# MIDUS Transportation Package
# Pre-Submittal Meeting

## November 3, 2005
## Rockville, MD

BNG Fuel Solutions A BNG America Company

# Agenda

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

# MIDUS Design Update

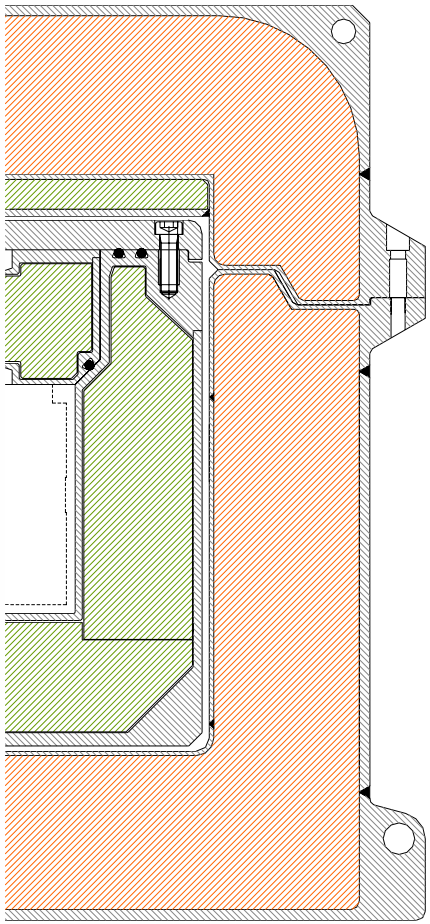
- **MIDUS Program Refresher**
- **Design Overview Refresher**
- **What's Changed Since July Meeting?**
  - Shielding-related changes
  - Structural-related changes
  - Thermal-related changes
  - Fabrication enhancements

# MIDUS Program Overview

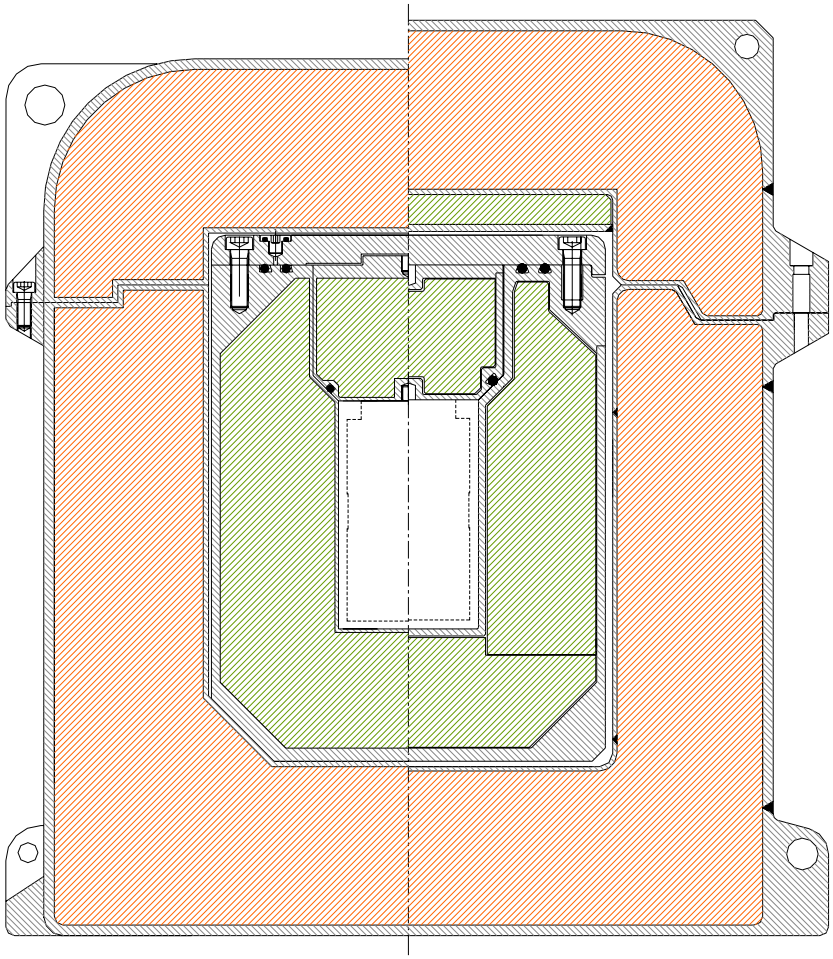
- **Purpose**
  - Medical Isotope Depleted Uranium-Shielded (MIDUS) cask is to ship Mo99 from the Tyco's facility in Petten, The Netherlands.
- **Need**
  - Tyco currently supplies most of the U.S. Mo99 (Tc99m)- over 15 million patient doses annually.
  - Ganuk cask currently used (USA/0656/B(U)-96). 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**

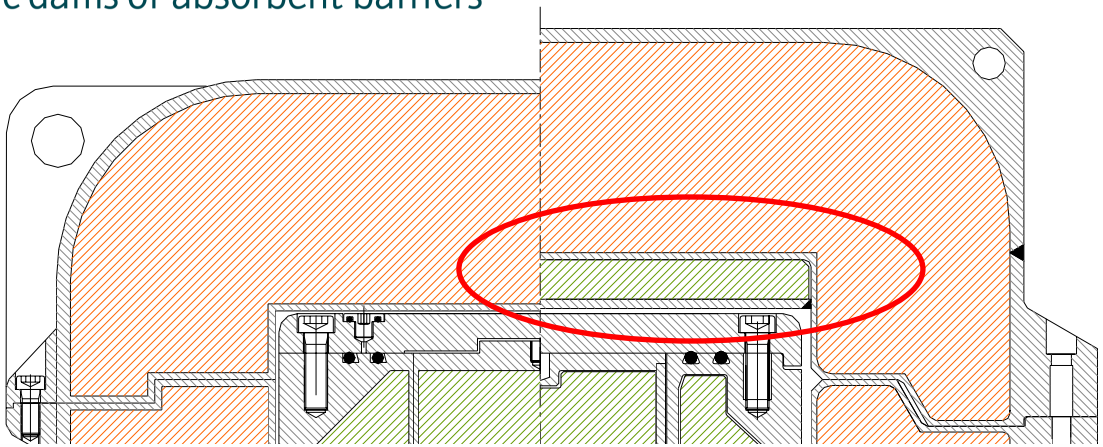
Depleted Uranium

Foam

Stainless Steel

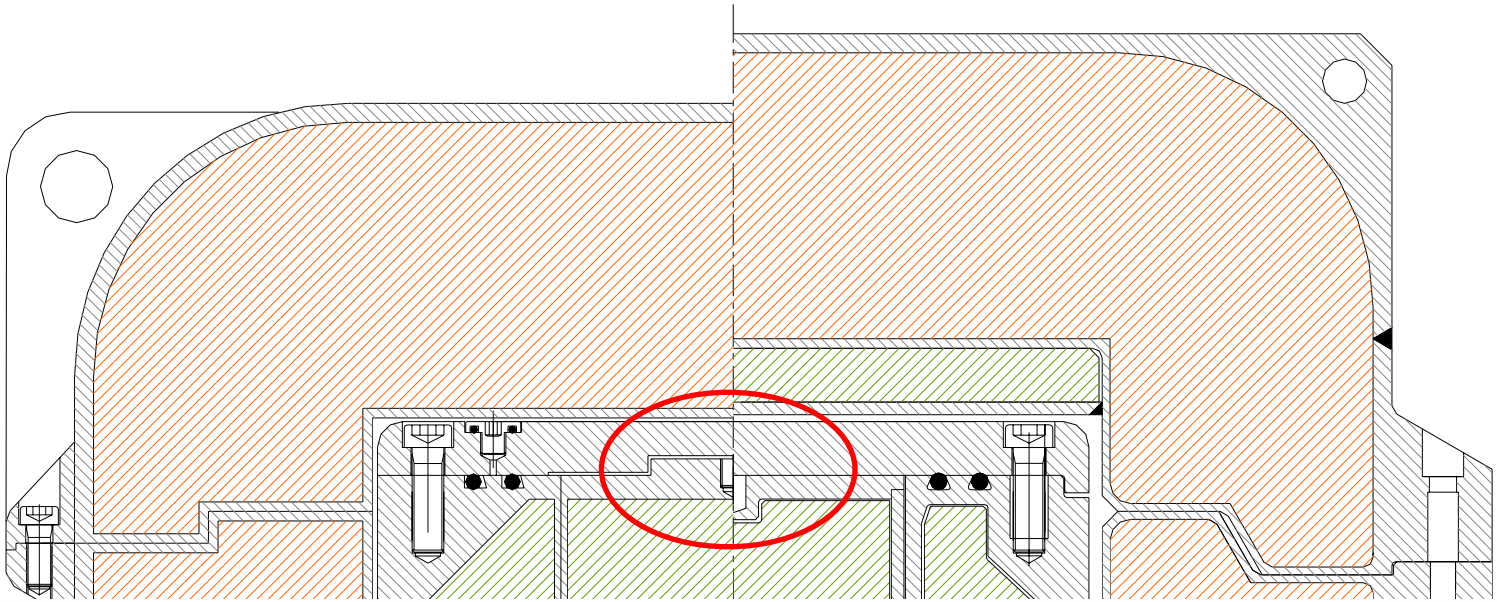
# Shielding-Related Changes

- **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



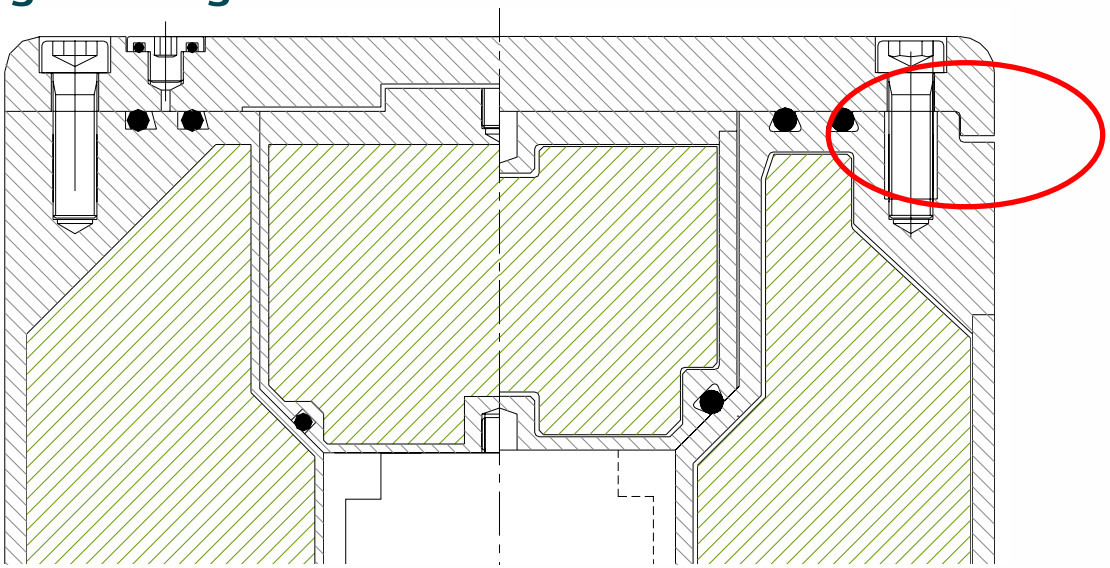
# Shielding-Related Changes

- **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.



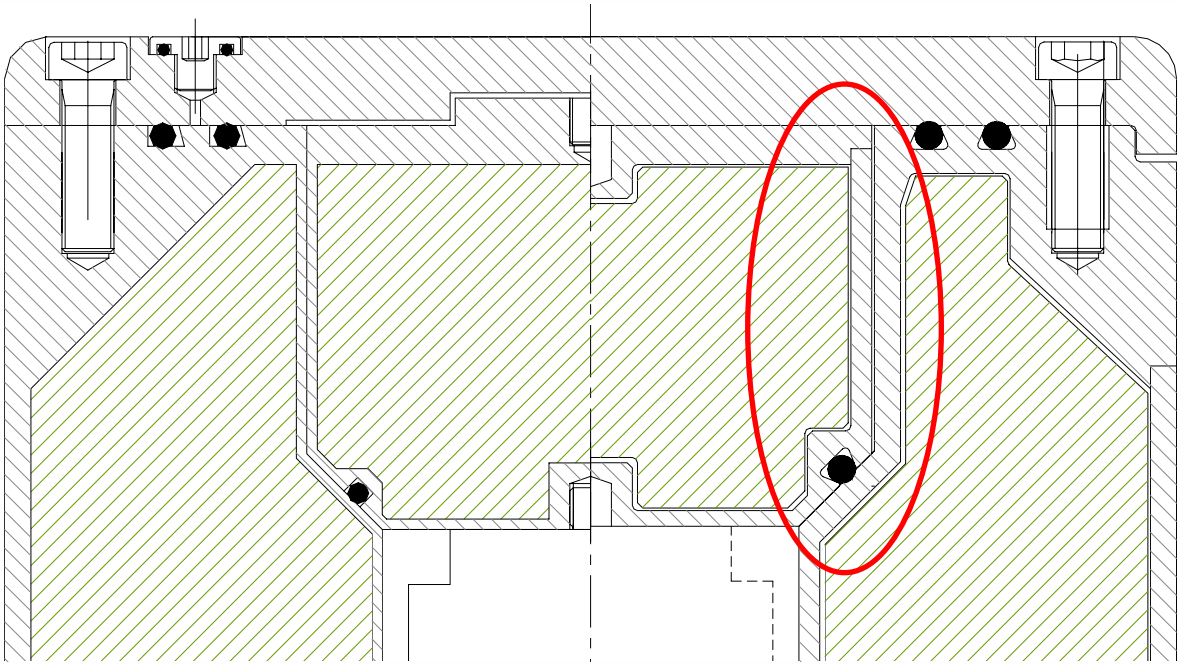
# Structural-Related Changes

- **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

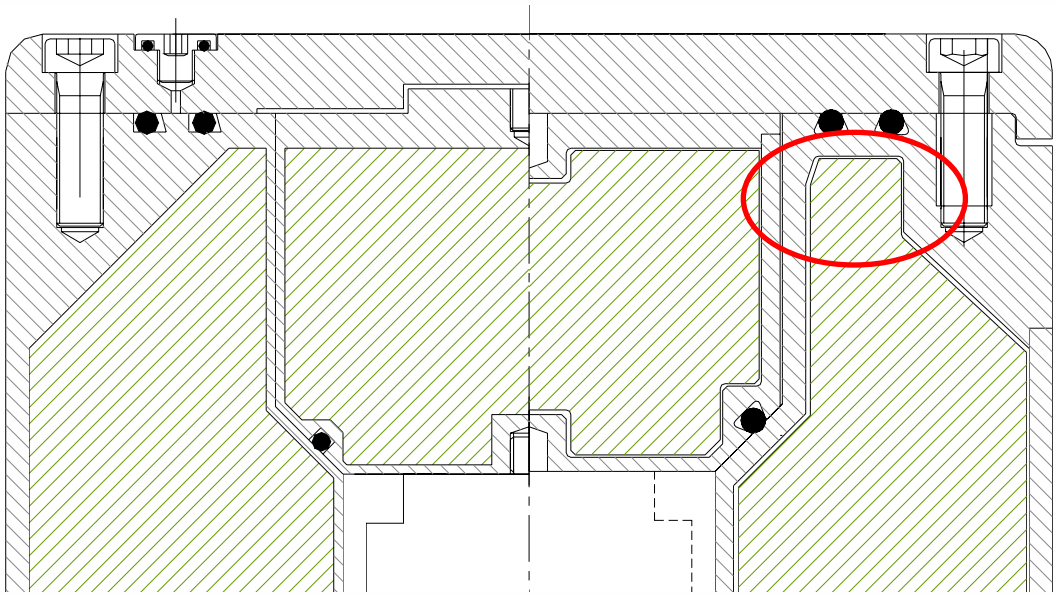
- **Increased Thickness of Containment Shell Near Shield Plug Region.**
  - Stresses due to side drop loads exceeded allowable stresses.
  - Containment shell acts as cantilever beam in side drop.



# Structural-Related Changes

## ➢ Modified DU Top End Detail on the Cask Body

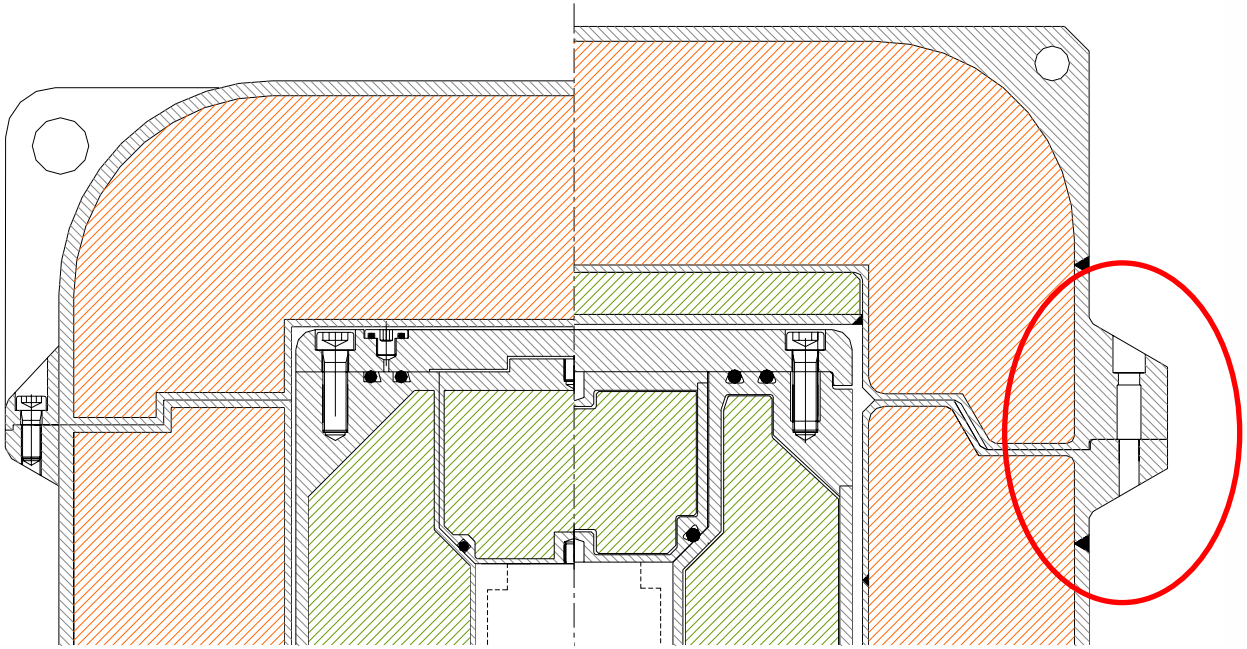
- Increased the bearing area between DU and bolting flange for top end drop.
- Prevent plastic deformation in flange area per NUREG/CR-6007.



# 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

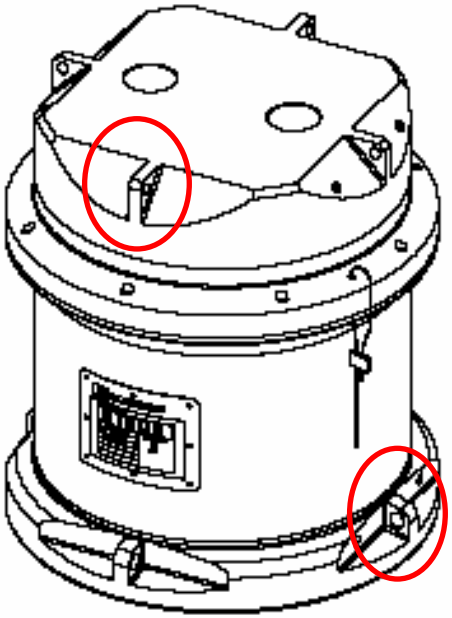


# Thermal-Related Changes

- **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

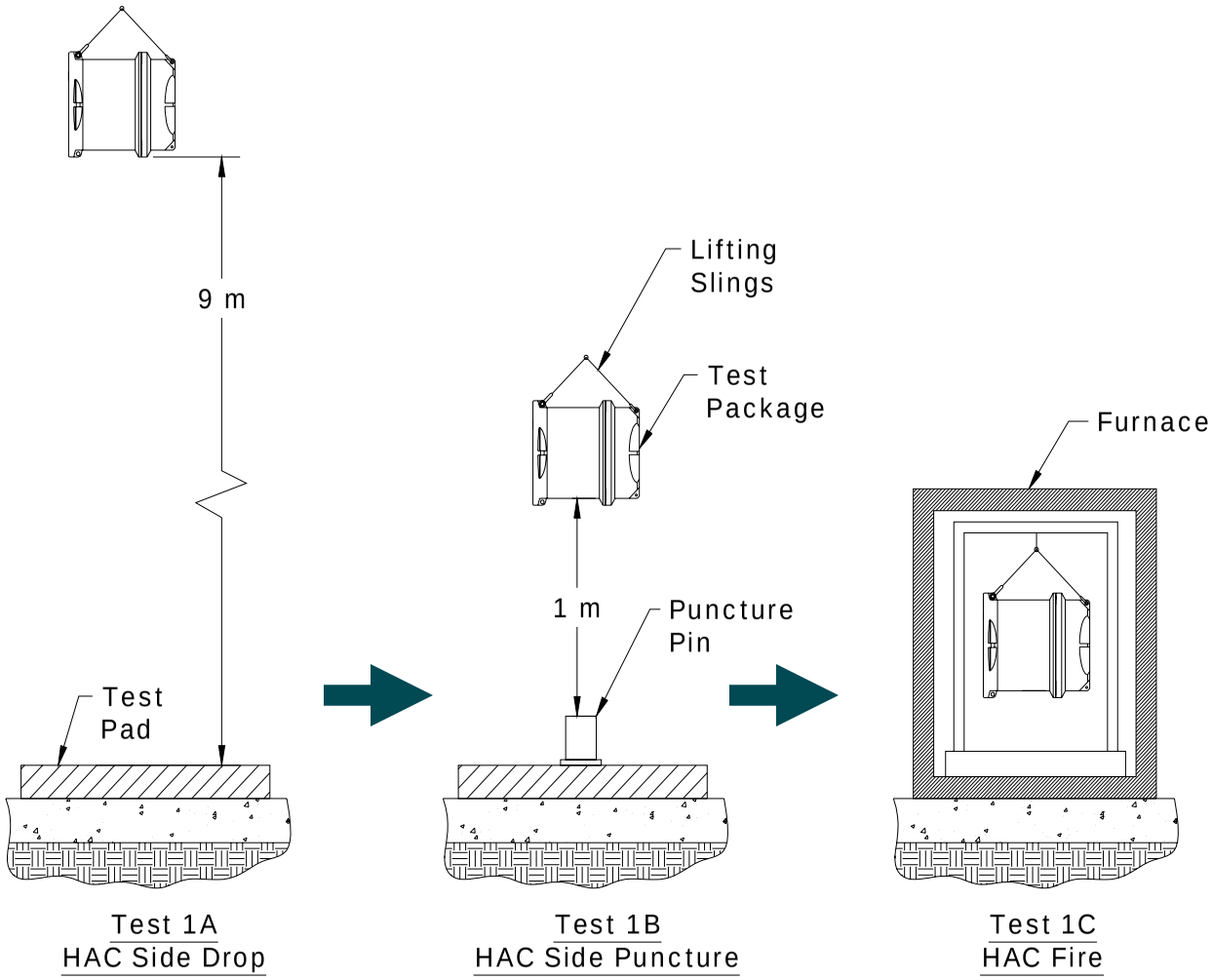
- **Pre-Test Predictions**
  - Calculations predict response of package to test conditions
    - > Use same tools and methodology employed in safety analyses
    - > Predictions based on conditions anticipated during tests
    - > Completed prior to performing confirmatory tests
  - Results used to form 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

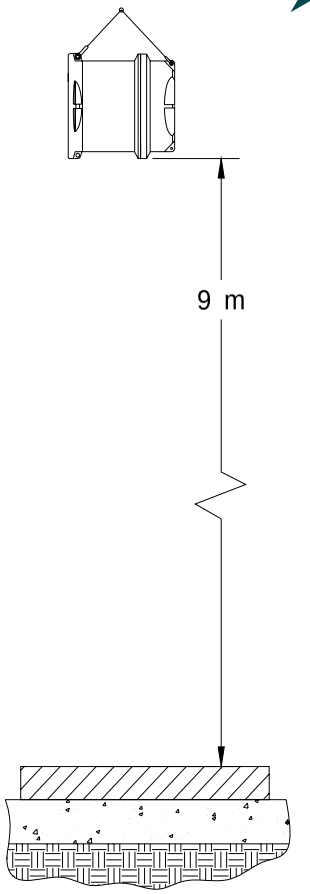
## ➢ Two Test Sequences Planned

- 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

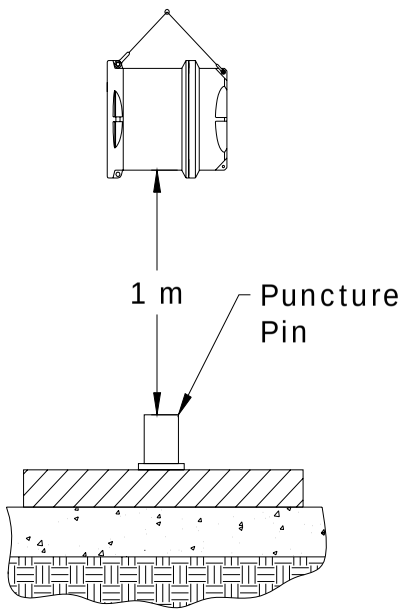


# Test Sequence #1




- **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

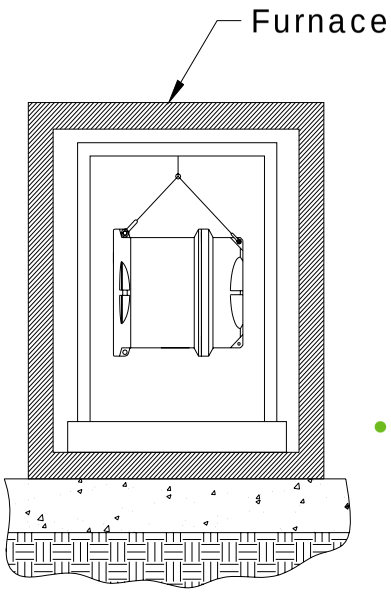



## ➢ HAC Side Puncture (Test 1B)

- **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

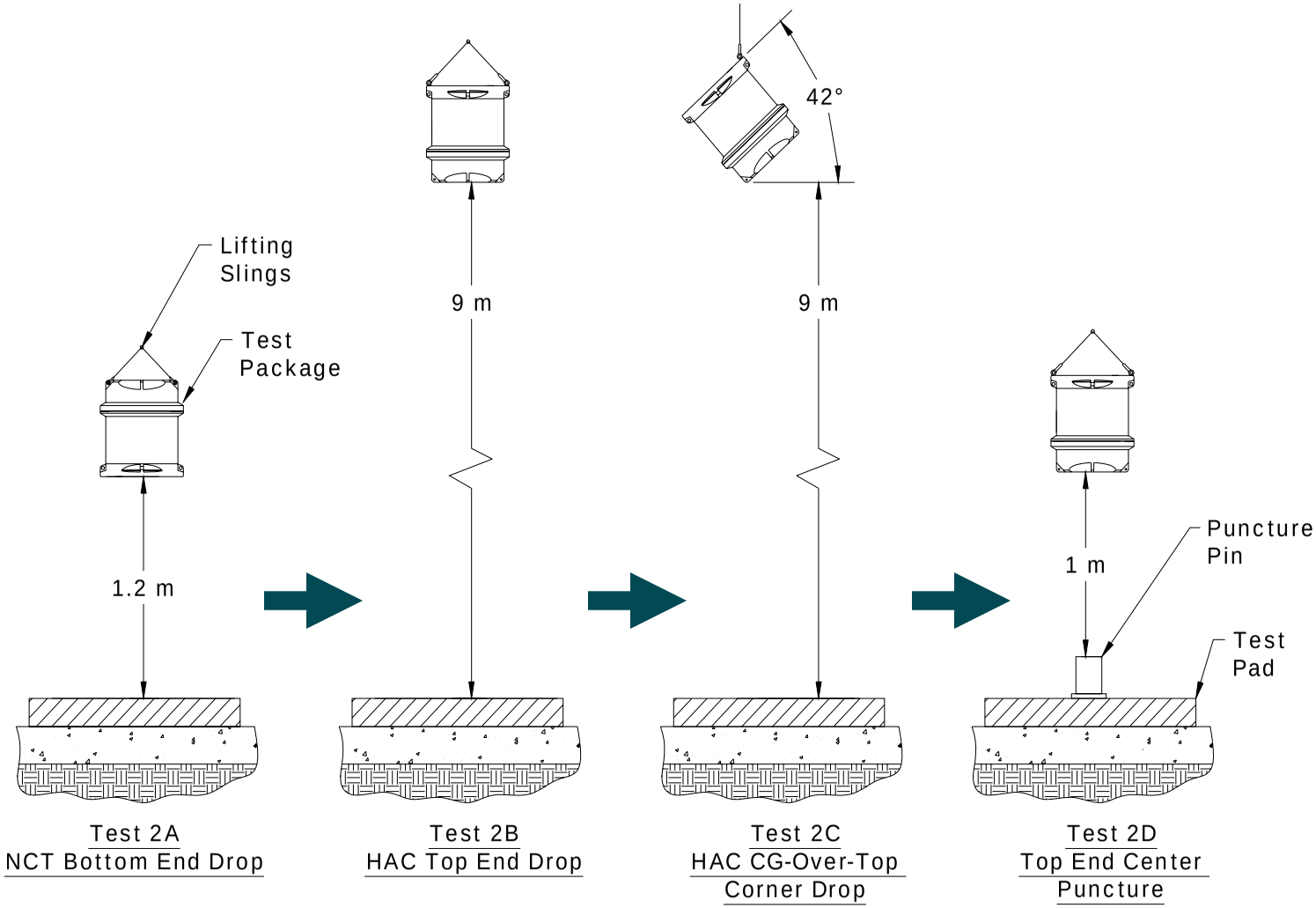
# Test Sequence #1

## ➢ HAC Fire (Test 1C)

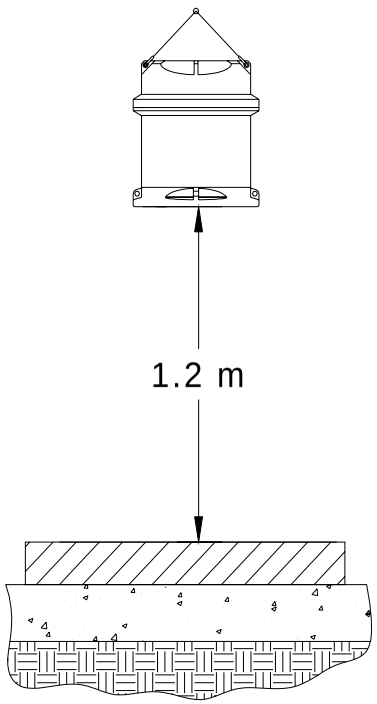



- **Test configuration**
  - > Expose package to time-avg. ambient air temperature of ≥800°C for ≥30 minutes
    - Simulate HAC thermal test of 10CFR71.73(c)(4)
  - > Package suspended horizontally from frame with damaged side down
    - Cask contacting damaged side of package expected to produce maximum 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



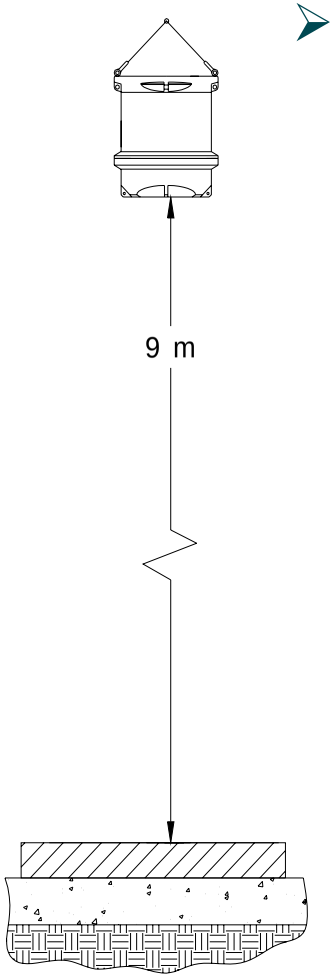
# Test Sequence #2




## ➢ NCT Bottom End Drop (Test 2A)

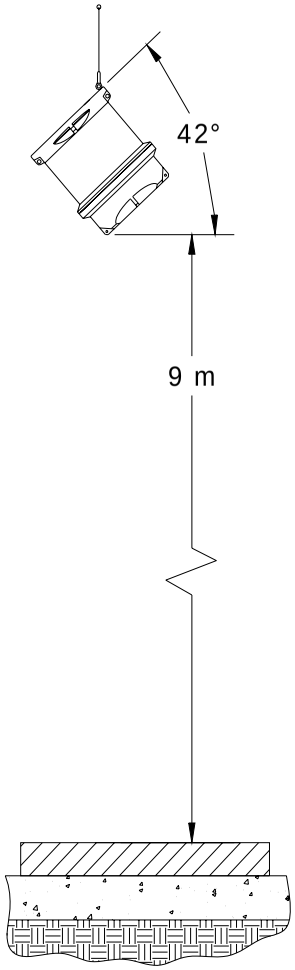
- **Test configuration**
  - > 1.2m free drop onto unyielding target per 10CFR71.71(c)(7)
  - > Perform test using undamaged specimen
  - > Vertical drop onto package bottom end
  - > Instrument with accelerometers
- **Primary test objectives**
  - > Confirm analytical predictions of peak package deceleration
  - > 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



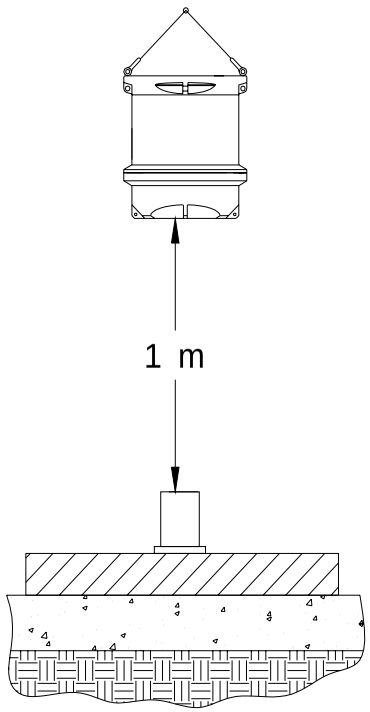

- **HAC Top End Drop (Test 2B)**
  - **Test configuration**
    - > 9m free drop onto unyielding target per 10CFR71.73(c)(1)
    - > Perform test using damaged specimen from Test 2A
      - Minor damage from Test 2A will have no measurable impact
    - > Vertical drop onto package top end
    - > Instrument 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



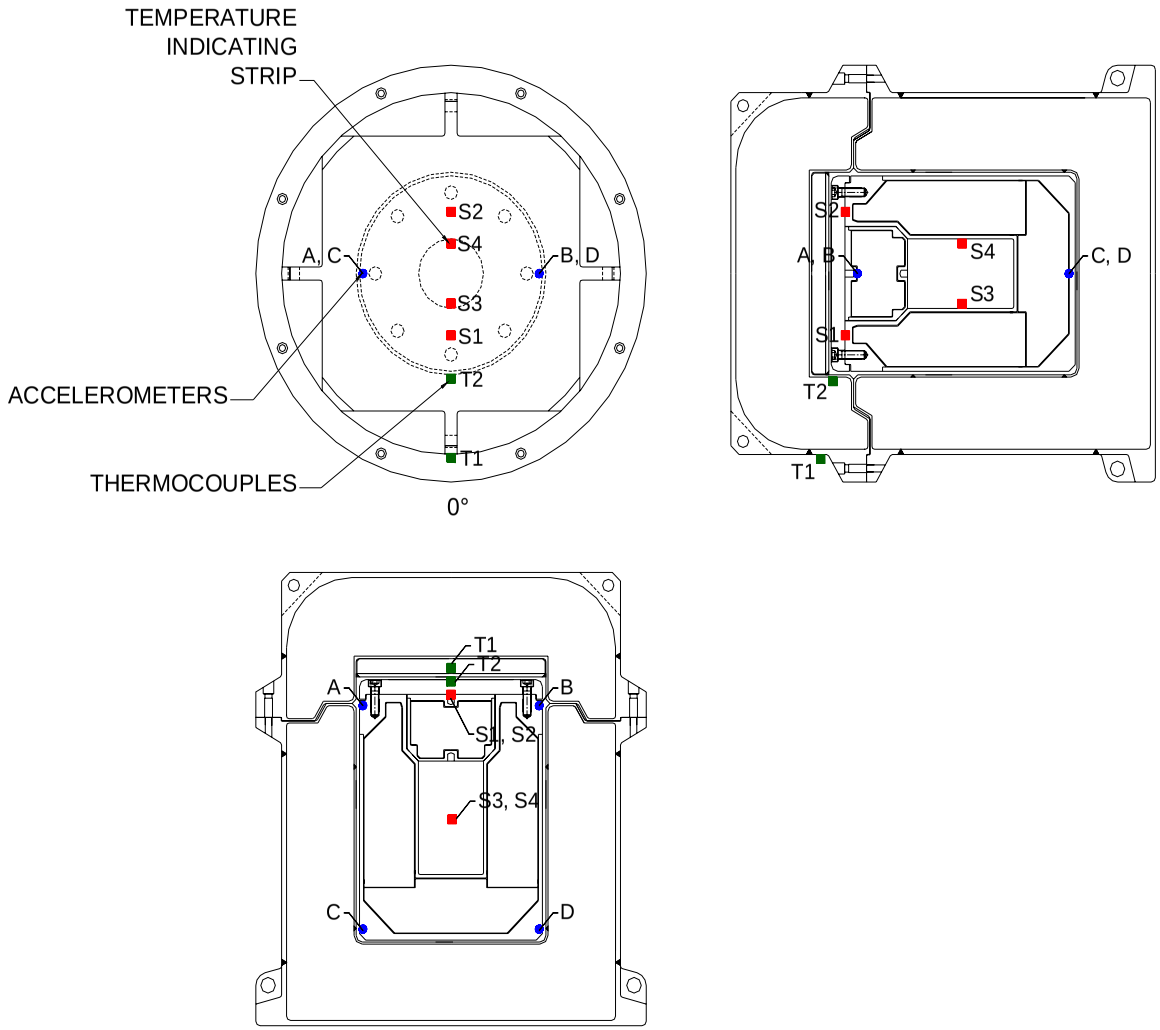

- **HAC Top Corner Drop (Test 2C)**
  - **Test configuration**
    - > 9m free drop onto unyielding target per 10CFR71.73(c)(1)
    - > Replace overpack lid from Test 2A with undamaged specimen
    - > Orient package center of gravity over top corner
    - > Instrument with accelerometers
  - **Primary 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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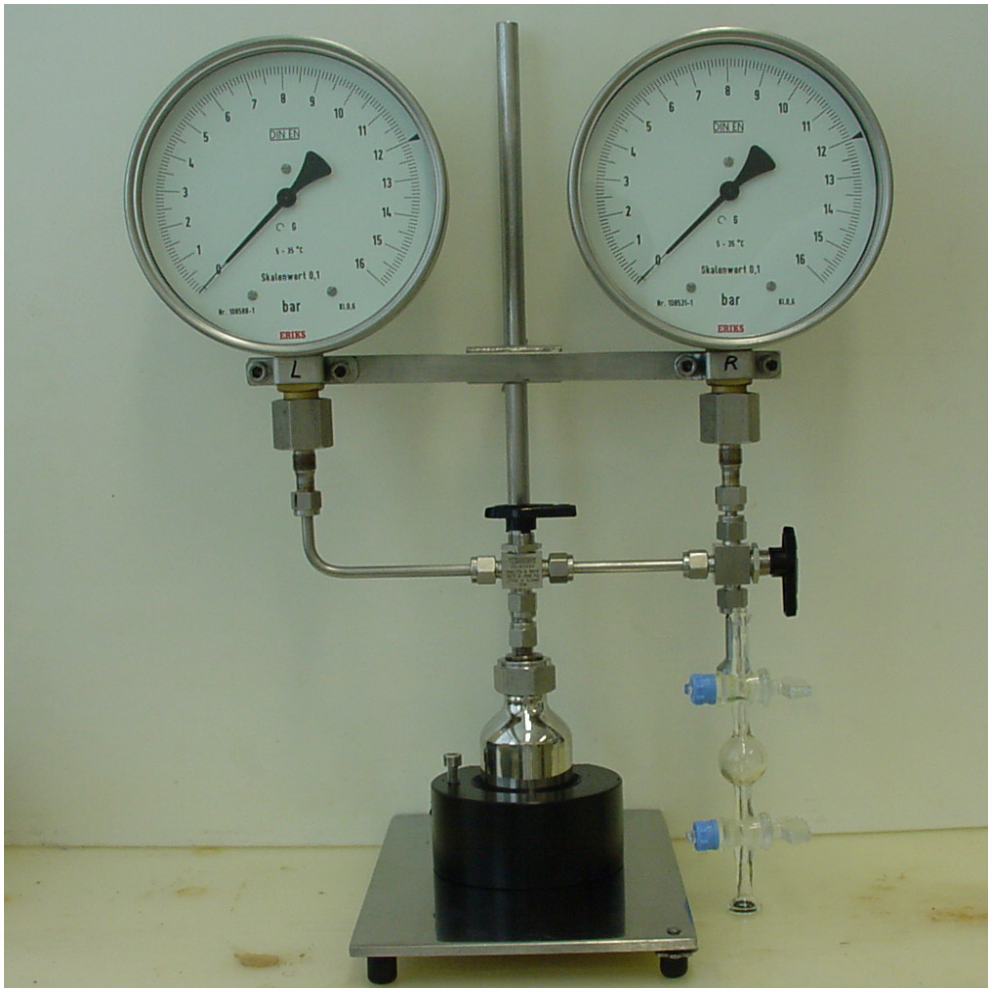
# Measurement equipment

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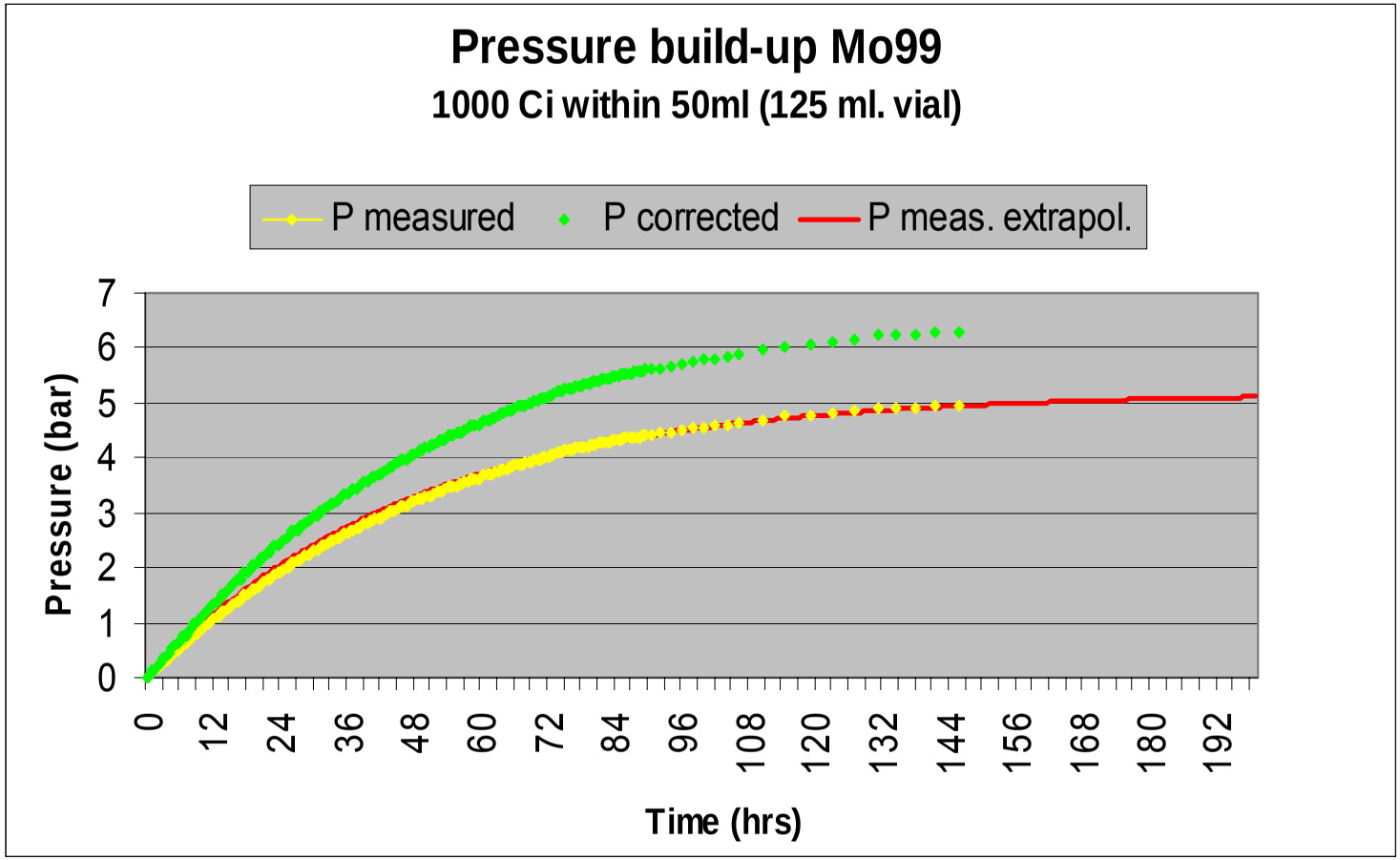
# Long term 1000 Ci test 145 h

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# 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.

German authority acceptance for licensing

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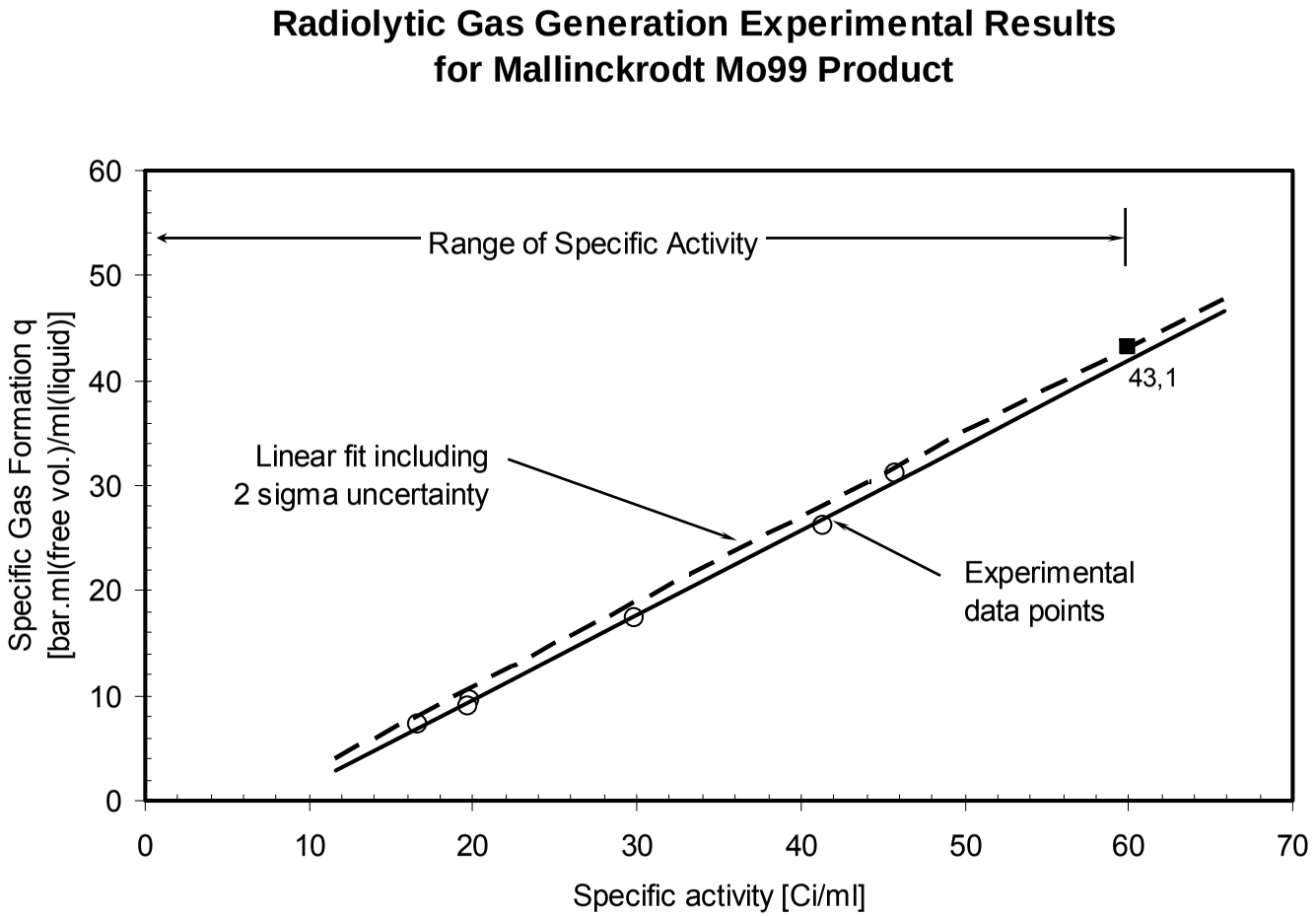
# Experimental results

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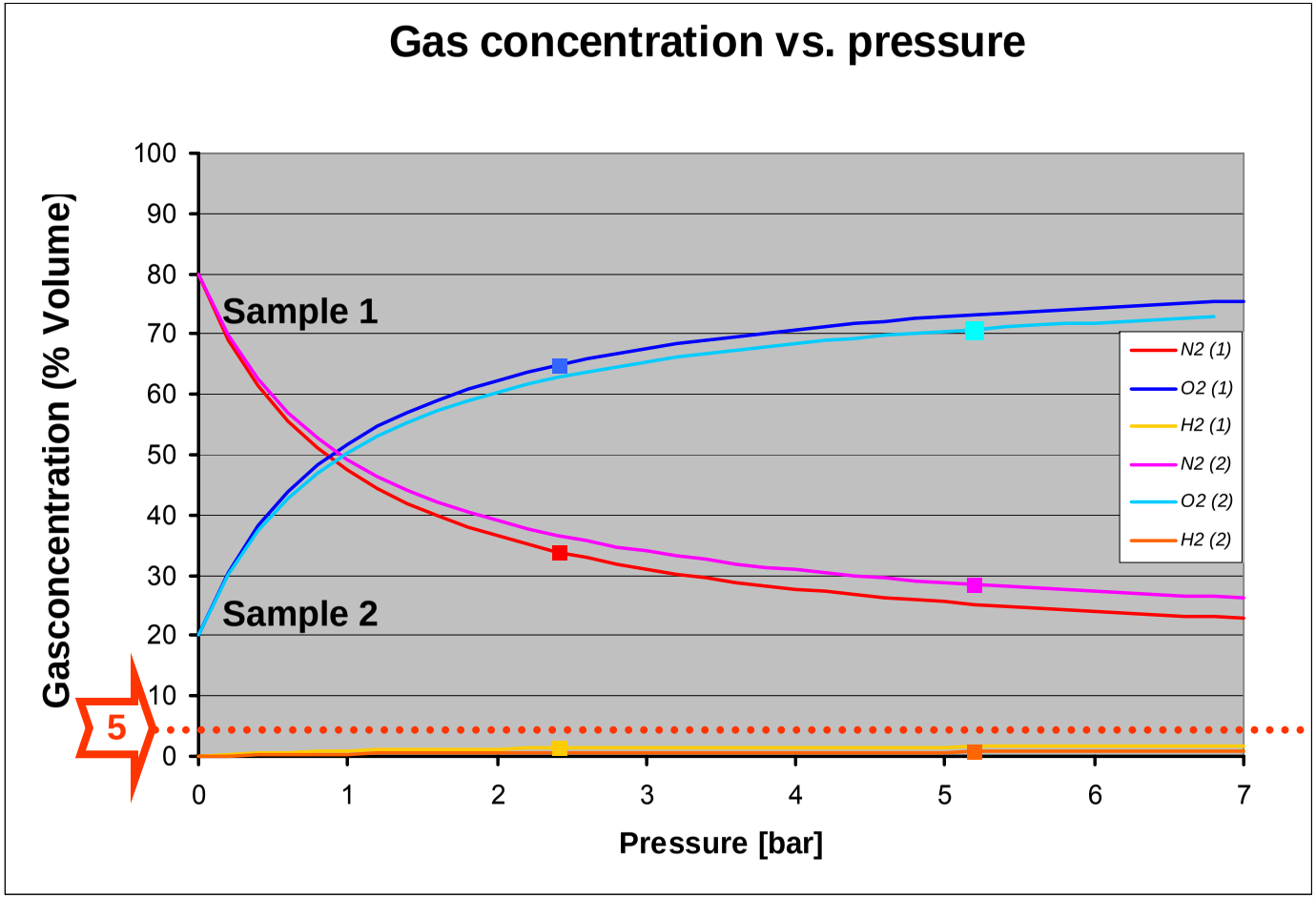
# Specification gas radiolysis (1)




**Sample 1:** 811 Ci at 2,42 bar (Vol % H2 => 1,3 %)
**Sample 2:** 1000 Ci at 5,2 bar (Vol % H2 => 0,7%)

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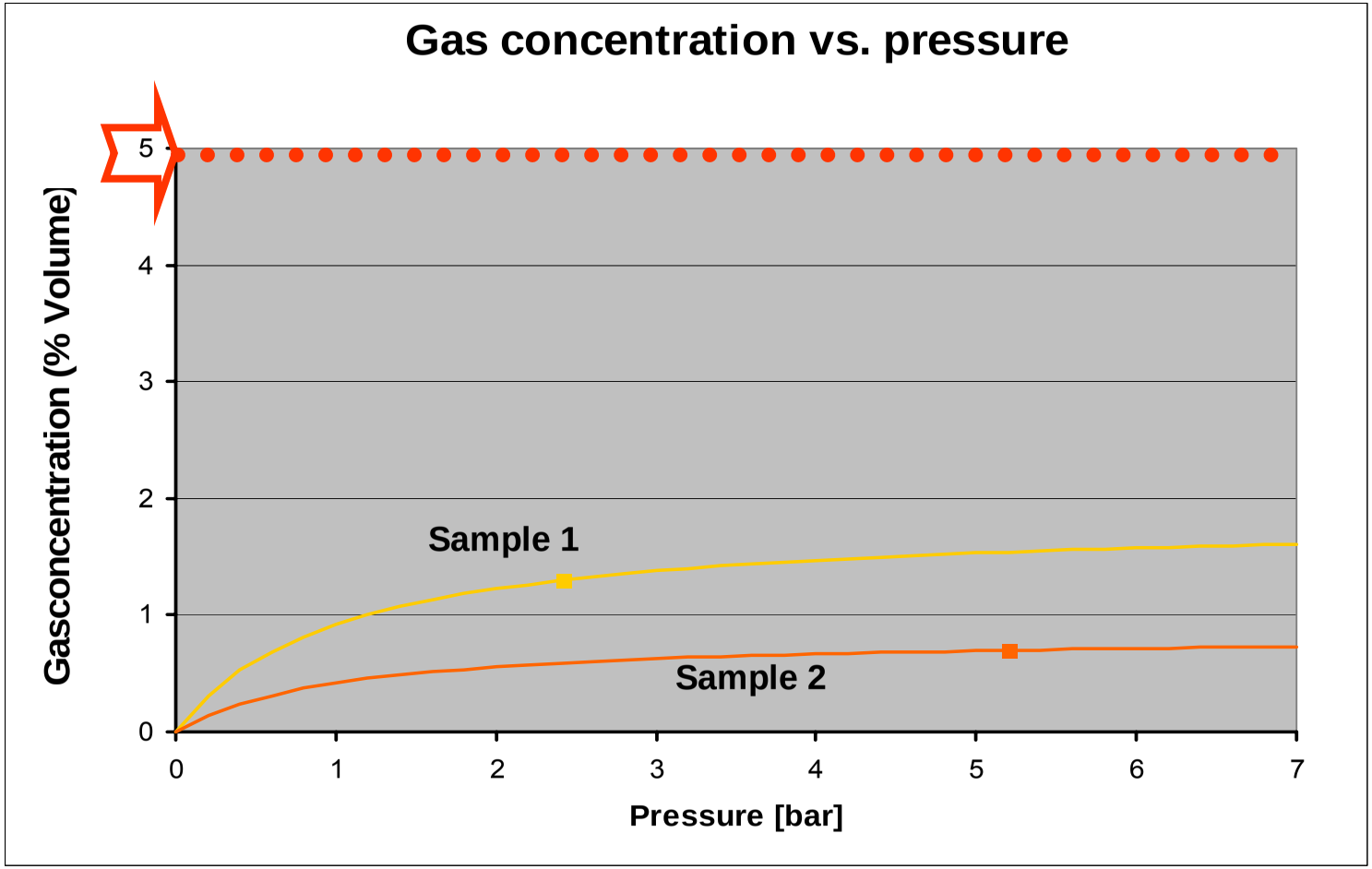
# Specification gas radiolysis (2)




**Sample 1:** 811 Ci at 2,42 bar (Vol % H2 -> 1,3 % when t = ∞ -> H2 = 1.9%
**Sample 2:** 1000 Ci at 5,2 bar (Vol % H2 -> 0,7% when t = ∞ -> H2 = 0.9%

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# 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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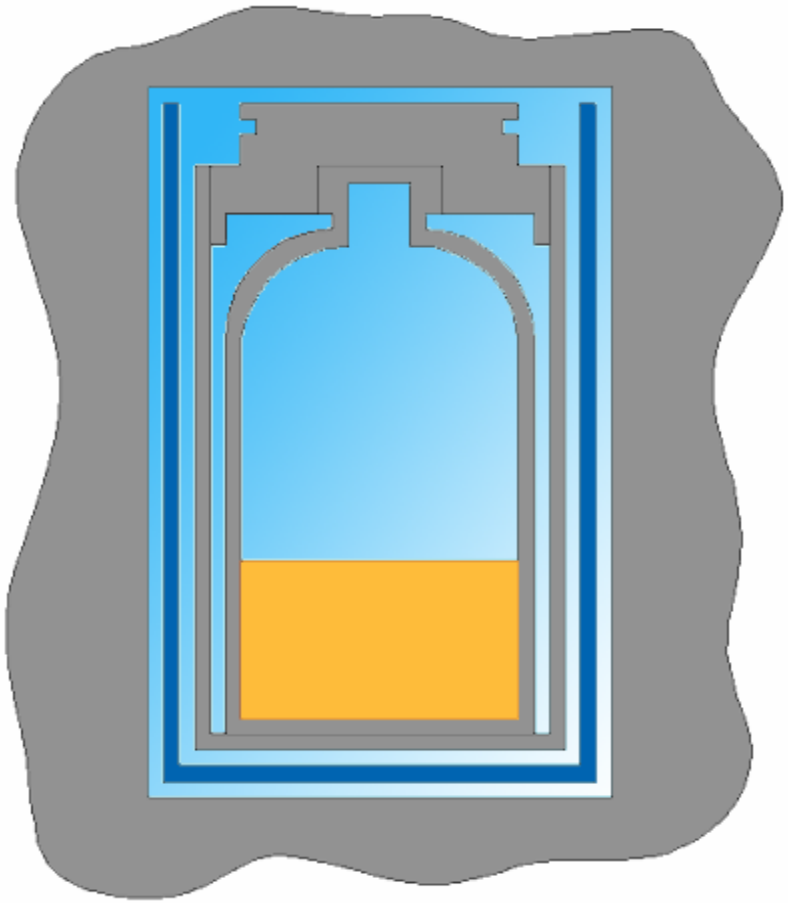
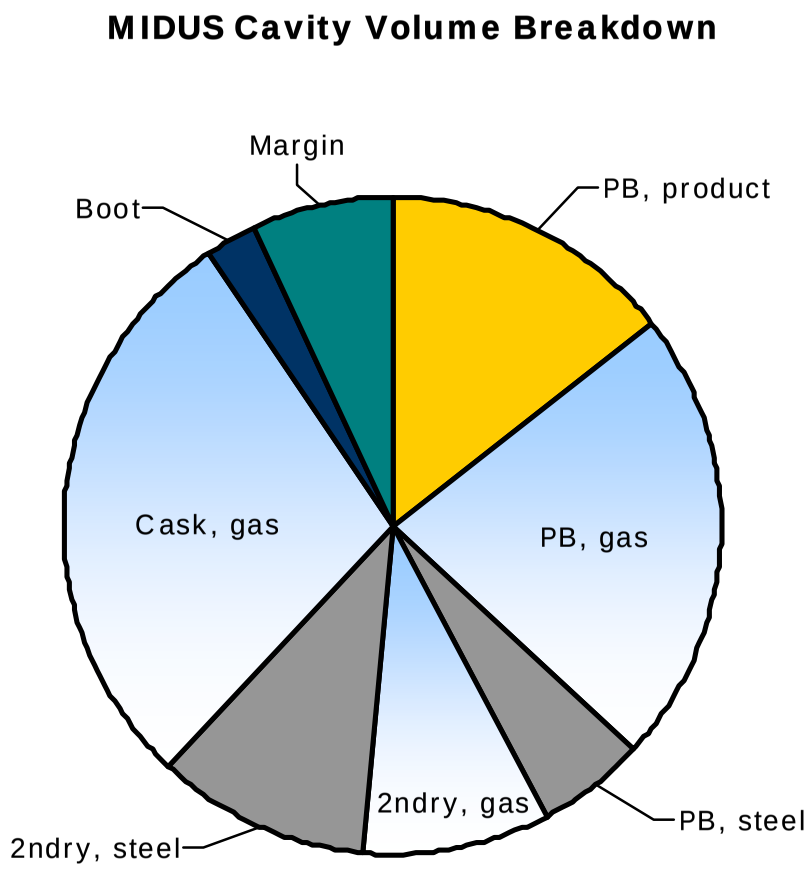
# Package Gas Generation & Hydrogen Content

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

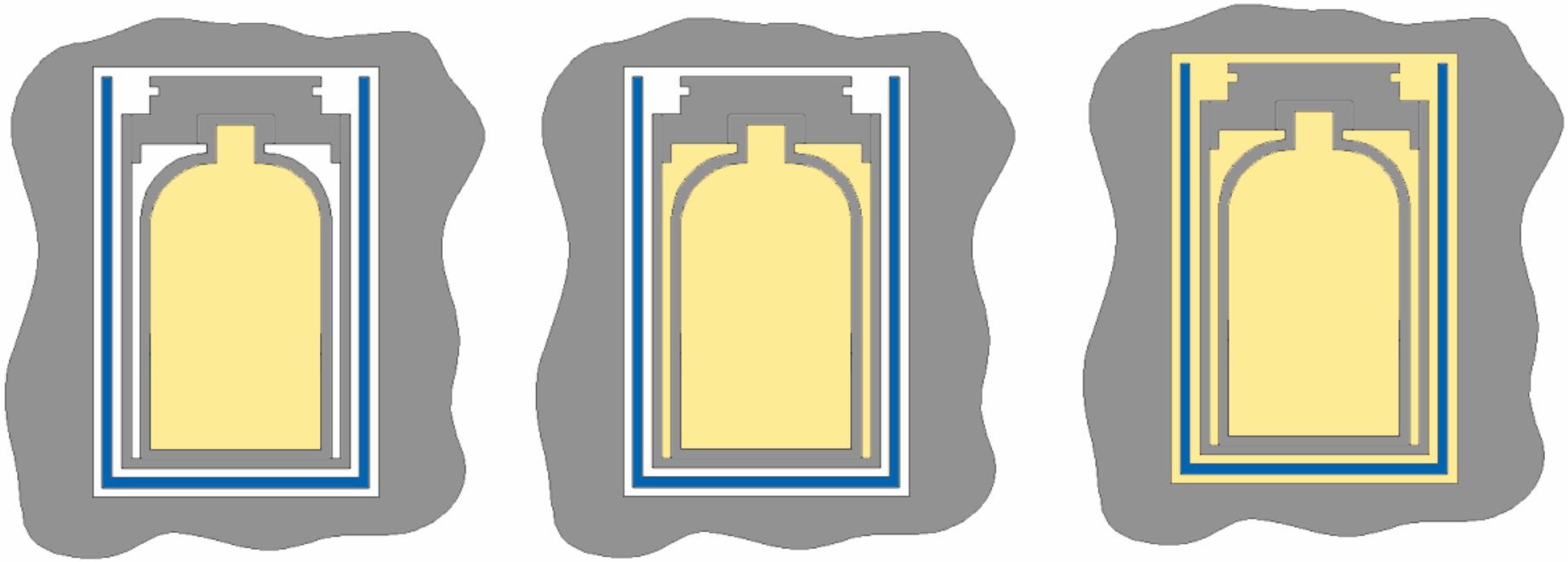
# Cask Cavity Volume Budget





# 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

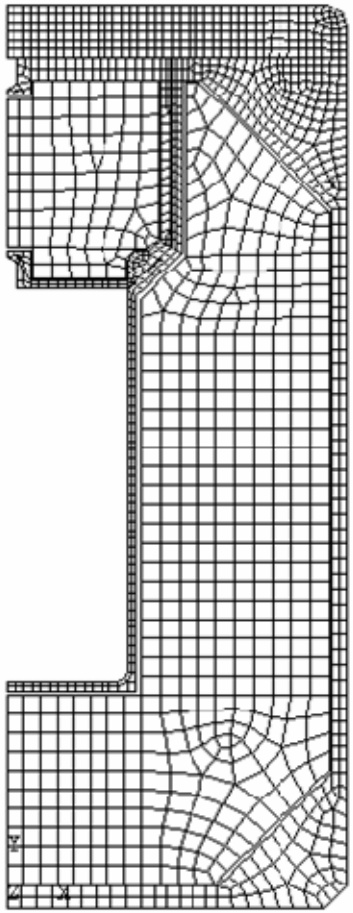
## ➢ Drop Loads Analysis

- Upper and lower bound F-$\delta$ curves developed for bottom end drop
- Foam F-$\delta$ 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-$\delta$ curve
- Overpack shell assembly and foam F-$\delta$ 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

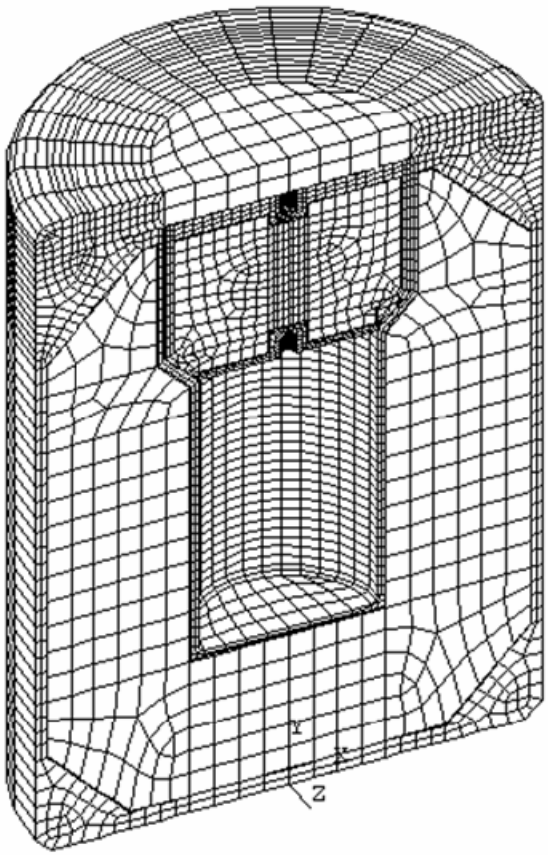
## ➢ End Drop Stress Analysis (continued)

- 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.

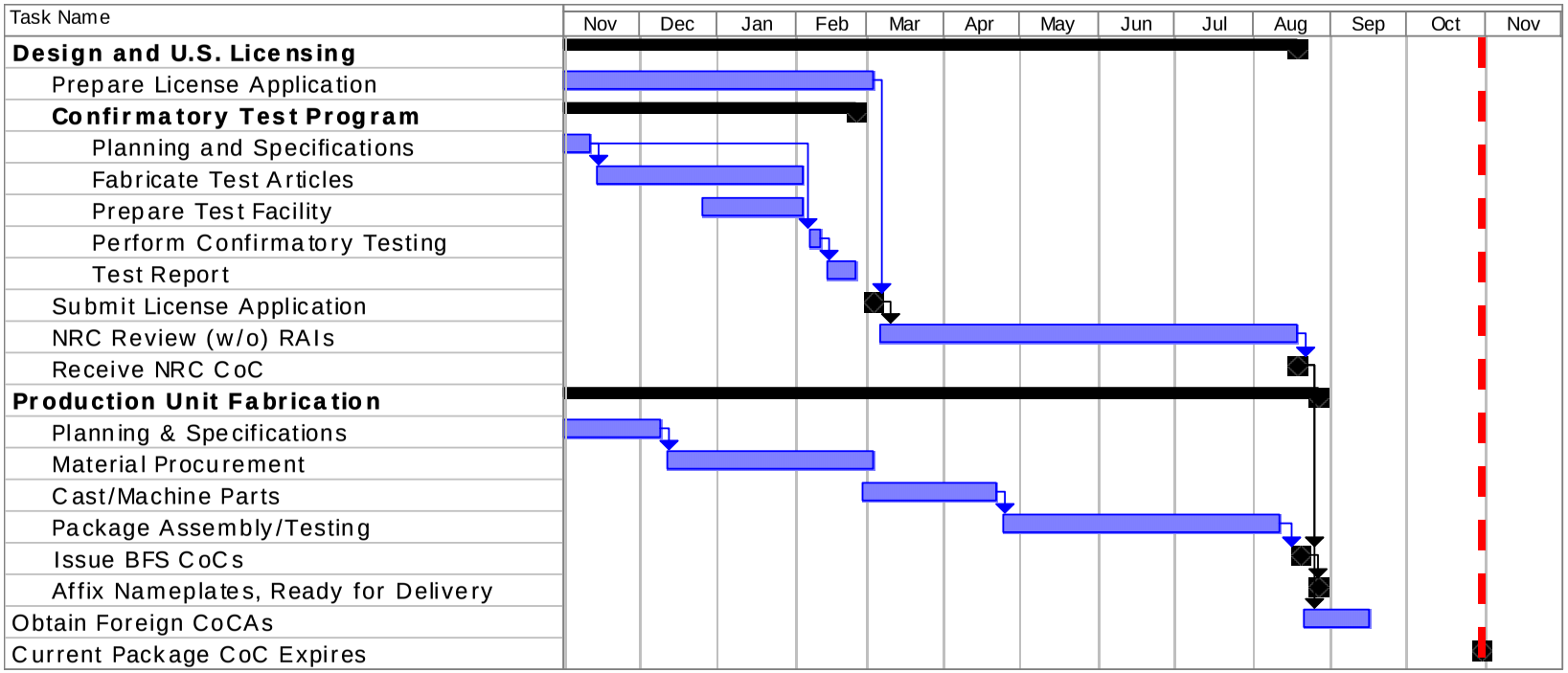
# Shielding Analysis

- **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