# Baltimore Tunnel Fire Evaluation

Thermal Analysis of HOLTEC Hi-Star 100 Transport System

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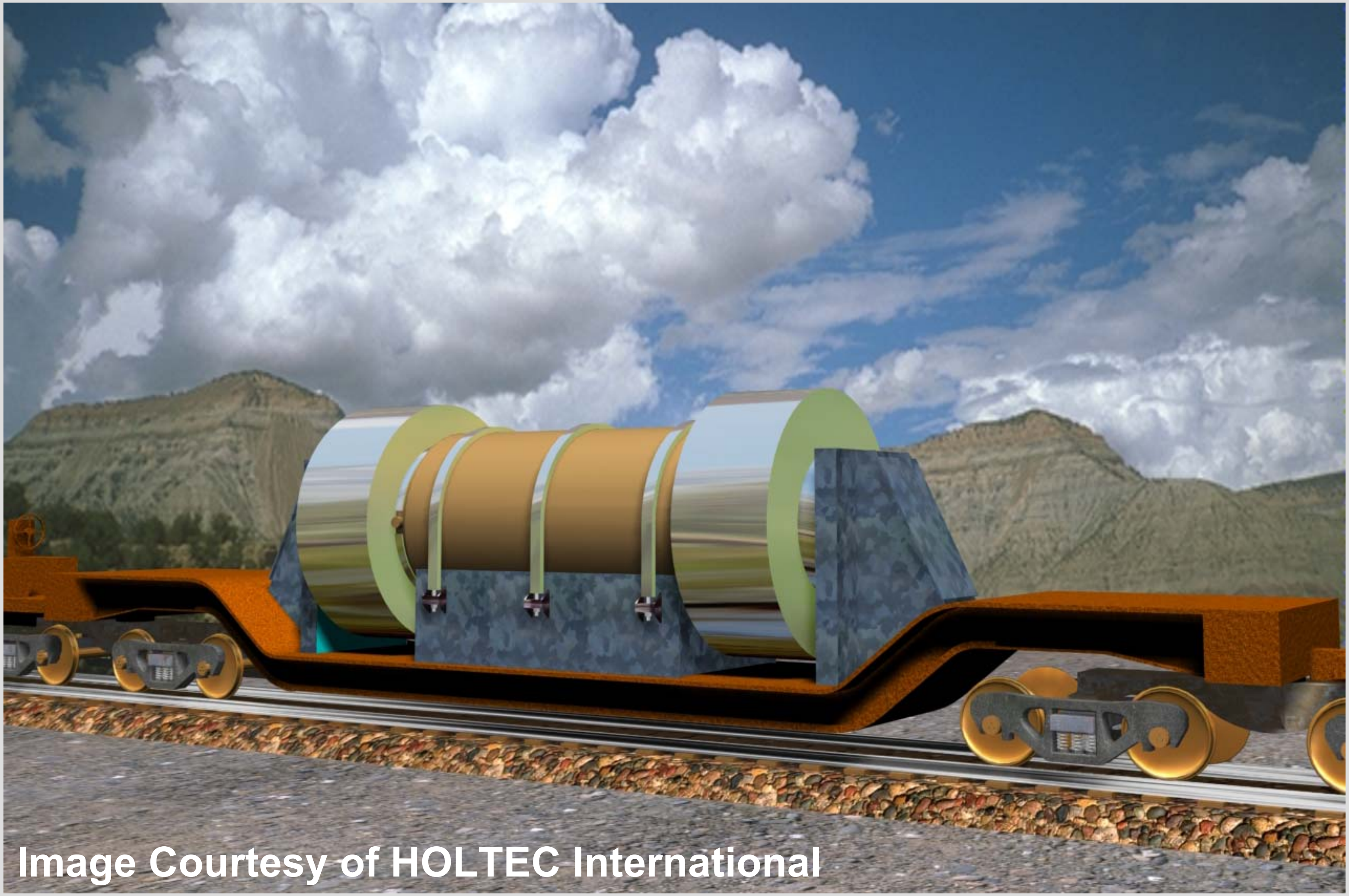
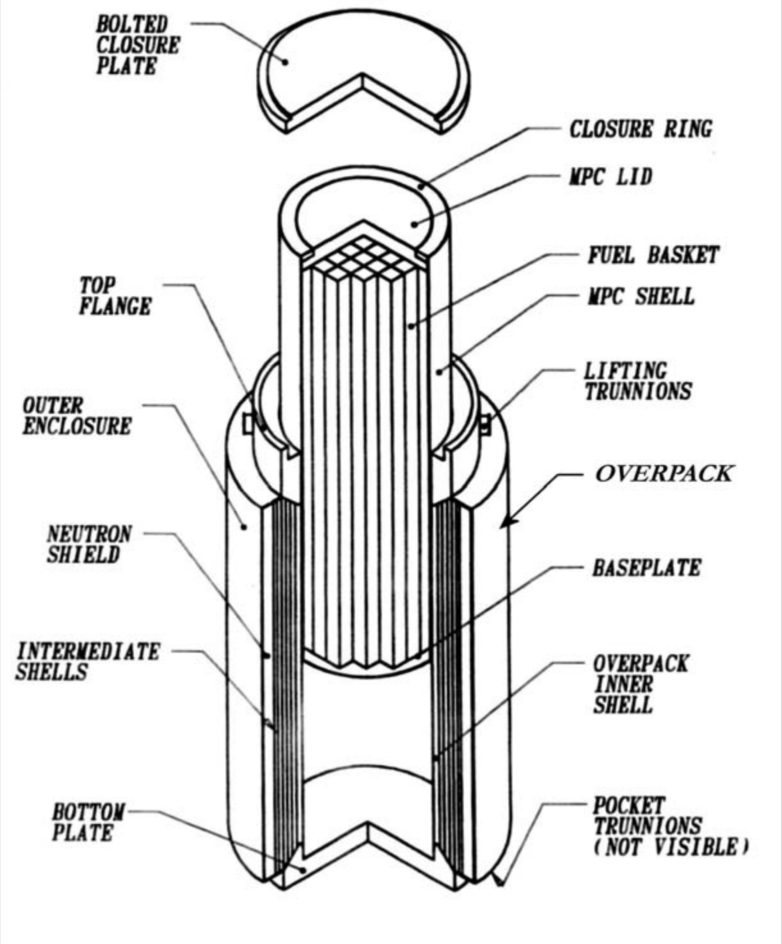
# System General Description



# System General Description



# System General Description

- HOLTEC Hi-Star 100 Cask
  - 306" long x 128" diameter (w/limiters)
  - Two forged end flanges & welded concentric shells
    - 2.5" thick primary SST containment shell
    - 5" thick composite CST gamma shield
    - Top forging - bolted closure
  - Two hybrid honeycomb impact limiters
  - 191" long x 68.75" diameter cavity
  - 5" thick composite neutron shield (channel/plate/epoxy)
  - Passive dissipation of SNF decay heat

# System General Description

- HOLTEC MPC-24 Canister
  - 190.3” long x 68.4” diameter
  - Thin-walled SST w/ two stayed end flanges
  - “Egg crate” style basket construction
    - 24 PWR fuel compartments (8.75”x8.75”x176.5”)
    - Flux traps
    - Boral poison sheets w/ SST wrappers/pockets
  - Helium cover gas backfill (5 atm)
  - Passive dissipation of SNF decay heat

# System General Description

- Hi-Star 100 Cask / MPC-24 Canister
  - Licensed for 20.0 kW decay heat load

# Analytical Approach

- Objective:
  - Perform detailed analysis of the Holtec transport system when subjected to the BTF fire condition (i.e.; all conductive, convective, and radiative heat transfer components must be incorporated)

# Analytical Approach

- Assumptions:
  - 2D model conservatively captures peak temperatures & transient response (poor heat transfer through impact limiters, Al honeycomb melts @ 1220ºF, SST skins, SNF decay heat profile)
  - Use of nominal dimensions acceptable
  - Fuel assemblies centered within basket cells

# Analytical Approach

- Assumptions (cont.):
  - Canister radially centered within cask
  - SNF decay heat profile peaking factor of 1.1 applies at represented hottest canister cross-section
  - Normal-Hot Steady State conditions reached prior to fire
  - Transport trailer conservatively neglected - in vicinity of cool (tunnel bottom circulation) NIST temperature data

# Analytical Approach

- Method:
  - Apply general FE solution code ANSYS to solve with
    - Well validated convection correlations (buoyant & forced)
    - Accurate thermal-physical properties (temperature & temperature deference dependent)
    - ANSYS Parametric Design Language (ADPL) for current convective coefficient determination
    - Incorporating all conductive, convective, and radiative components (explicit representations)
    - Using NIST tunnel surface temperatures, air temperatures and velocity data

# Analytical Approach

## Model Construction: Canister body

- **Conduction**
  - 18489 PLANE55 elements
  - Standard conduction coefficients for all except SNF, Helium, and Boral areas
  - Boral composite sheet conductivity handled with series/parallel circuit analogies (effective coefficients)

- **Convection**
  - Helium conduction multipliers applied to represent minor convective enhancements
  - [$K_{helium} = Cmult * K_{helium\text{-}1atm}$] (Cmult = 3.66 for convective – consistent with COBRA SFS)
  - $K_{fuel}$ extracted from TRW Report BBBA000000-01717-5705-00010, Rev 0

- **Radiation**
  - modeled as 72 small 2D enclosures via LINK31 boundaries → processing in /AUX12 → defining MATRIX50 w/output
  - SNF assembly ↔ cell wall / Basket ↔ canister wall and supports / Basket supports ↔ canister wall
  - Exchange between Boral plate and cell wall/sheathing via linearized radiation expression [$k_{eff} = \sigma \varepsilon L_{gap} 4T^3$]
    - gap conduction added to this component
    - total incorporated into Boral composite sheet effective conductivity calculation

# Analytical Approach

## Model Construction: Cask body

- **Conduction**
  - 8667 PLANE55 elements
  - Standard conduction coefficients
- **Convection**
  - Ignored between cask and canister
  - 1022 SURF151 for external convection to ambient (pre & during fire)
- **Radiation**
  - Cask -to- canister - modeled as 2D enclosure via LINK31 boundaries → processing in /AUX12 → defining MATRIX50 w/output
  - 1022 SURF151 for external radiation w/ ambient (pre-fire only)
  - Cask -to- Tunnel - modeled as 2D enclosure via LINK31 boundaries → processing in /AUX12 → defining MATRIX50 w/output (during fire only)

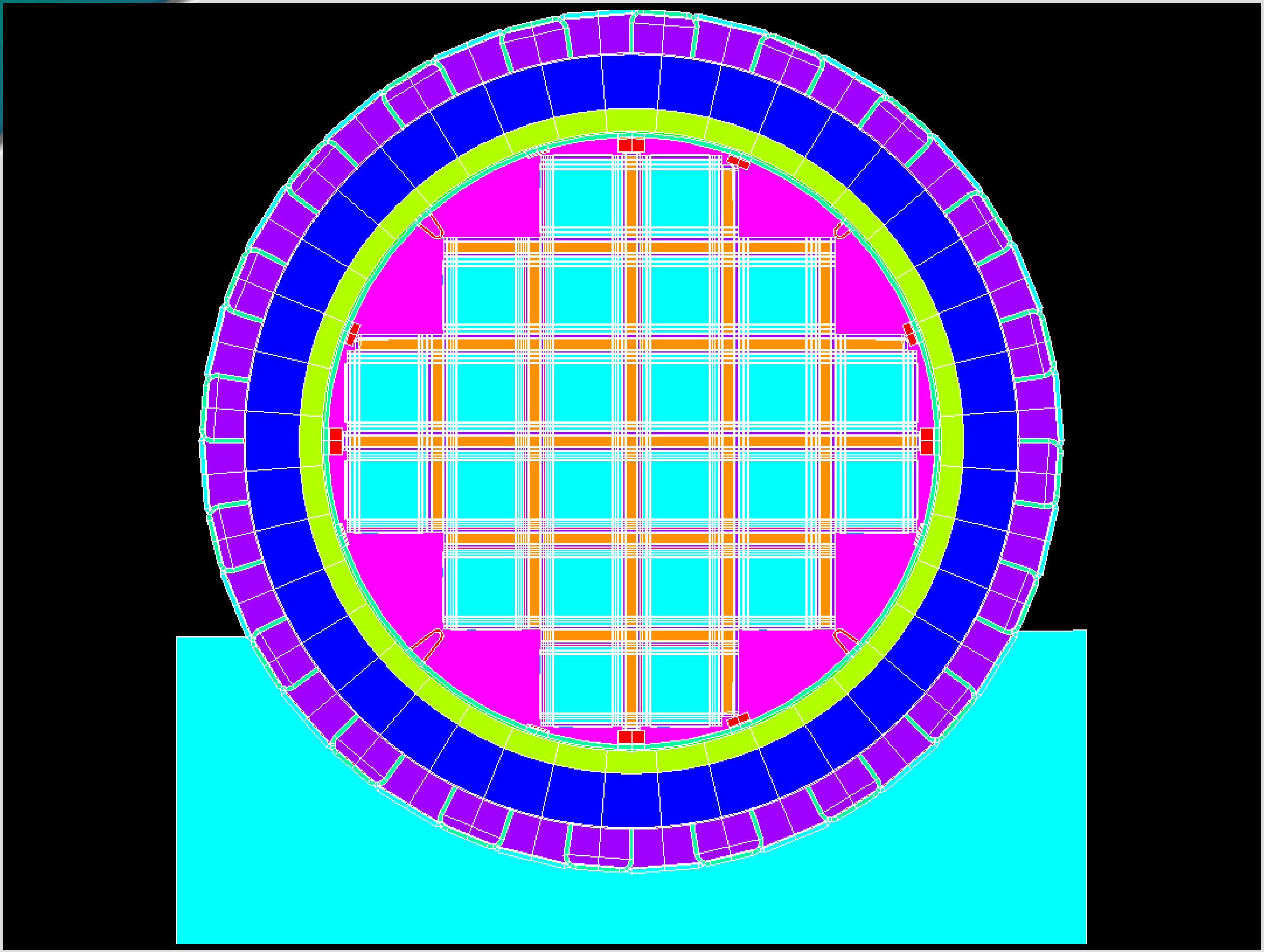
# Analytical Approach

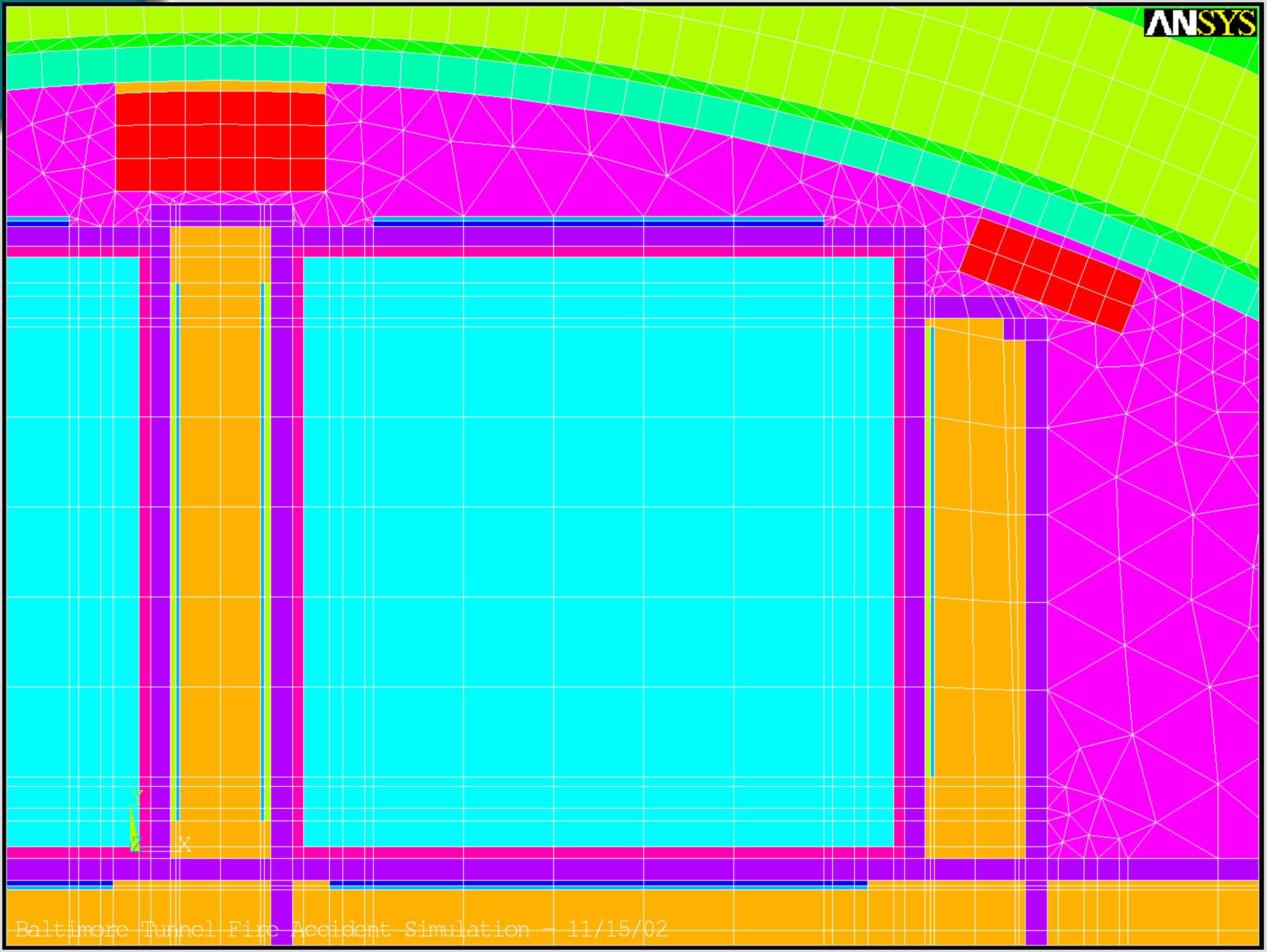
## Model Construction: Cask Cradle body

- **Conduction**
  - 1112 PLANE55 elements
  - Conductivity defined via volumetric averages of air and steel

- **Convection**
  - Nu=10 for internal convecting air volume)
  - Utilizes above 1022 SURF151 defined for external convection to ambient (pre & during fire)

- **Radiation**
  - Utilizes above 1022 SURF151 defined for external radiation w/ ambient (pre-fire only)
  - Cask -to- Tunnel - modeled as 2D enclosure via LINK31 boundaries → processing in /AUX12 → defining MATRIX50 w/output (during fire only)

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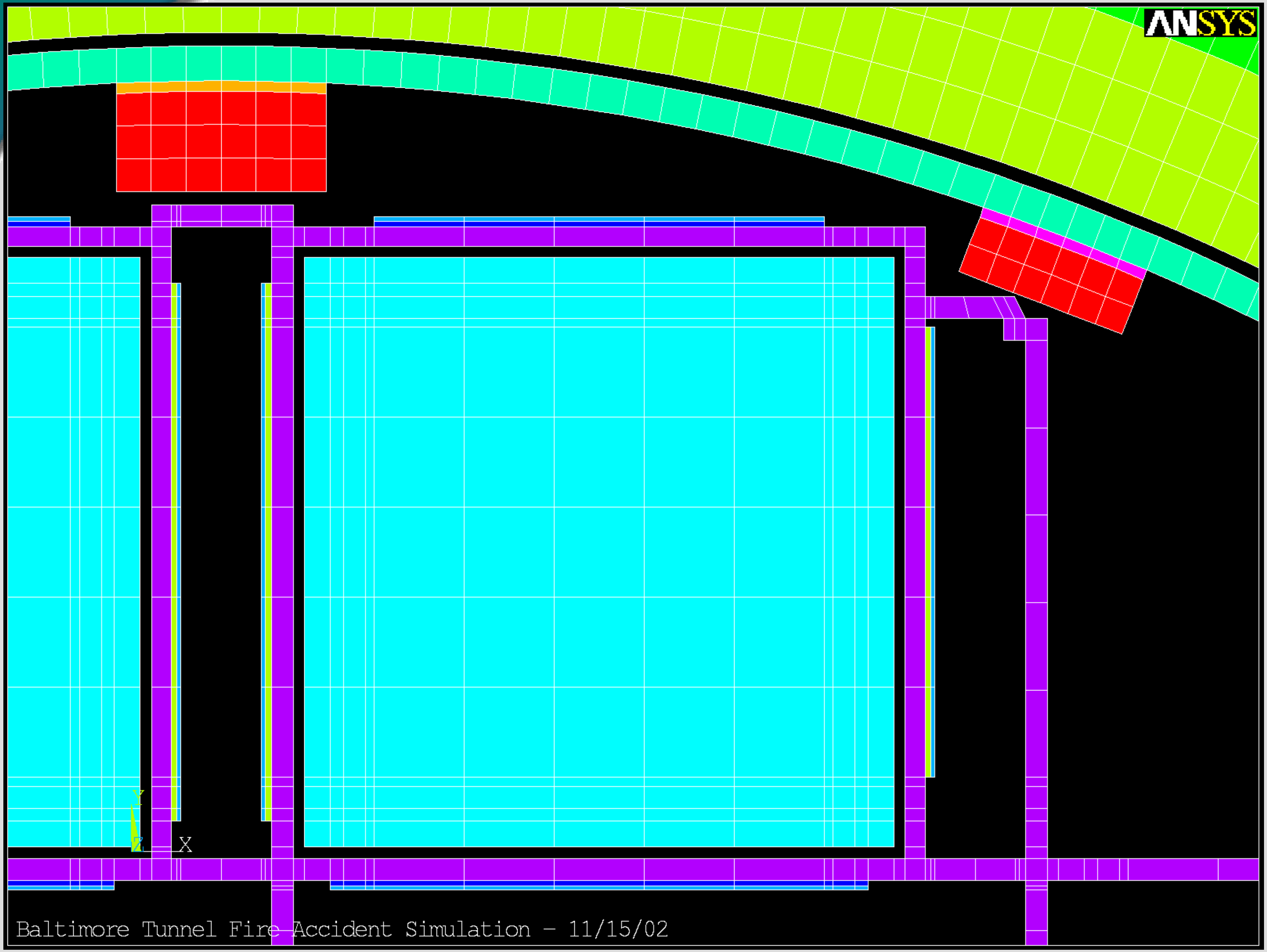
Baltimore Tunnel Fire Accident Simulation - 11/15/02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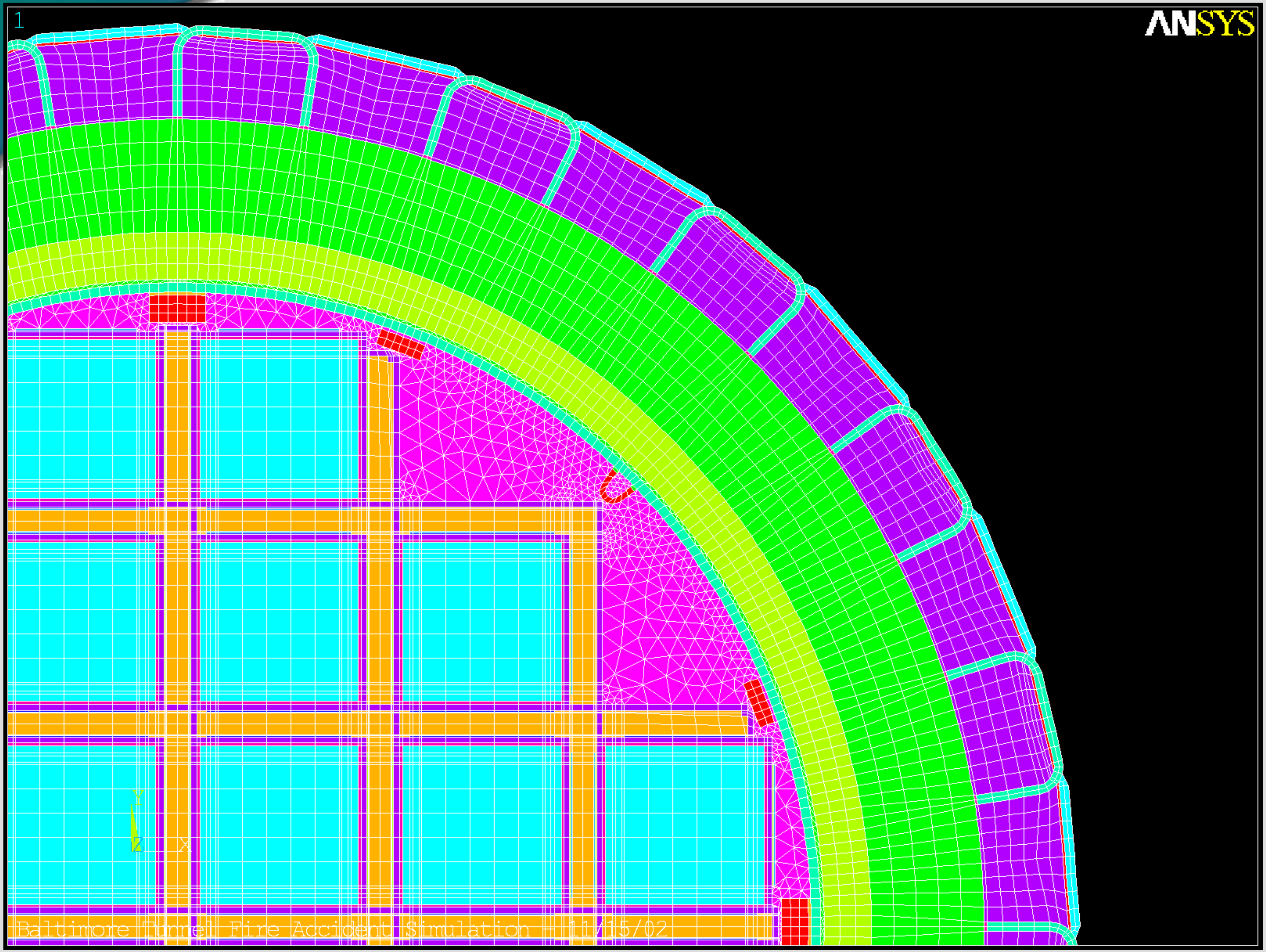
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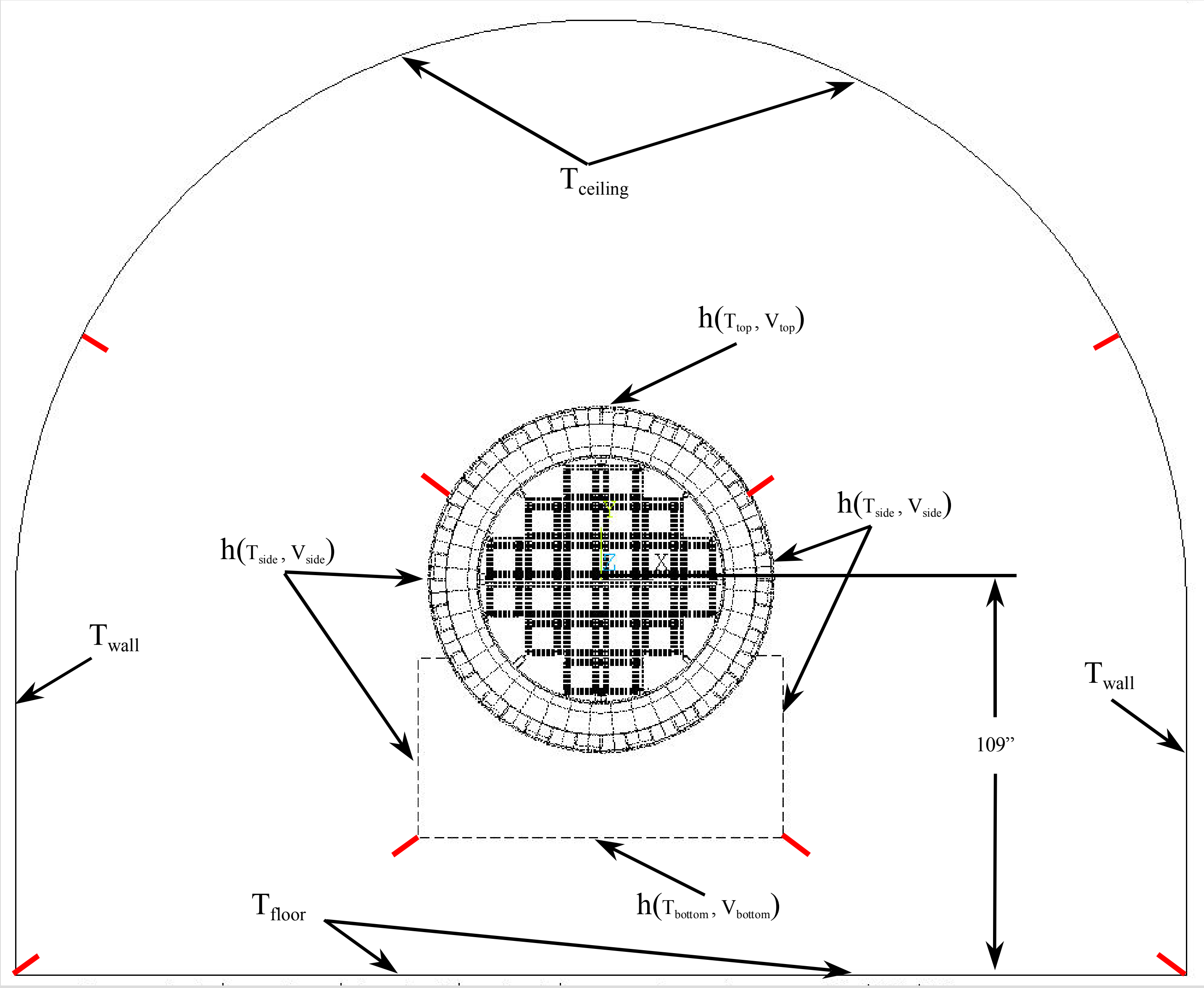
# NIST Boundary Conditions As Applied To Model



# Analytical Approach

- Loading & Boundary Conditions:
  - 20.0 kW SNF decay heat load
  - Fuel geometry / conductivity of W17X17 OFA w/ 1.1 peaking factor

- **Pre-fire conditions**
  - 100°F Ambient - (Normal-Hot Conditions)
  - 12 hour solar insolation data averaged over 24 hours (per 10 CFR §71.71(c)(1))
  - $\varepsilon_{cask/cradle} = 0.85$, $\varepsilon_{ambient} = 1.0$ (per HOLTEC SAR)
  - Buoyant convection correlations applied w/ APDL logic (horizontal cylinder, horizontal & vertical flat plate)
  - Radiation & convection interaction with ambient via SURF151's
  - Allowed to reach steady state

# Analytical Approach

- Loading & Boundary Conditions (cont.):
  - **Fire conditions**
    - BC's defined by NIST temperature/velocity data @ 5m & 20m from fire source
    - $\varepsilon_{cask/cradle} = 0.9$, $\varepsilon_{tunnel} = 0.9$ (per 10 CFR §71.71(c)(1))
    - Forced convection correlations applied w/ APDL logic (laminar & turbulent)
    - Convection interaction via SURF151's
    - Radiative interaction with via MATRIX50's (radiation enclosure)
    - Gamma shield gaps removed to maximize energy input
    - NIST data BC's assumed constant after 30 minutes (peak fire temperatures) and ran out 150 hours to maximize energy input
    - Additional fire radiation contribution accounted for in 5m case (flame sheet at 1562°F - view factors include actual geometric bodies)

# Analytical Approach

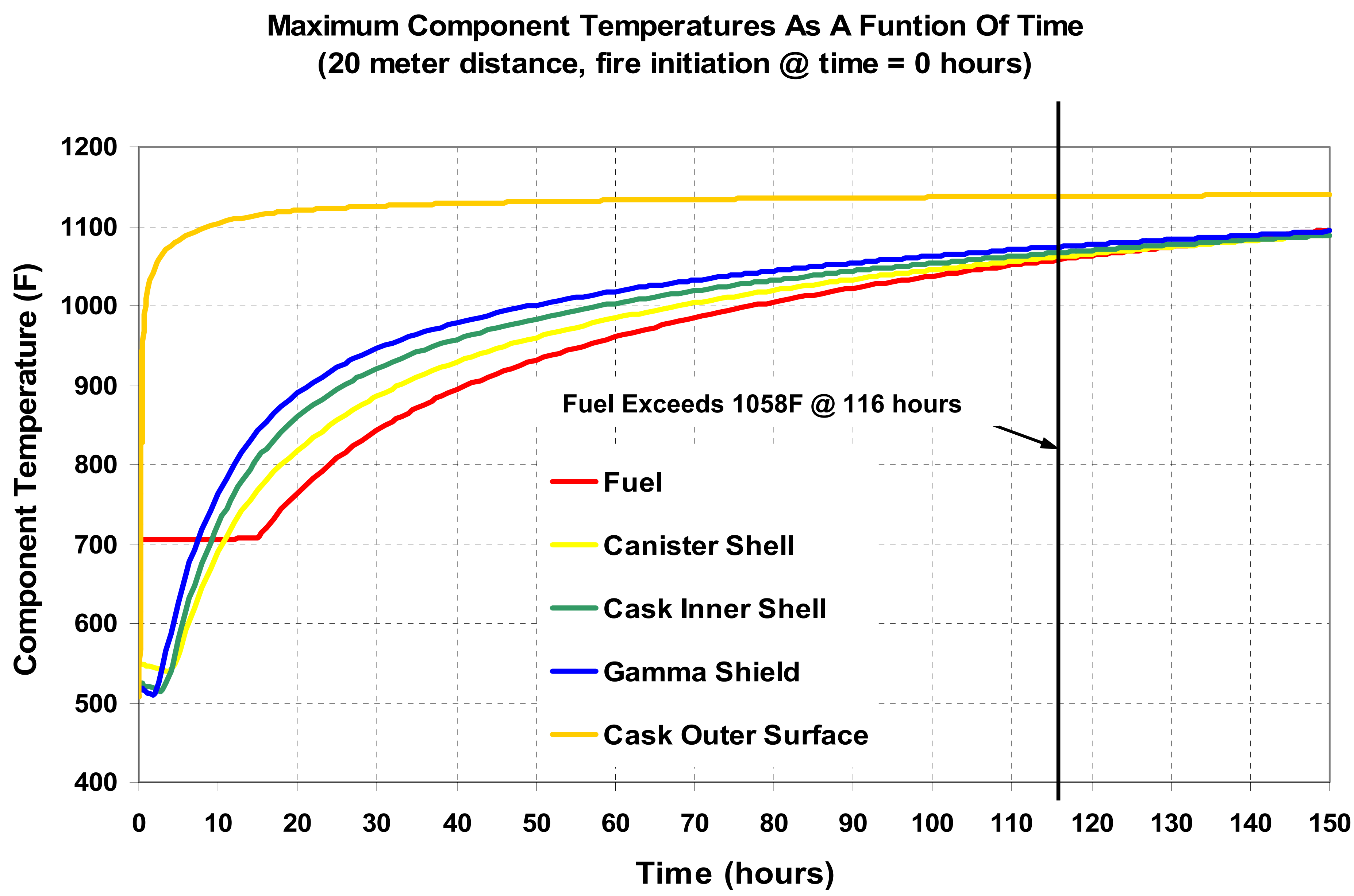
- Conservatisms:
  - System reached Normal-Hot Steady State prior to fire
  - 2D model w/ 1.1 decay heat peaking factor (hottest possible x-section represents infinitely long cask)
  - Full conduction of Holtite-A considered during fire (no degradation to epoxy-like substance)
  - Fire BC's considered steady state after reaching maximum potential (30 minute NIST data)
  - Max tunnel ceiling temperatures applied over entire ceiling

# Results

- Model was run until peak cladding temperatures exceeded 1058°F (short-term regulatory limit)

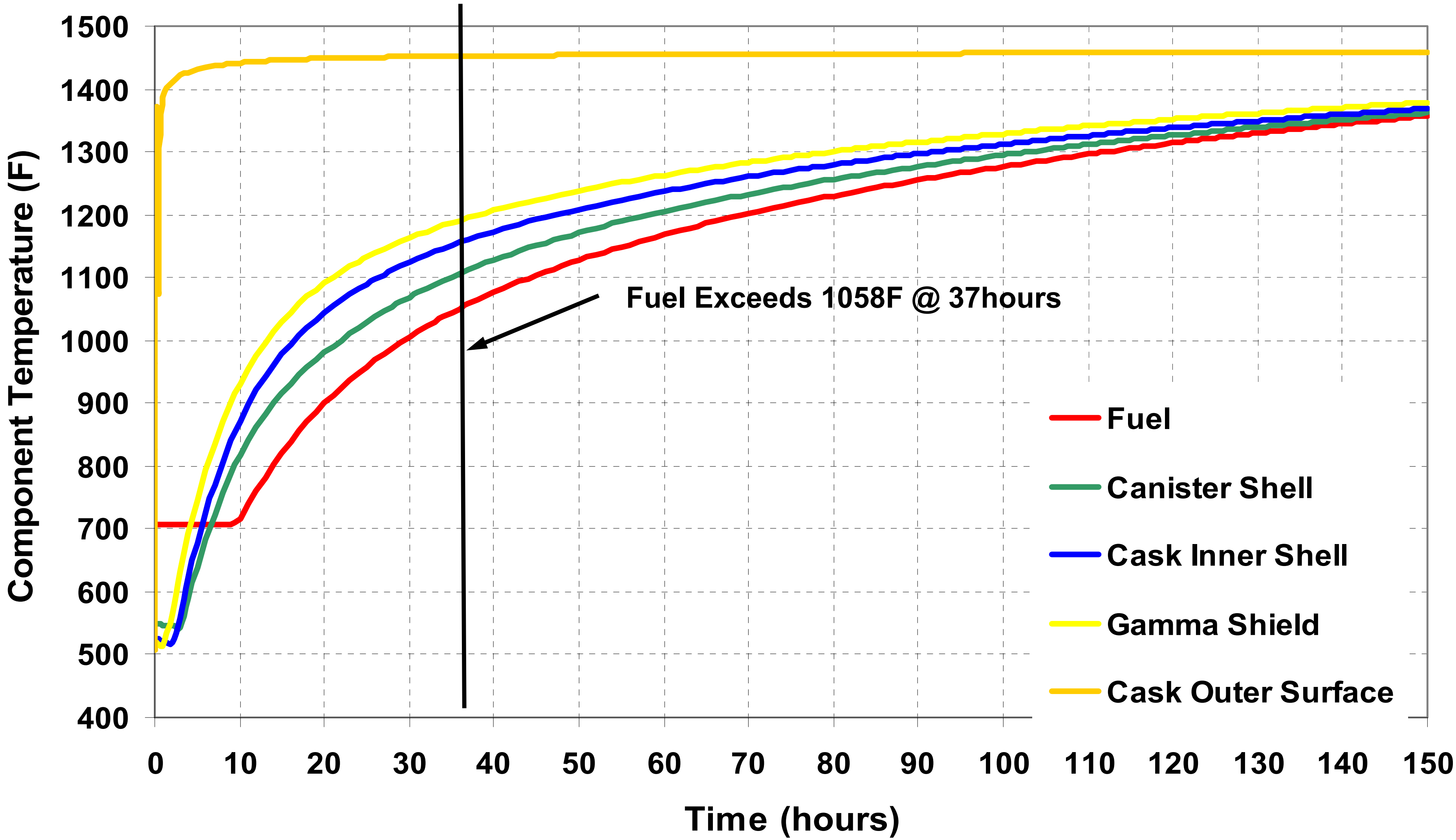
  - 20m source - 116 hours (~5 days) after ignition

  - 5m source - 37 hours (~1.5 days) after ignition (conservatively ignores required buffer car)



Maximum Component Temperatures As A Funtion Of Time
(20 meter distance, fire initiation @ time = 0 hours)
Component Temperature (F)
1200
1100
1000
900
800
700
600
500
400
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Time (hours)
Fuel Exceeds 1058F @ 116 hours
Fuel
Canister Shell
Cask Inner Shell
Gamma Shield
Cask Outer Surface

# Maximum Component Temperatures As A Funtion Of Time
## (5 meter distance, fire initiation @ time = 0 hours)



# Questions

# Additional Evaluation Results

- 30 Hour NIST Fire Simulation Data:
  (~7hr fire, 23 hour post-fire)
  - Pre-fire conditions
    - Same as previous, same modeling methodology
  - Fire conditions
    - 20m fire distance (buffer car as required)
    - Gamma shield gaps removed (maximize energy input)
    - Neutron shield material property remains intact (no degradation)
  - Post-fire conditions
    - Neutron shield material degraded to air properties @ temperature
    - Tunnel BC's held at steady state 23 hours after cessation of fire (highly conservative)

# Additional Evaluation Results

- 30 Hour NIST Fire Simulation Data:
  (~7hr fire, 23 hour post-fire)

  - Maximum report temperatures

    - Fuel - 764°F @ 118 hours
    - Canister shell - 809°F @ 7.8 hours
    - Cask inner shell - 859°F @ 7.4 hours
    - Gamma shield - 934°F @ 7 hours
    - Cask outer surface - 1873°F @ 4.8 - 7 hours

# Additional Evaluation Results

- 26 Hour NIST Ventilated Fire Simulation Data: (~7hr fire, 19 hour post-fire)
  - Pre-fire conditions
    - Same as previous, same modeling methodology
  - Fire conditions
    - 30m fire distance (location yielding highest average temperatures)
    - Gamma shield gaps removed (maximize energy input)
    - Neutron shield material property remains intact (no degradation)
  - Post-fire conditions
    - Neutron shield material degraded to air properties @ temperature
    - Tunnel BC's held at steady state 19 hours after cessation of fire (highly conservative)

# Additional Evaluation Results

- 26 Hour NIST Ventilated Fire Simulation Data: (~7hr fire, 19 hour post-fire)
  - Maximum report temperatures
    - Fuel - 776°F @ 283+ hours
    - Canister shell - 773°F @ 7.5 hours
    - Cask inner shell - 821°F @ 7.2 hours
    - Gamma shield - 924°F @ 7 hours
    - Cask outer surface - 1821°F @ 6.3 - 7 hours