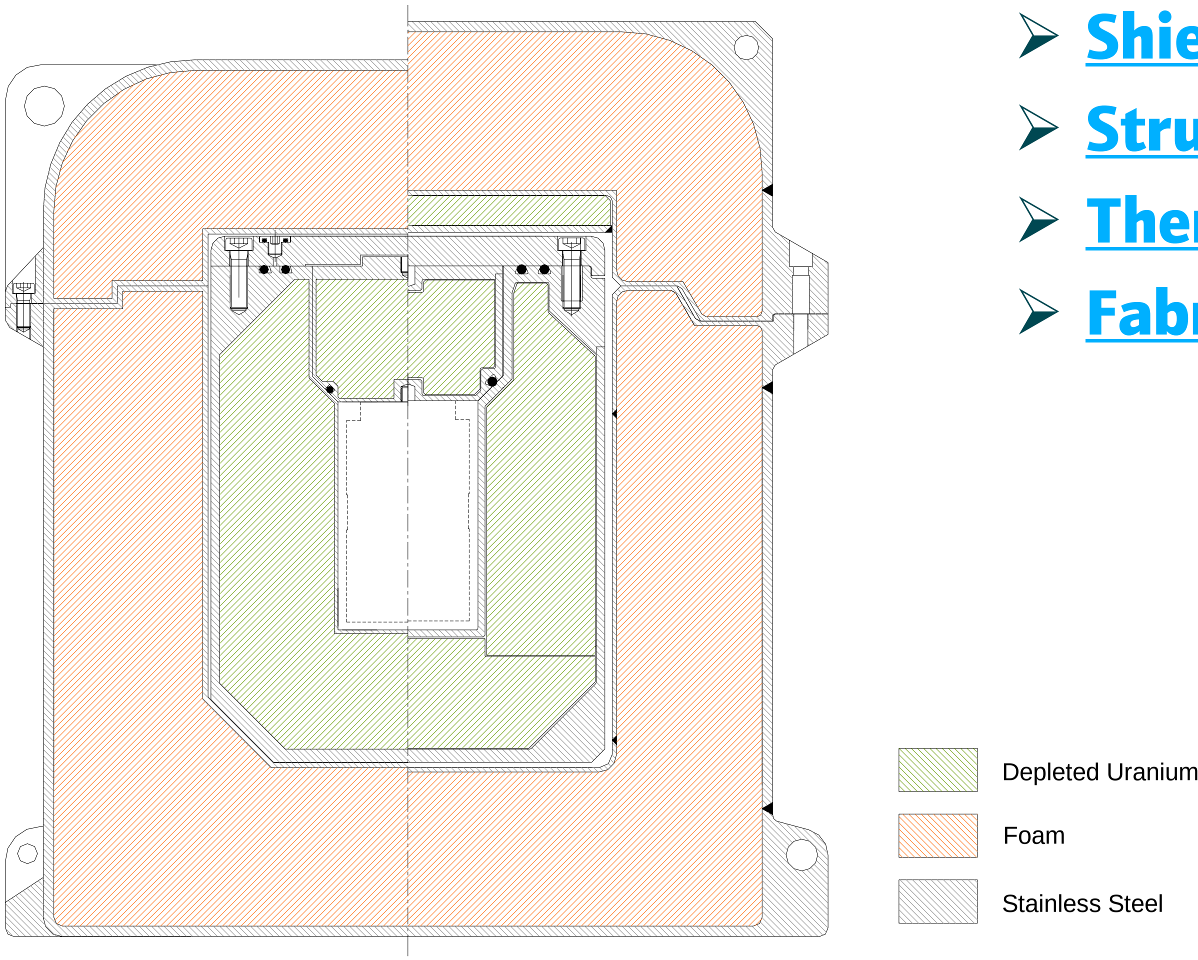
- **Purpose**
  - Medical Isotope Depleted Uranium-Shielded (MIDUS) cask is to ship Mo99 from the Tyco's facility in Petten, The Netherlands.
- **Need**
  - Tyco currently supplies most of the U.S. Mo99 (Tc99m)- over 15 million patient doses annually.
  - Ganuk cask currently used (USA/0656/B(U)-96). German certificate holder is retiring and the certificate will expire in October, 2006.
- **Program Goals**
  - Certification by October, 2006
  - Application tailored for accelerated certification
    - > Simple, robust design with margin
    - > High quality license application
    - > Confirmatory testing
    - > Frequent NRC meetings

MIDUS Design Overview

➢ Package ID	MIDUS
➢ Package Type	B(U)
➢ Contents	up to 4,500 Ci Mo99 $NaNO_3$/NaOH solution 60 Ci/ml max 100 ml max
➢ Approx Height	524 mm (21 in)
➢ Approx Diameter	480 mm (19 in)
➢ Approx Weight	300 kg (660 lb)
➢ Materials	Stainless Steel Depleted Uranium Polyurethane Foam



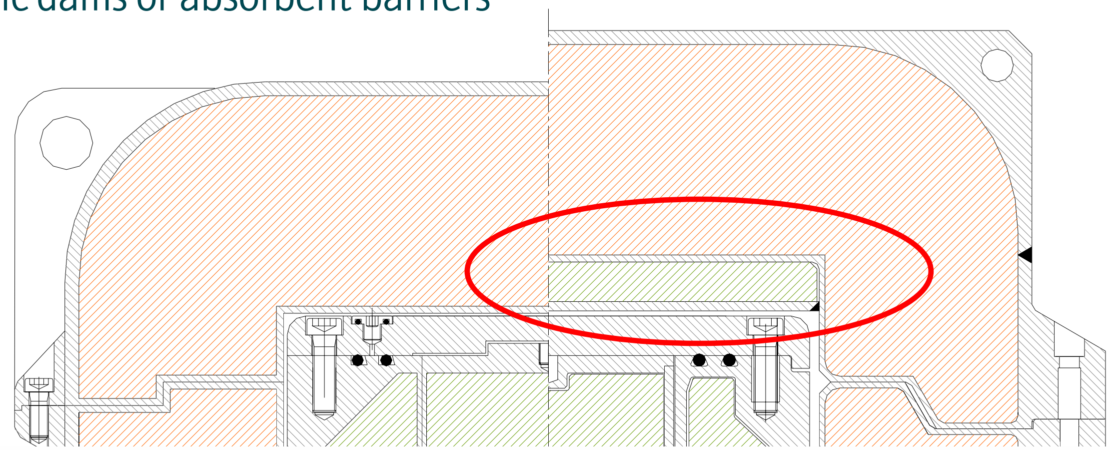
Design Changes Since July



- **Shielding**
- **Structural**
- **Thermal**
- **Fabrication**

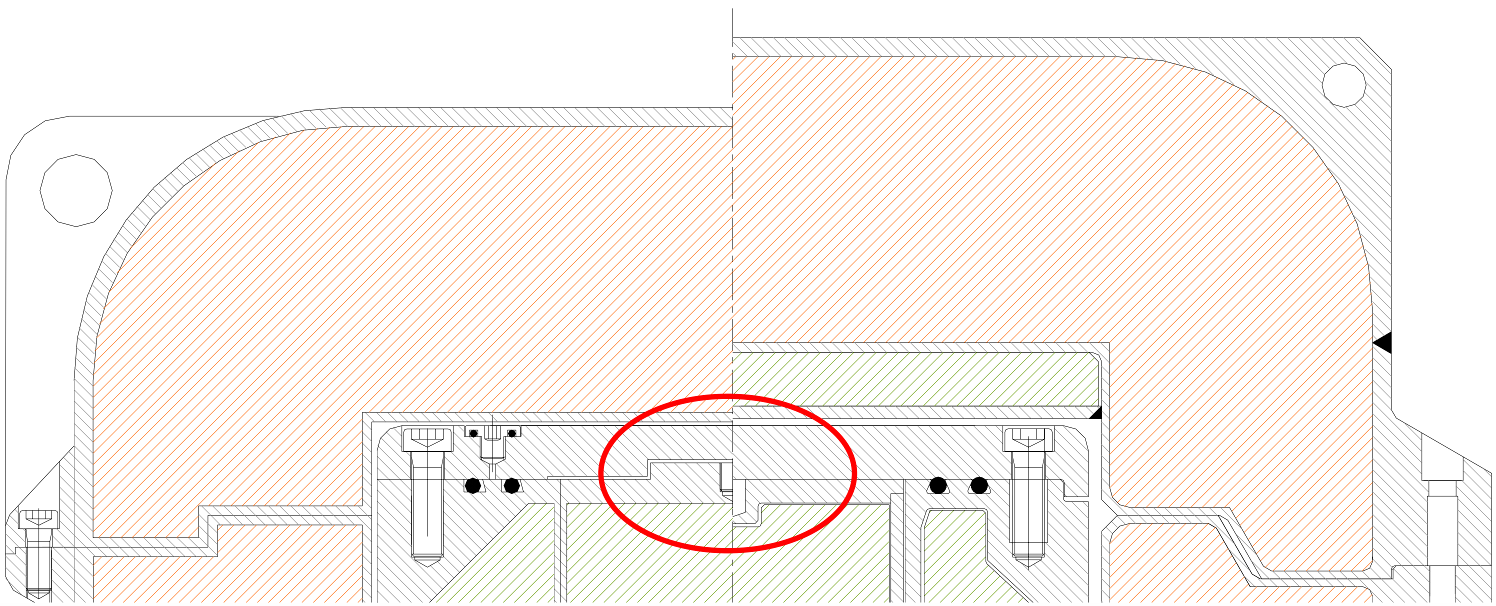
Shielding-Related Changes

- **NRC Comment from July 21 Meeting (Studsvik Lesson Learned)**
  - **Liquid payload could wick up into the shield plug gap- bypassing much of the package shielding.**
  - **Looked at four options:**
    - > Make the cleanliness seal the containment seal (process problem)
    - > Separate containment vessel (process problem)
    - > Precision tolerances (not effective)
    - > Additional DU shielding on overpack lid (added lid weight a problem)
    - > Elastomeric dams or absorbent barriers



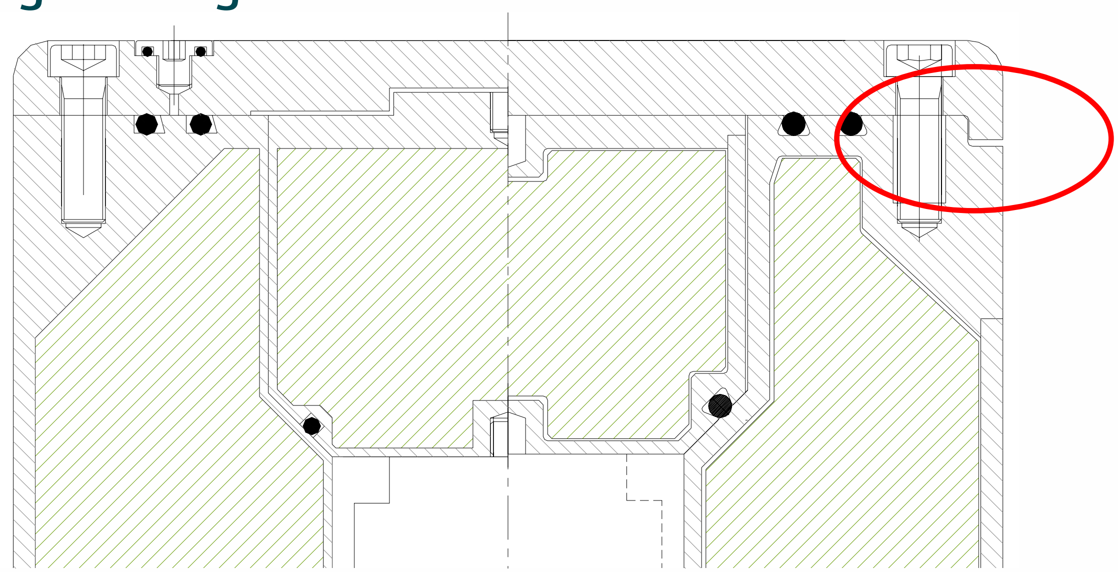
Shielding-Related Changes

- **Changed to Flush Shield Plug Top Surface.**
  - Removing stepped shield plug top eliminates a major potential “trap” for liquid product to collect.
  - Minimizes need for high precision machining.



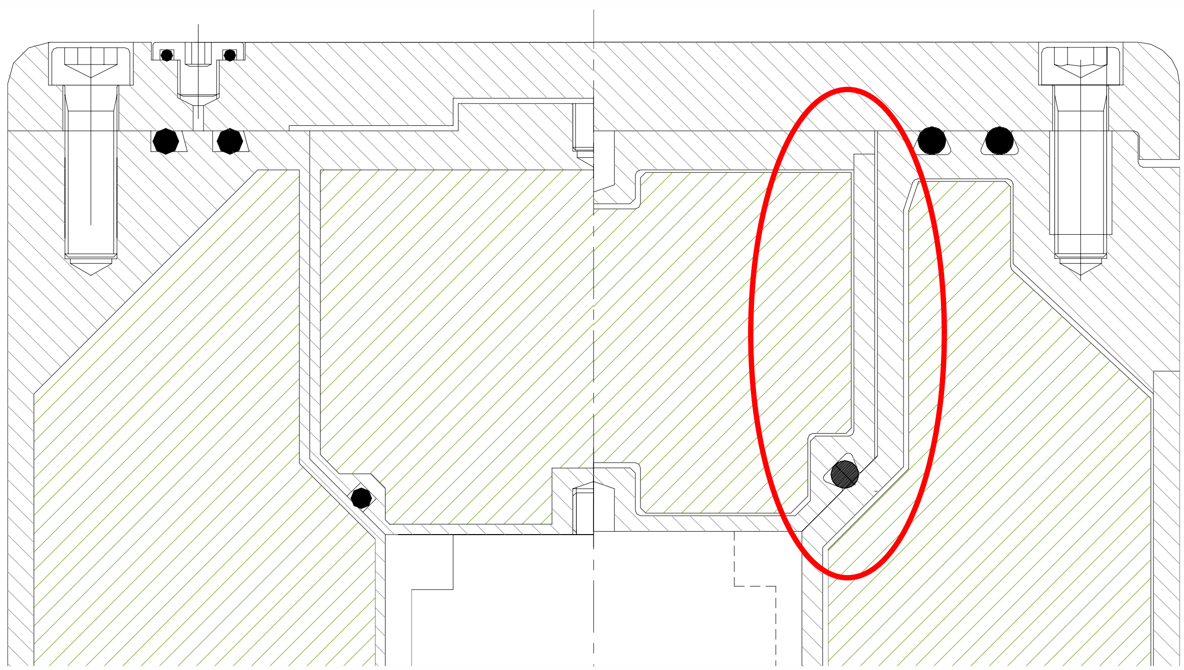
Structural-Related Changes

- **Stepped Lid Modified to Protect Bolts from Shear Loading**
  - Preliminary bolt evaluation showed bolt shear stresses due to NCT side drop exceeded allowable stress limits.
  - Considered increasing number/size of bolts, adding shear pins, or modifying lid design.



Structural-Related Changes

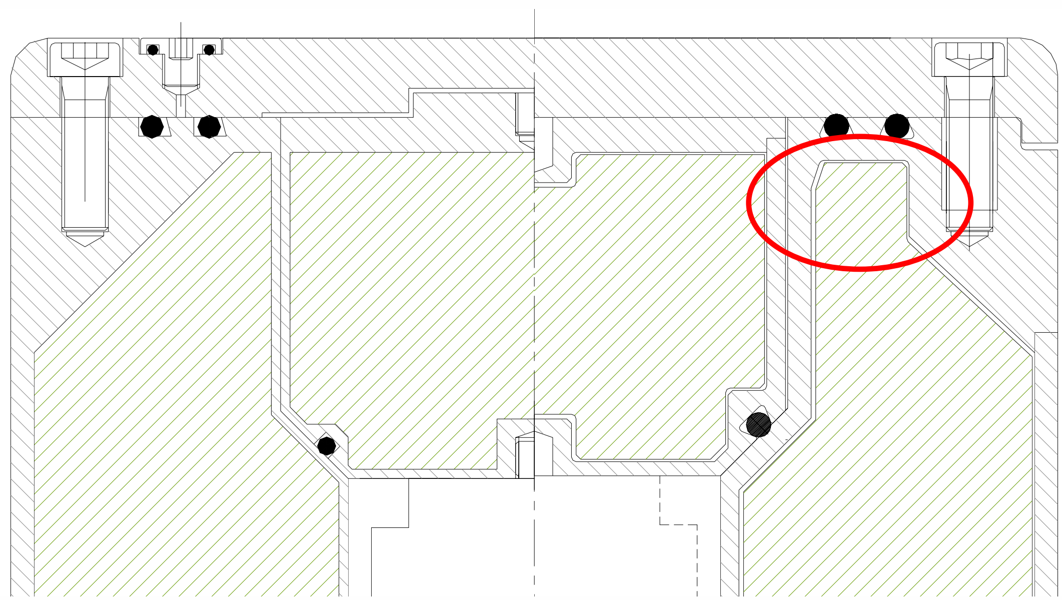
- **Increased Thickness of Containment Shell Near Shield Plug Region.**
  - Stresses due to side drop loads exceeded allowable stresses.
  - Containment shell acts as cantilever beam in side drop.



Structural-Related Changes

➢ Modified DU Top End Detail on the Cask Body

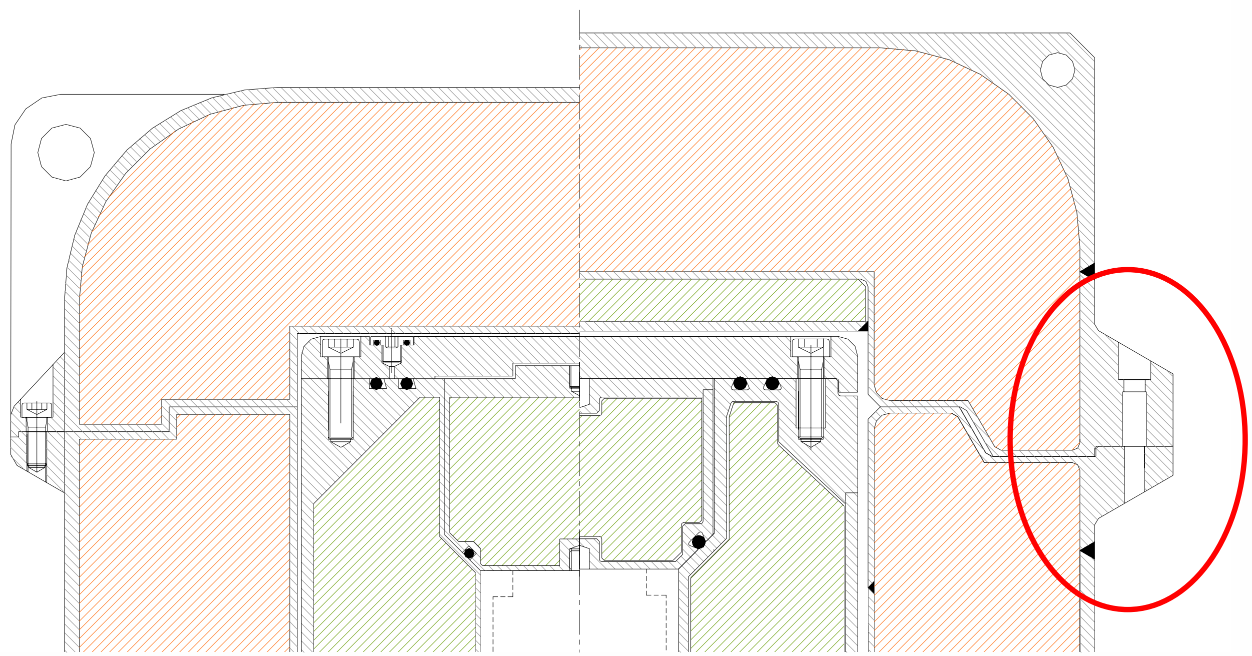
- Increased the bearing area between DU and bolting flange for top end drop.
- Prevent plastic deformation in flange area per NUREG/CR-6007.



Structural-Related Changes

➢ Increased Size of Overpack Bolting Flange

- Increased size of shear lip
- Increased bolt length for added flexibility
- Added bolt shear relief pocket

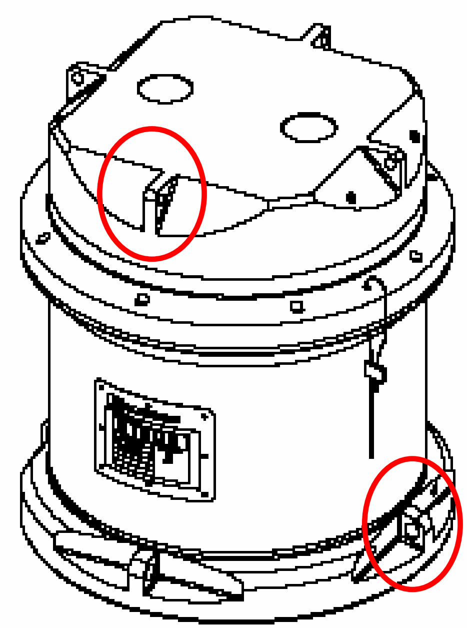


Thermal-Related Changes

- **Increased Foam Density From 10 to 12 lb/ft^3**
  - Initial thermal review showed that the containment O-ring seal area temperatures might be a problem.
  - Temperatures are a strong function of foam density.
  - 12 lb/ft^3 foam should provide good thermal margin.
- **Added Thermal Test to Confirmatory Test Program.**

Fabrication-Related Changes

- **Added Integral Lifting and Tiedown Lugs**
  - Eliminated welded lugs by going to machined construction.
- **Added Fabrication Details (fill ports, etc.)**



Confirmatory Test Overview

➢ Confirmatory Tests Planned

- Full-scale MIDUS transportation package test article
- Range of NCT and HAC test conditions
  - > Free drop, puncture, and thermal
- Results will be included in the initial license application submittal

➢ Purpose of Confirmatory Test Program

- Confirm that the analytical tools/methods used to predict the package performance are adequate
- The MIDUS license application will provide "Evaluation-by-Analysis" in accordance with NUREG-1609

➢ Test Objectives

- Demonstrate reasonable agreement between the measured and calculated package response for the tested conditions

Confirmatory Test Overview

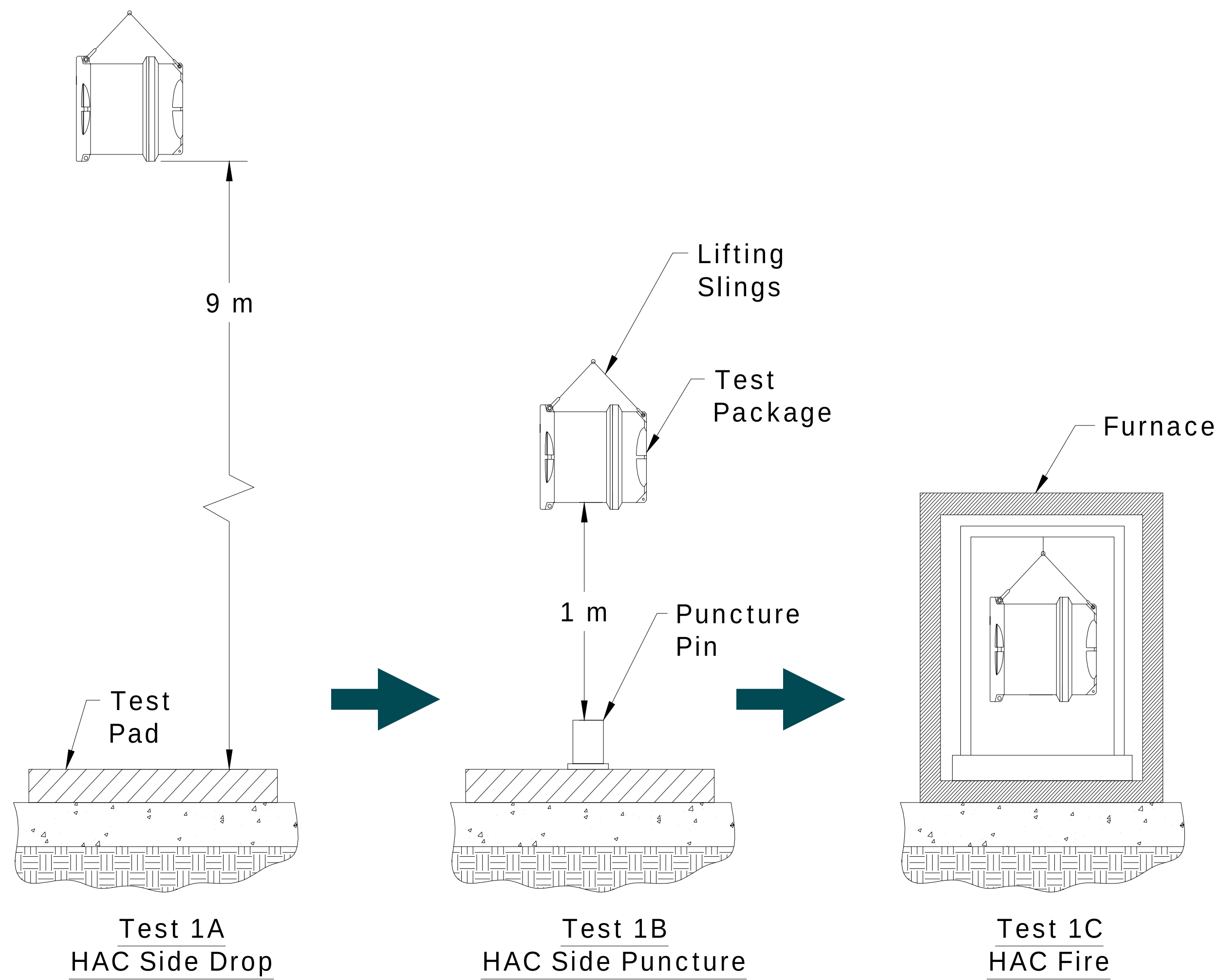
- **Pre-Test Predictions**
  - Calculations predict response of package to test conditions
    - > Use same tools and methodology employed in safety analyses
    - > Predictions based on conditions anticipated during tests
    - > Completed prior to performing confirmatory tests
  - Results used to form test acceptance criteria
- **Package Instrumented To Measure Response**
  - Accelerometers measure package decelerations in drop tests
  - Temperature-indicating strips and thermocouples measure package thermal response in HAC thermal test
- **Package Deformations**
  - Determined from pre- and post-test measurements
  - Post-test destructive examination of overpacks reveal condition of foam following tests

Confirmatory Test Overview

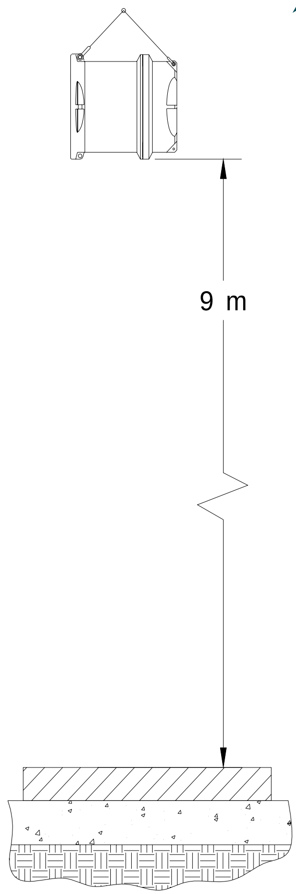
➢ Two Test Sequences Planned

- **Test Sequence #1**
  - > Subject single specimen to sequential application of HAC test conditions
  - > Cumulative damage to package will be evaluated
  - > Damage to package interior will not be assessed mid-sequence
- **Test Sequence #2**
  - > Tests of several free drop conditions using multiple specimens
    - Critical drop test orientations selected
  - > Package damaged assessed after each drop condition
  - > Damaged overpack assemblies replaced as necessary for subsequent drop tests

Test Sequence #1



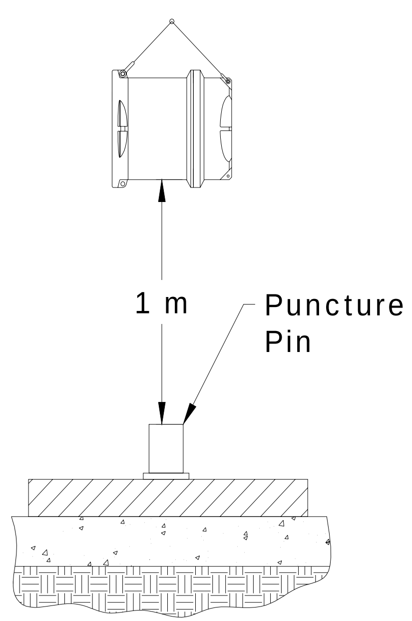
Test Sequence #1



➢ HAC Side Drop (Test 1A)

- **Test configuration**
  - > 9m free drop onto unyielding target per 10CFR71.73(c)(1)
  - > Perform test using undamaged specimen
  - > Horizontal drop onto package 0° azimuth
  - > Instrument with accelerometers
- **Primary test objectives**
  - > Confirm analytical predictions of peak package deceleration
  - > Confirm analytical predictions of overpack crush depth
- **Leak test containment system before test**
- **Measure deformation of package exterior**
  - > Anticipated damage
    - Moderate inside-out crush of overpack assembly
    - Minor deformation of package exterior

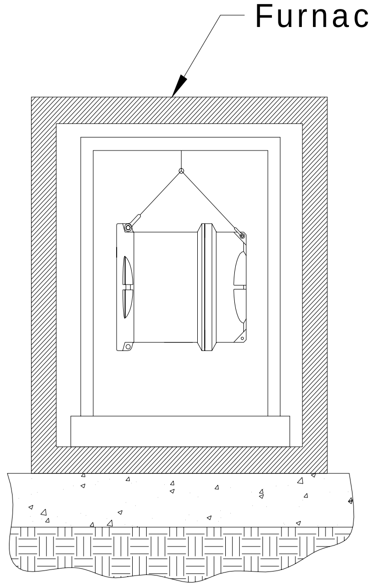
Test Sequence #1



➢ HAC Side Puncture (Test 1B)

- **Test configuration**
  - > 1m free drop onto upper end of mild steel bar in accordance with 10CFR71.73(c)(3)
  - > Use damaged package from Test 1A
  - > Horizontal drop onto package 0° azimuth
  - > Impact between overpack base assembly flanges
- **Primary test objective**
  - > Confirm analytical predictions of package puncture resistance
- **Measure damage to package exterior**
  - > Anticipated damage
    - Local yielding of overpack outer shell in puncture pin impact region
    - No shell perforation expected

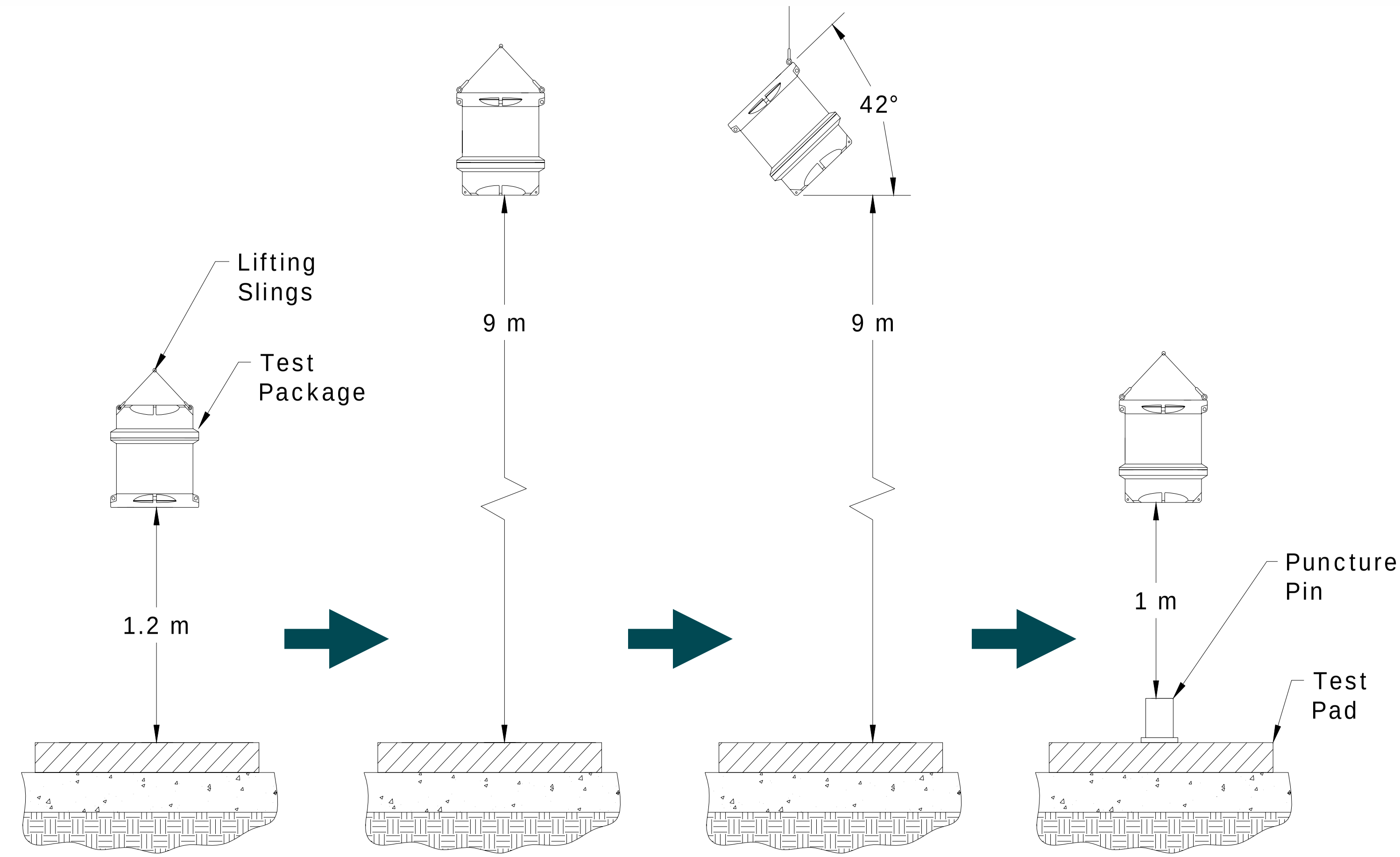
Test Sequence #1



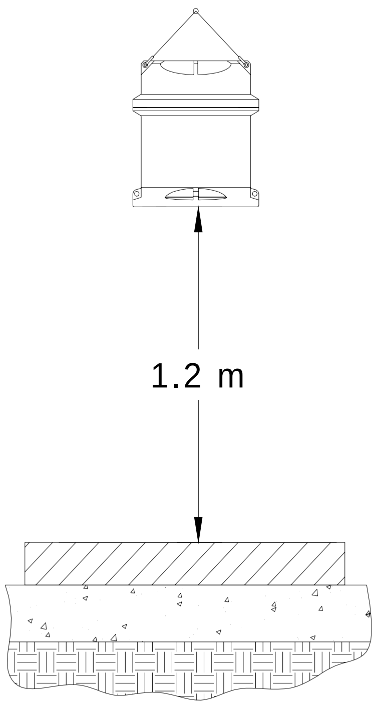
➢ HAC Fire (Test 1C)

- **Test configuration**
  - > Expose package to time-avg. ambient air temperature of ≥800°C for ≥30 minutes
    - Simulate HAC thermal test of 10CFR71.73(c)(4)
  - > Package suspended horizontally from frame with damaged side down
    - Cask contacting damaged side of package expected to produce maximum temperature in cask assembly
  - > Instrument package with thermocouples & temperature-indicating strips
- **Primary test objective**
  - > Confirm analytical predictions of peak containment o-ring seal temperature and foam performance
- **Leak test containment system after test**
- **Measure deformations of package interior and exterior**
- **Record temperature-indicating strip readings**
- **Section overpack to examine foam damage**

Test Sequence #2

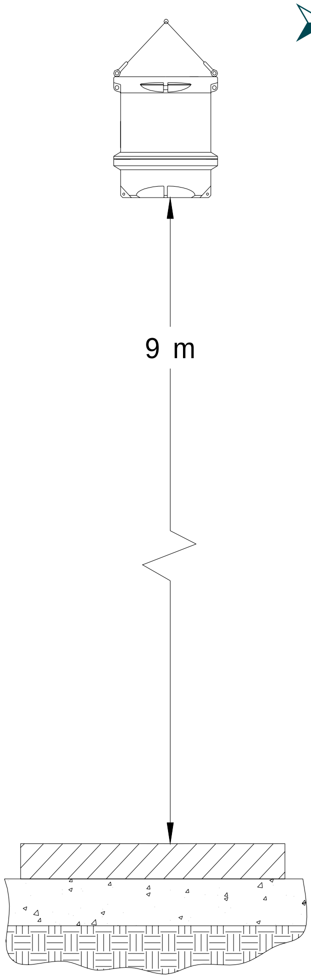


Test Sequence #2



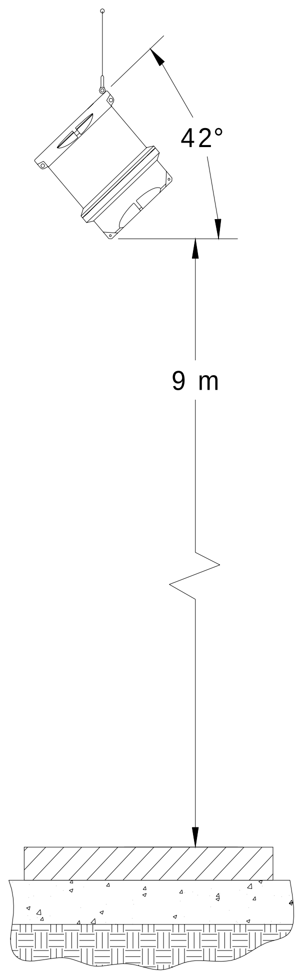
- **NCT Bottom End Drop (Test 2A)**
  - **Test configuration**
    - > 1.2m free drop onto unyielding target per 10CFR71.71(c)(7)
    - > Perform test using undamaged specimen
    - > Vertical drop onto package bottom end
    - > Instrument with accelerometers
  - **Primary test objectives**
    - > Confirm analytical predictions of peak package deceleration
    - > Confirm analytical predictions of overpack crush depth
  - **Post-test measurements**
    - > Measure and document damage to package interior and exterior
  - **Leak test containment system before and after test**
  - **Measure package deformations**
    - > Anticipated damage – minor inside-out crush of overpack base

Test Sequence #2



- **HAC Top End Drop (Test 2B)**
  - Test configuration
    - > 9m free drop onto unyielding target per 10CFR71.73(c)(1)
    - > Perform test using damaged specimen from Test 2A
      - Minor damage from Test 2A will have no measurable impact
    - > Vertical drop onto package top end
    - > Instrument with accelerometers
  - Primary test objectives
    - > Confirm analytical predictions of peak package deceleration
    - > Confirm analytical predictions of overpack crush depth
  - Leak test containment system before and after test
  - Measure package deformations
    - > Anticipated damage – moderate inside-out crush of overpack lid

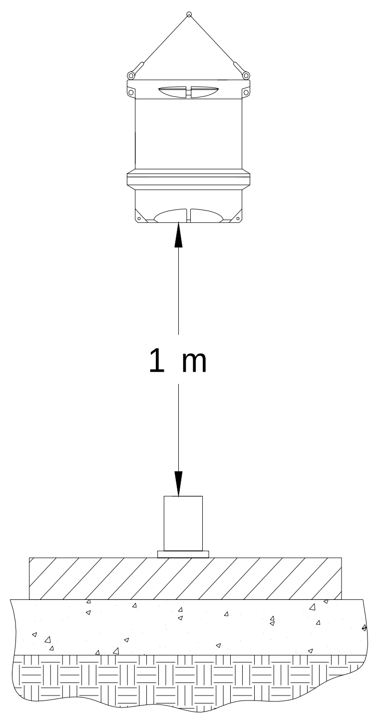
Test Sequence #2



➢ HAC Top Corner Drop (Test 2C)

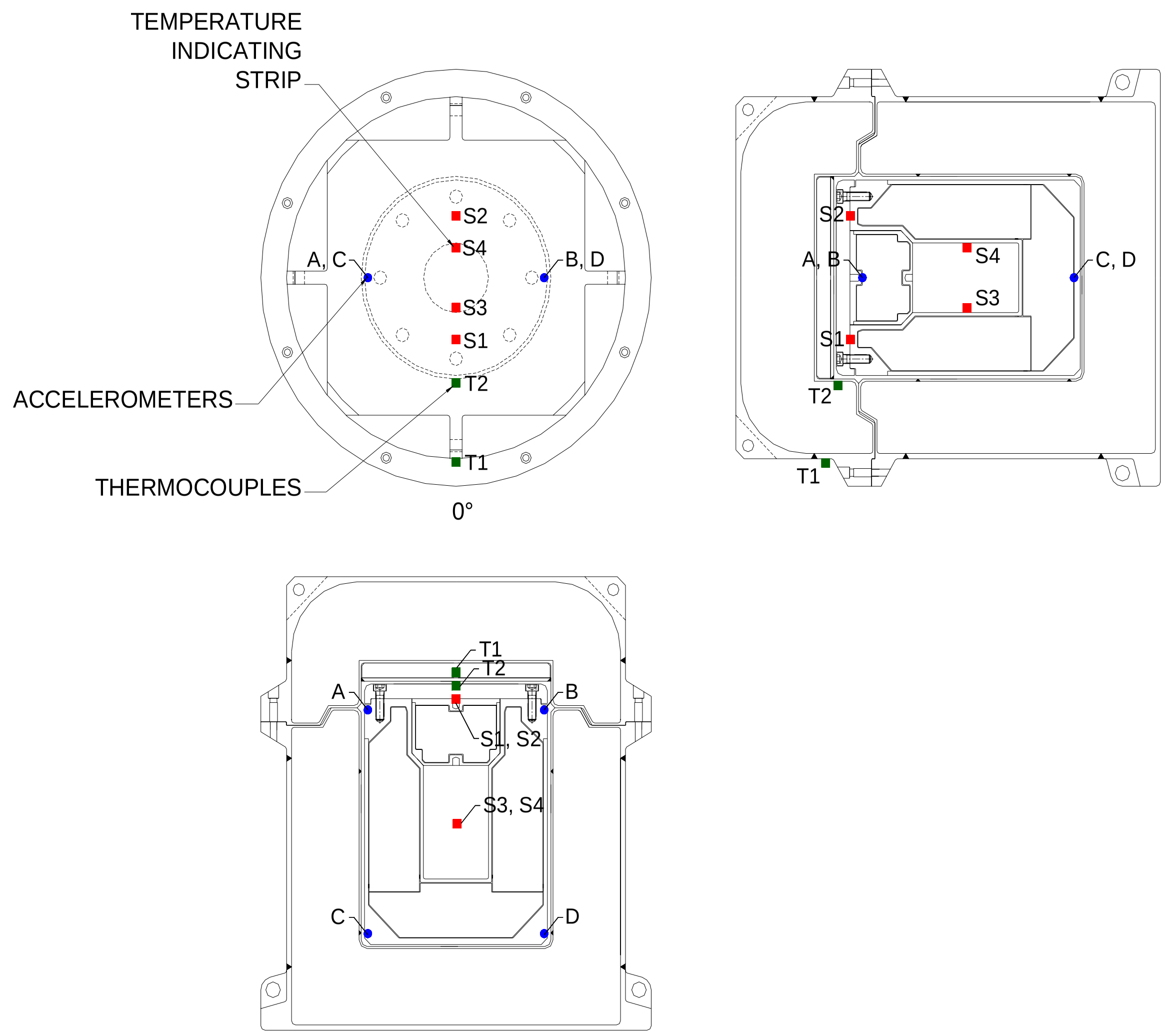
- **Test configuration**
  - > 9m free drop onto unyielding target per 10CFR71.73(c)(1)
  - > Replace overpack lid from Test 2A with undamaged specimen
  - > Orient package center of gravity over top corner
  - > Instrument with accelerometers
- **Primary test objectives**
  - > Confirm analytical predictions of peak package deceleration
  - > Confirm analytical predictions of overpack crush depth
- **Leak test containment system before and after test**
- **Measure package deformations**
  - > Anticipated damage – moderate inside-out crush of overpack lid and base assemblies

Test Sequence #2



- **HAC Top Center Puncture (Test 2D)**
  - **Test configuration**
    - > 1m free drop onto upper end of mild steel bar in accordance with 10CFR71.73(c)(3)
    - > Use damaged package from Test 1A
    - > Vertical drop onto package top centerline
  - **Primary test objective**
    - > Confirm analytical predictions of package puncture resistance
  - **Measure damage to package exterior**
    - > Anticipated damage
      - Local yielding of overpack outer shell in region of puncture pin impact
      - No shell perforation expected

Package Instrumentation



Photometrics

➢ Digital Photographs

- Provide visual evidence
  - > Test configuration
  - > Package condition before and after test

➢ Video Recording of Confirmatory Tests

- Provide additional visual evidence
- Regular speed color video
- Two fields of view for each drop
  - > Full view to capture entire free fall and impact
  - > Close-up view at impact
- 4’ x 8’ stadia board used as photographic backdrop
  - > 6-inch square grid on light background

Testing Facility

➢ **Test Facility**

- **Tests will be performed at the Manufacturing Sciences Corporation (MSC) facility in Oak Ridge, TN**
- **Drop test facility**
  - > Overhead crane with release mechanism
  - > “Unyielding” target per IAEA recommendations
    - Target mass at least 10 times mass of test specimen
    - Reinforced concrete with steel cover plate
- **Furnace used for HAC thermal test**

Test Location and Dates

- When: February 2006
- Where: MSC Facility in Oak Ridge, TN

Radiolysis in Mallinckrodt Mo^{99} product

Chronological program: (September 20th 2002 till December 15th 2002)

-Pressure built up test with 811 Ci over 33 hours => Curve function

-**Research based on function of variables**:

- Temperature
- Specific activity
- Gas analyses
- Catalyzing material
- Activity amount

* *Activity 500 - 3000 Ci Mo99*
* *Concentration 15 - 48 Ci/ml*
* *Measure time: 4 - 145 hours*
* A total of 11 experiments

Long term radiolysis curve function confirmation:

1000 Ci within 50 ml over 145 hour
2000 Ci within 47,5 ml over 24 hour

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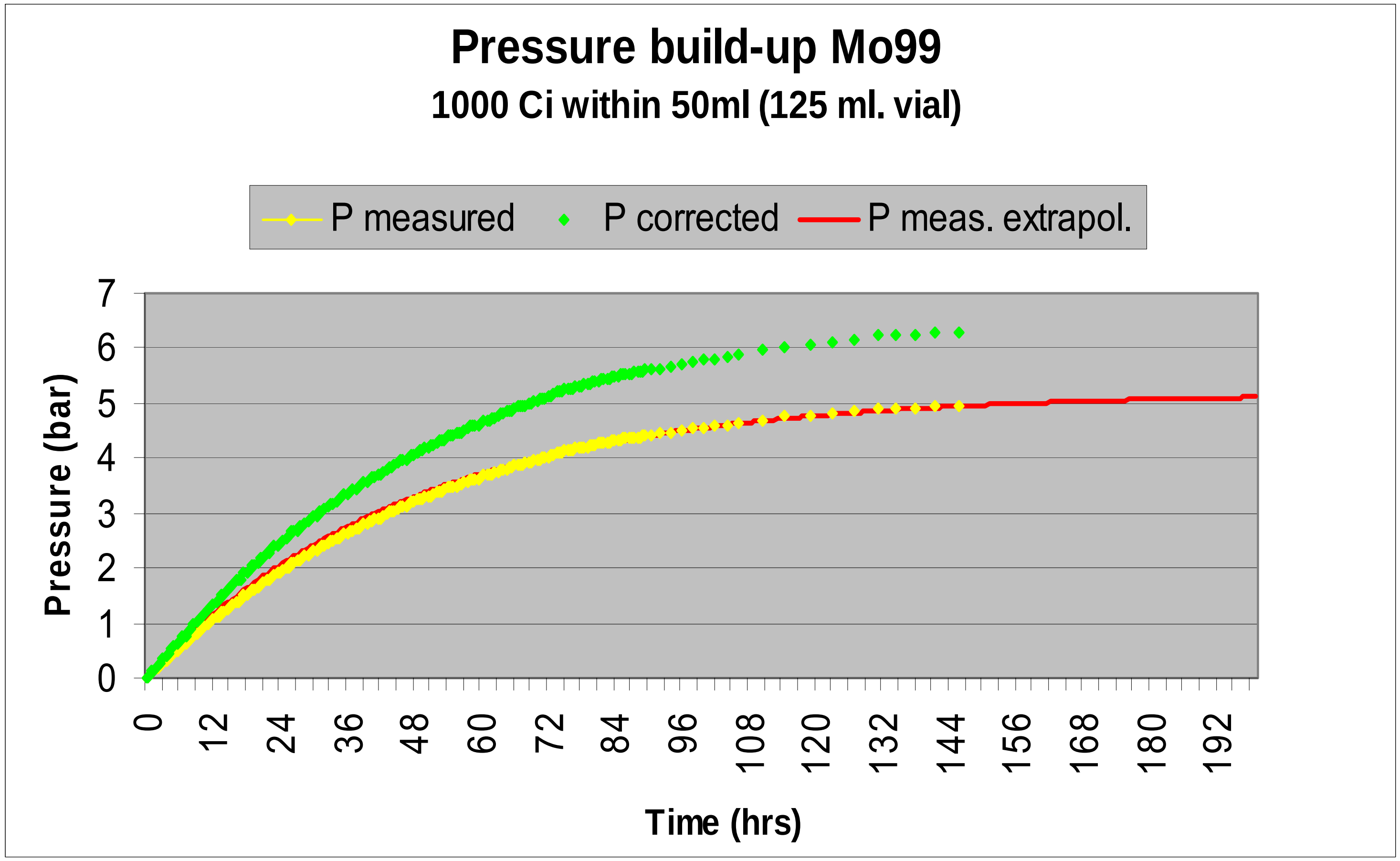
Measurement equipment

Long term 1000 Ci test 145 h



Healthcare

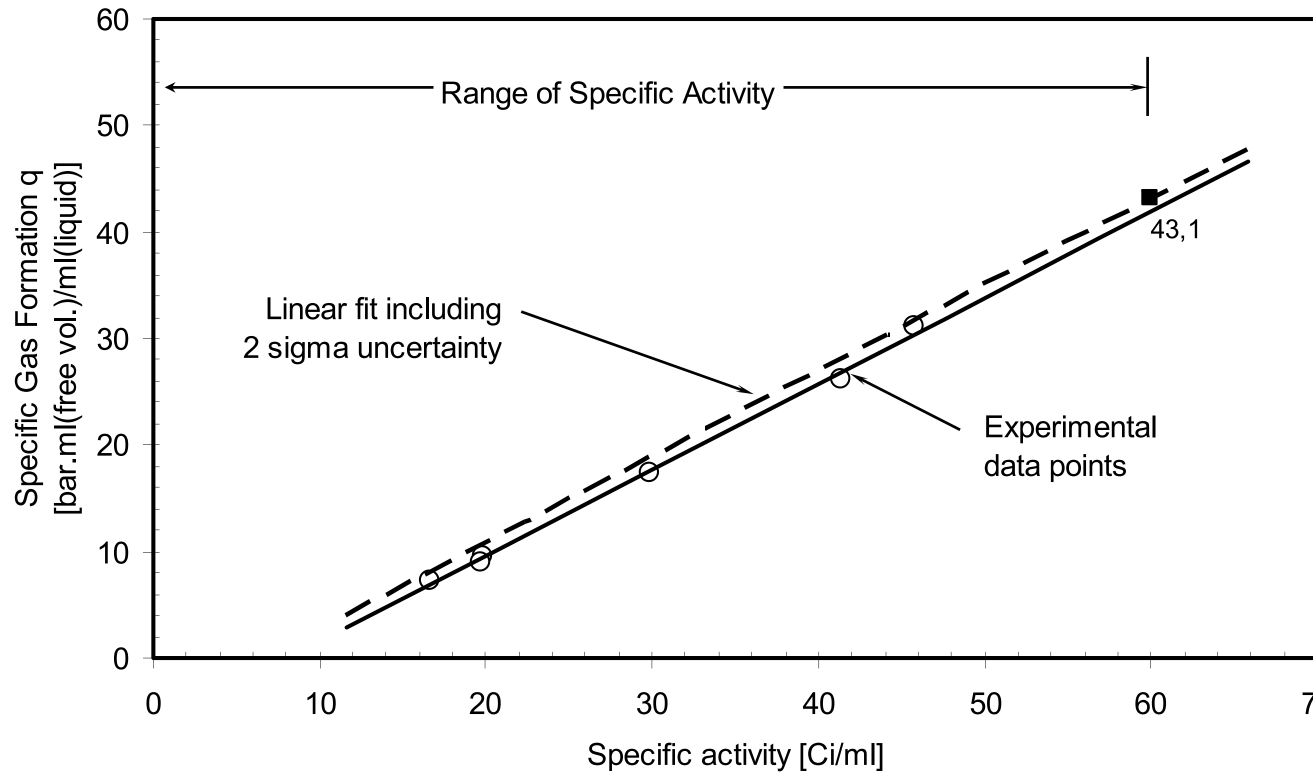
Short term test with 2000 Ci

- Curve function of 1000 Ci fits the 2000 Ci short term test.
  - 1000 Ci: 145h, 125 ml vial, < 7 bar ($P_{max, MNOP}$)
  - 2000 Ci: 24h, 250 ml vial, 6 bar (P_{max})

- This Curve function is used to calculate the A_{max} in a 250 ml vial.
  - Result is maximal 2200 Ci in 250 ml vial.

Experimental results

Radiolytic Gas Generation Experimental Results for Mallinckrodt Mo99 Product



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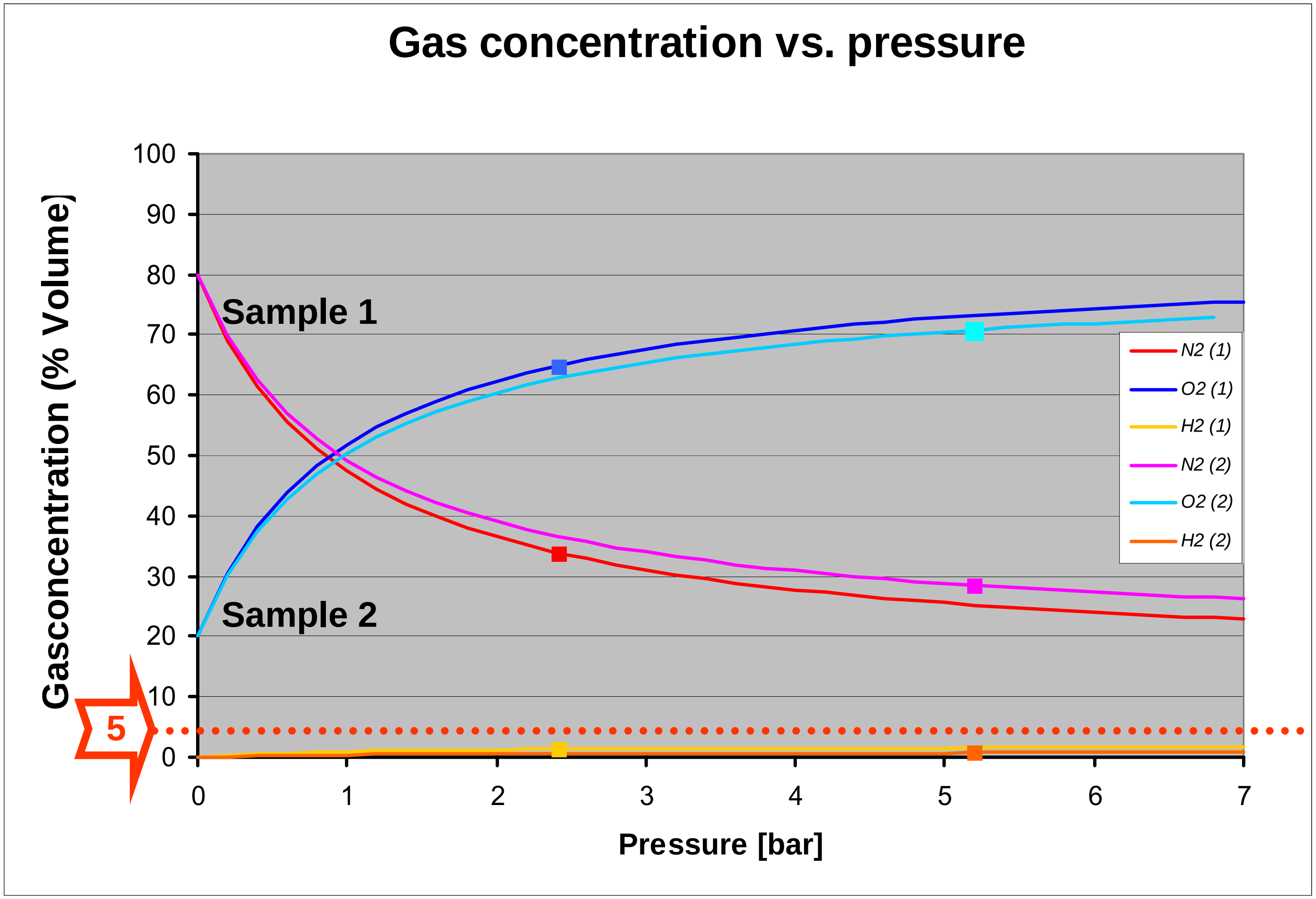
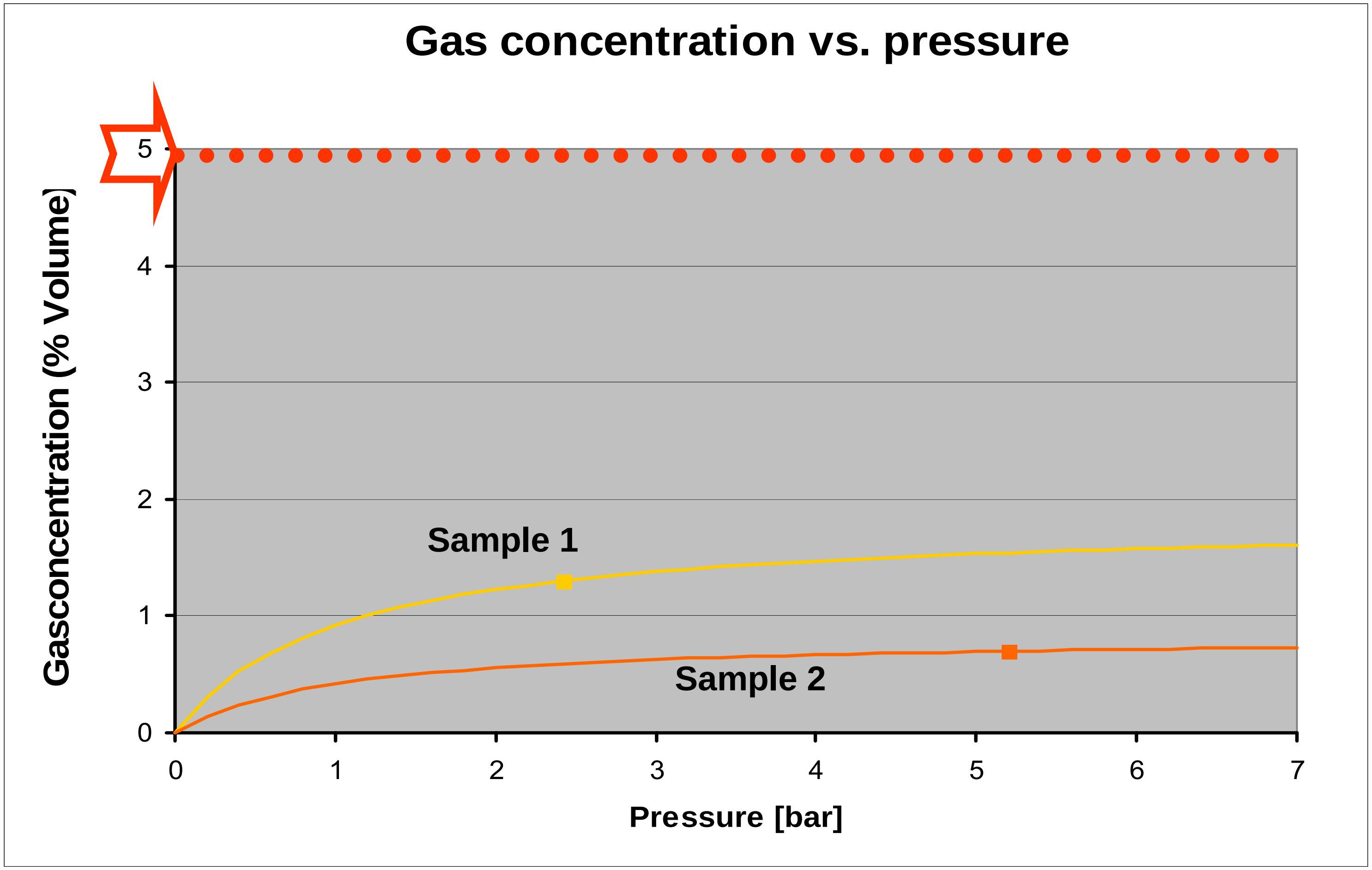
Specification gas radiolysis (1)



Sample 1: 811 Ci at 2,42 bar (Vol % H_2 => 1,3 %)
Sample 2: 1000 Ci at 5,2 bar (Vol % H_2 => 0,7%)

tyco Healthcare

Specification gas radiolysis (2)



<u>Sample 1:</u> 811 Ci at 2,42 bar (Vol % H_2 -> 1,3 % when $t = \infty$ -> H_2 = 1.9%

<u>Sample 2:</u> 1000 Ci at 5,2 bar (Vol % H_2 -> 0,7% when $t = \infty$ -> H_2 = 0.9%

tyco Healthcare

Summary & Conclusions

- Testing was done on the exact $NaOH/NaNO_3$ solution to be shipped in MIDUS.
- Pressure buildup:
  - Ganuk data testing is valid for MIDUS
  - Gas generation is a function of total activity only
- Hydrogen generation
  - Both samples were well below 5% limit
  - Percentage is constant, not a function of pressure or activity

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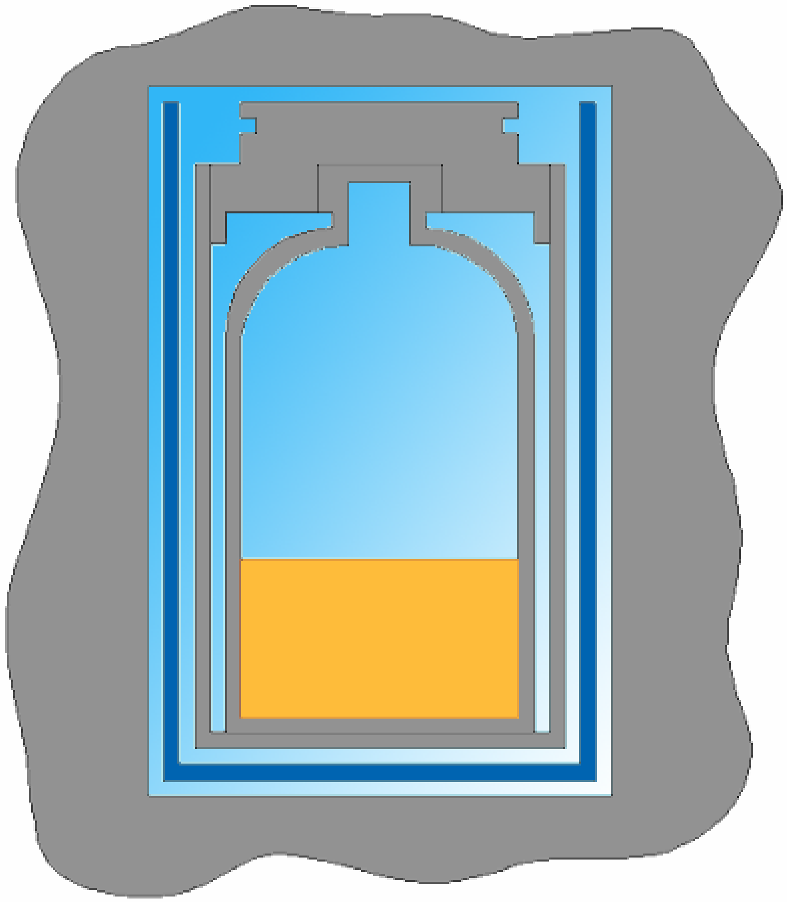
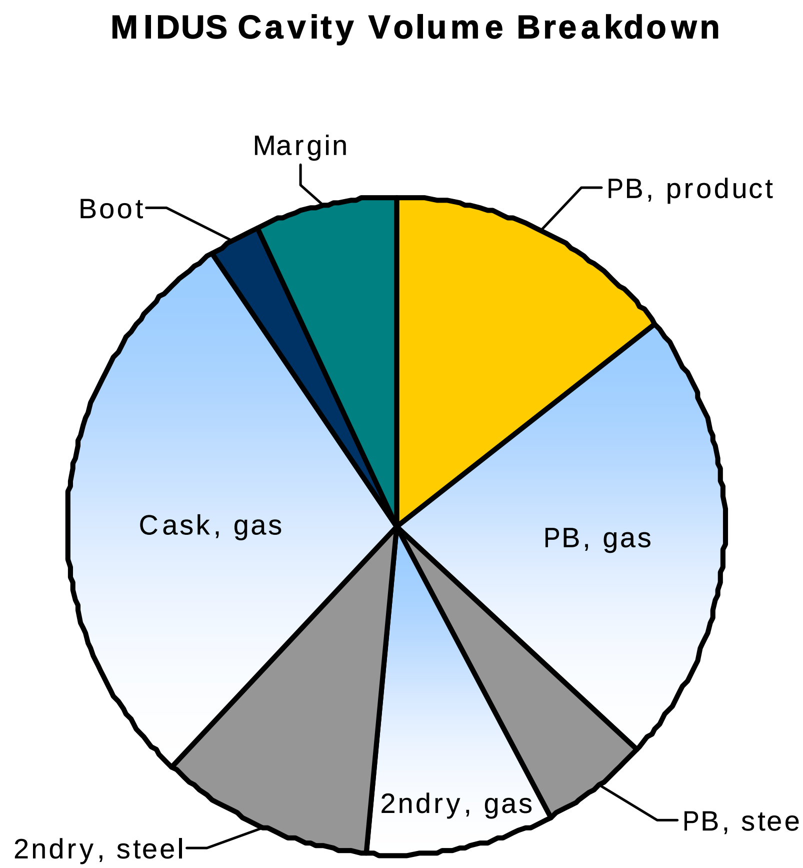
Package Gas Generation & Hydrogen Content

- Cask cavity volume budget
- Three closure scenarios
- Gas generation limits

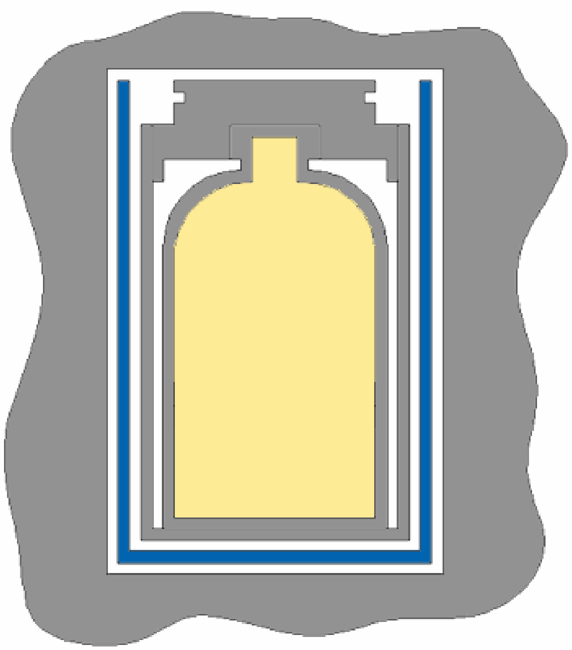
Cask Cavity Volume Budget

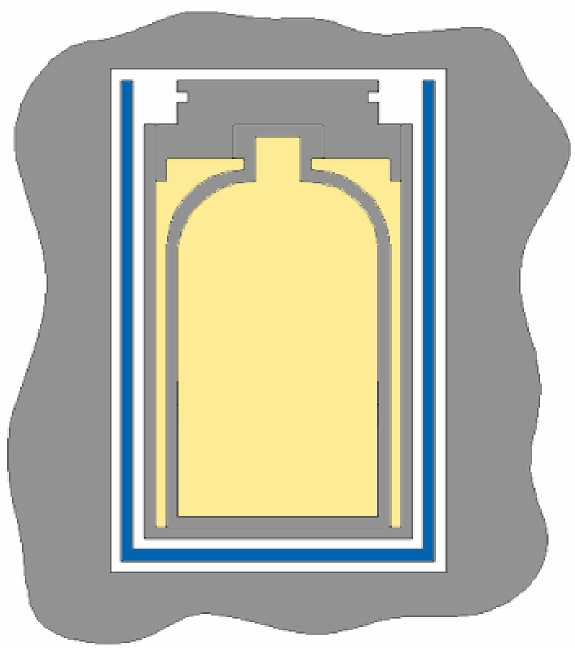


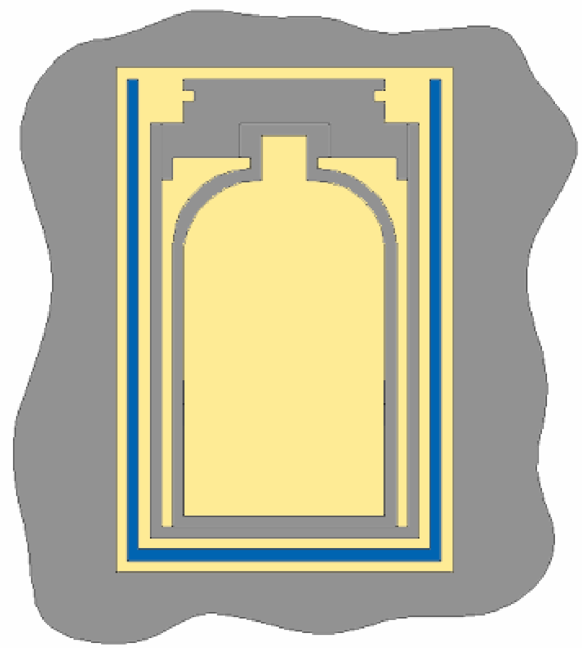


Three Closure Scenarios for Gas Buildup

- All seals hold
- Product bottle seal breached
- Secondary container seal breached







Gas Generation Limits

Scenario	Pressure (MNOP)	Hydrogen Percentage
1	Containment not challenged- demonstrate no package damage	5% in product bottle
2	Containment not challenged- demonstrate no package damage	5% in product bottle / 2ndry container
3	7 bar in containment	5% in entire containment

Structural Analyses

- **Preliminary Structural Analyses**
  - Methodology
  - Results
  - Design improvements
- **Drop Loads Analysis**

Preliminary Structural Analysis

- **Evaluated Initial Design Concept for Governing Loads**
  - NCT and HAC drop loads
  - NCT and HAC end drop and side drop stress analyses
  - Closure bolt evaluation
- **Develop Methodologies for Safety Analyses**
- **Identify Design Modifications/Improvements**
  - Satisfy applicable U.S. Regulations and design criteria
  - Address feedback from initial meeting with NRC

Preliminary Structural Analysis

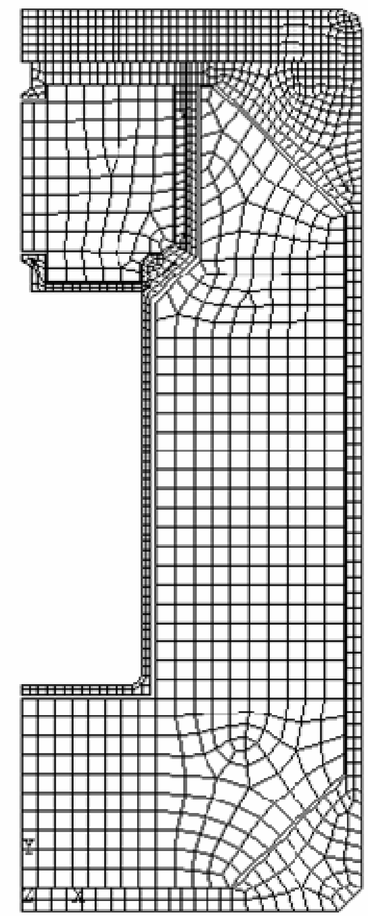
➢ Drop Loads Analysis

- Upper and lower bound F-δ curves developed for bottom end drop
- Foam F-δ curves determined using classical methods
  - > Upper bound: -20°F properties and +15% crush strength tolerance
  - > Lower bound: 140°F properties and -15% crush strength tolerance
- ANSYS model used to determine overpack shell F-δ curve
- Overpack shell assembly and foam F-δ curves superimposed
- Energy balance approach used to determine package g-loads
  - > NCT: 200g maximum peak acceleration
  - > HAC: 330g maximum peak acceleration

Preliminary Structural Analysis

➢ End Drop Stress Analysis

- Bounding equivalent static drop loads assumed
  - > NCT end drop load: 250g
  - > HAC end drop load: 500g
- Top and bottom end drops evaluated using axisymmetric finite element model
- Uniform pressure reaction at impacted end
- Uniform pressure load for contents at end of cavity nearest impact



Preliminary Structural Analysis

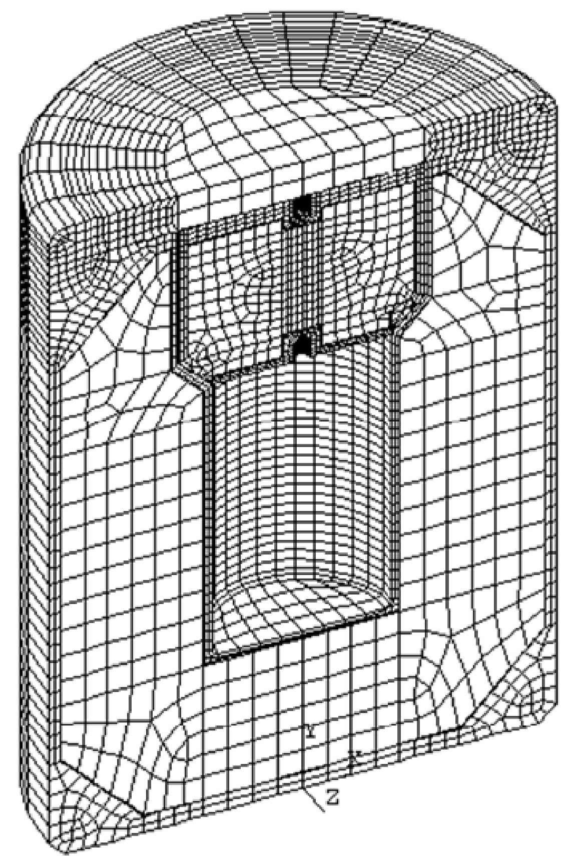
➢ End Drop Stress Analysis (continued)

- Preliminary Analysis Results
  - > Stresses due to NCT and HAC end drop are low
  - > HAC top end drop results in high bearing stress in containment seal region of flange
    - Seal region stresses limited to S_y per NUREG/CR-6007
    - Modify top end geometry to increase DU bearing area

Preliminary Structural Analysis

➢ Side Drop Stress Analysis

- Equivalent static drop loads assumed to be the same as end drop
  - > NCT Side Drop Load: 250g
  - > HAC Side Drop Load: 500g
- ½ symmetry finite element model used
- Payload loading modeled as strip pressure
- Knife-edge support assumed along line of impact



Preliminary Structural Analysis

➢ Side Drop Stress Analysis (continued)

- Preliminary Analysis Results
  - > Inner containment shell stresses in shield plug region exceed allowable stress limits
  - > Reduce stresses by increasing inner shell thickness in shield plug region

Preliminary Structural Analysis

➢ Closure Bolt Evaluation

- Bolt Stresses Evaluated in Accordance with Requirements of NUREG/CR-6007
- Evaluated controlling load conditions and load combinations in accordance with NUREG/CR-6007
  - > Bolt torque: 24 to 27.7 ft-lb
  - > NCT temperature: 4°F through-lid gradient
  - > Internal pressure: 100 psig (MNOP)
  - > NCT free drop: 250g (end, side, and corner impacts)
  - > HAC free drop: 500g (end, side, and corner impacts)
  - > Puncture: lid edge and center
  - > Immersion pressure: 21.7 psi
  - > HAC temperature: 40°F through-lid gradient

Preliminary Structural Analysis

➢ Closure Bolt Evaluation (continued)

- **Results show that maximum interaction ratio > 1.0 for load combination including NCT side drop**
  - > Due to high shear stress from NCT side drop impact load
- **Modify cask closure lid and bolting flange to include shear lip**
  - > Better protection from closure bolt shear failure
  - > Relieve closure bolts from shear loading

Structural Safety Analyses

➢ Drop Loads Evaluation

- **Will be performed using LS-DYNA computer code**
  - > Discussed using ANSYS for drop loads analysis at last NRC meeting
    - NRC staff suggested using LS-DYNA for drop load evaluation
  - > LS-DYNA more accurately simulates package impact response
- **Drop testing will be performed to confirm analytical methodology**
- **Range of Impact Orientations will be Evaluated for both NCT and HAC Free Drops**
  - > Top and bottom end drops
  - > Side drop
  - > Center of gravity over top and bottom corners
  - > Oblique drop (including slapdown)
- **Analyses of Hot and Cold Thermal Conditions**

Structural Safety Analyses

➢ Drop Loads Evaluation (continued)

- **LS-DYNA Model**
  - > ½-symmetry model
  - > Detailed model of overpack assembly
    - Overpack polyurethane foam modeled using LS-DYNA crushable foam material model (volumetric stress-strain)
    - Overpack steel shells modeled using LS-DYNA multi-linear plasticity model (true stress-strain)
  - > Cask assembly modeled as rigid body
    - Simulate cask mass properties and interface with overpack
    - Cask rigid body acceleration loads used to develop the design basis equivalent static accelerations used for the cask stress analysis

Shielding Analysis

- **Have completed preliminary evaluations**
  - MicroShield used to do rough sizing for 4,500 Ci payload
  - TI < 1 for normal conditions
  - HAC case requires extra DU shield in overpack lid
- **Final Calculations to be performed using MCNP**
- **Planned Approach for Normal Conditions**
  - The package is assumed to be in its normal vertical orientation, with the source in the product bottle (most conservative case-source closer to shield plug)
  - Product is assumed to remain in sealed product bottle during normal operating conditions
    - > Breaching of three independent seals (one metal, two elastomeric) would be required for product leakage.

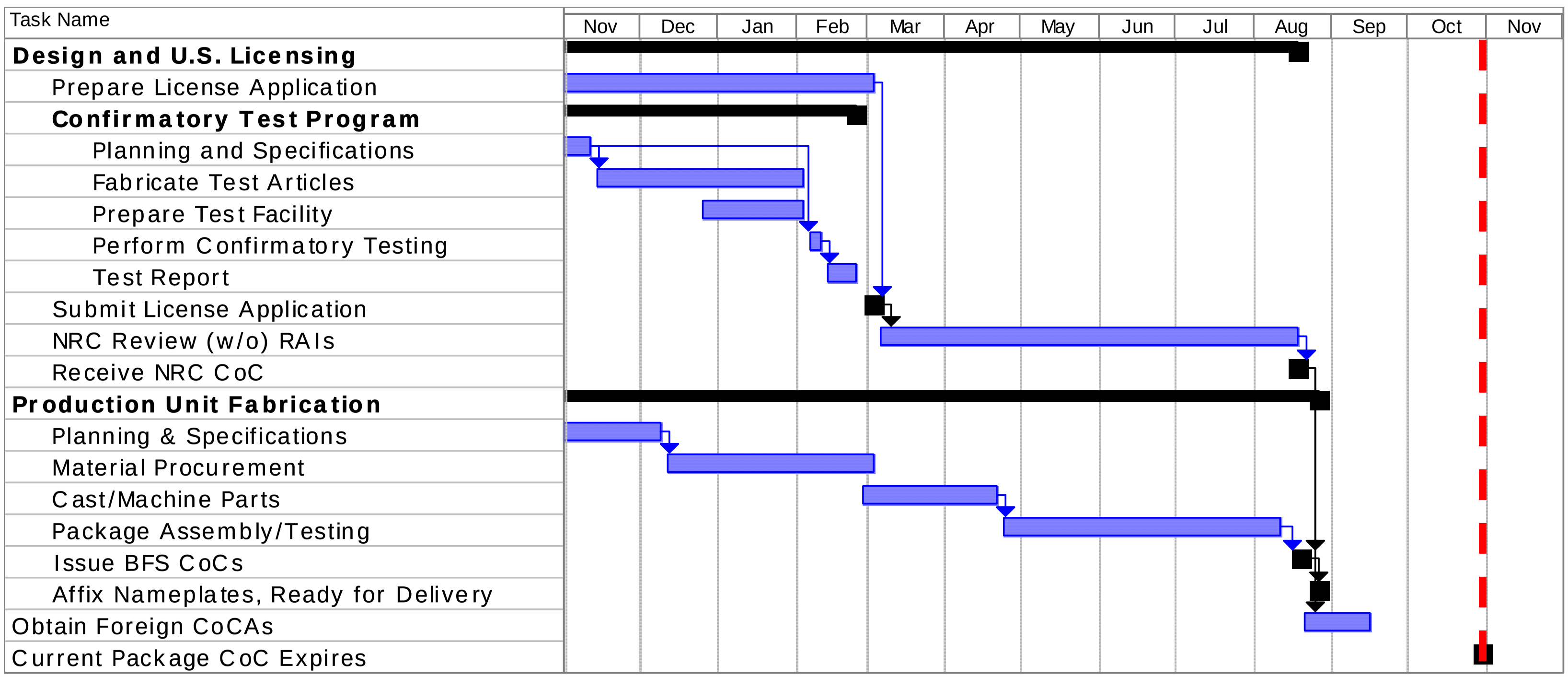
Shielding Analysis

- **Planned Approach for Hypothetical Accident Conditions**
  - Assume breach of all non-containment seals
    - > Breaching of the product bottle Swagelok seal
    - > Breaching of the secondary container elastomeric o-ring
    - > Breaching of the shield plug cleanliness o-ring Packaging Configuration Assumptions
  - Assume
    - > Package inversion, resulting in liquid product flooding the shield plug annular and disk-shaped gaps
    - > Maximum specified specific activity
    - > No radioactive decay
    - > Cleanliness o-ring seal provides mechanical compliance- minimizes disk source atop the shield plug. No credit for containment, but credit taken for presence.

Thermal Analysis

- **Have completed thermal “first-look”**
  - Manufacturer’s tests, 30 minute open flame on 3” slab
  - Containment seal temperature margins looked too low
  - Changed from 10 to 12 pcf foam
- **Safety analyses to be performed using SINDA/FLUINT**
- **Analysis will consider boiling**
  - Will show boiling does not occur, or package design will consider pressure due to boiling.

Licensing and Fabrication Schedule



Conclusions

- **Preliminary Design Completed**
  - Design changes from preliminary analyses and fabrication review
- **Confirmatory Test Plan Developed**
  - Added thermal test
- **Pressure Buildup and H_2 Generation Well-Known**
- **Safety Analyses**
  - LS-DYNA will be used for drop loads analysis
- **Schedule Has Not Changed**
  - Concurrent fabrication and licensing
  - CoC for current package expires in October 2006
  - BFS committed to support accelerated NRC review schedule