# Analysis of Rail Car Components Exposed to a Tunnel Fire Environment

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# Tasks

- Review anecdotal information on the Howard Street Tunnel fire
  - Photographic documentation and initial reports
- Visit site and inspect damaged railcars
  - Focused on the source of the fire and adjacent cars
- Analyze recovered train components using metallurgical techniques
- Apply simple convection and radiation models governing heat transfer to specific targets
  - Backed-up with a "reality-check," small-scale test

# Goal

*Use physical evidence, backed by numeric models to estimate fire duration and temperature witnessed by components during the post derailment fire.*

# Analyses Performed

*Materials Analyses:*

- Paint Degradation
- Oxidation of Steel Components

*Empirical/Computational Analyses:*

- Transient Heat Transfer Model
- Aluminum Air Brake Valve Component Melting

# ***Data Collection***

# Railcars

# Samples Collected

- Steel Scale (Car 51)
  - Collected from Brake End (30 ft "uphill")
- Section of Roof Plate (Car 50)
  - Source of substantial exposure due to long-burning paper car fire
- Sand Sample from Base of Rail #44
  - Near point of derailment
  - Illustrated some "clumping"

# Railcar Components

# Samples Collected *(cont.)*

- Remainder of ABDX-L Air Brake Valve
  - Exhibited the most notable damage
  - Comparable to other air brake valves
- Exposed Bolts on Air Brake
  - Bolts in the vicinity of the completely melted aluminum cover
- New Air Brake Valve Cover
  - Supplied directly from manufacturer

# ***Paint Analysis***

# Analysis of Paints

- Rail cars painted with a Dupont air-dried, high-solid, alkyd-enamel paint
  - Blistering temperature for paint: 700 $^{o}$C [1,292 $^{o}$F]

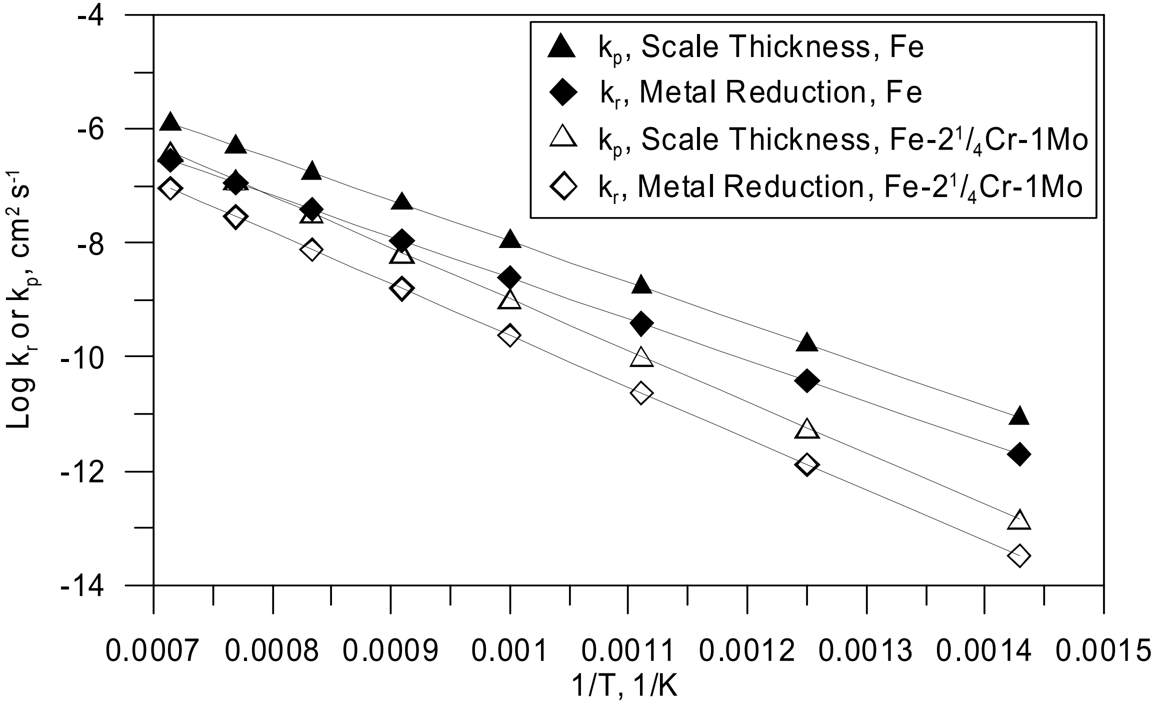
- Study burn patterns on tripropylene car and paper box cars for signs of exposure

# Analysis of Paints: Findings

- No blistering on Rail Car 53
  - Adjacent to Tripropylene tanker car
  - ~50 ft *downhill* from spill source
- Blistering was observed on paper box cars
  - Not caused by the tripropylene spill fire
  - Likely caused by burning materials *within* the car itself
    - (i.e. no damage from external fire exposure)

# ***Materials Analyses***

# Oxidation of Steel Components




$X^2 = k_p t$

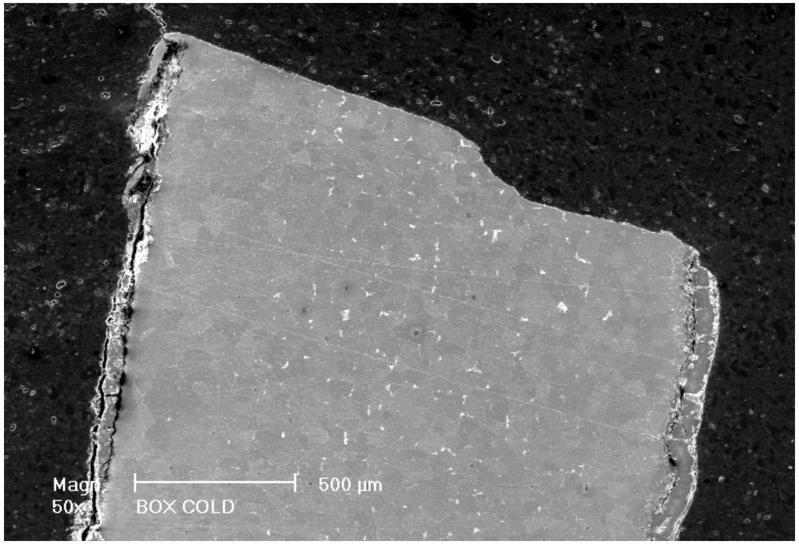
where t is time

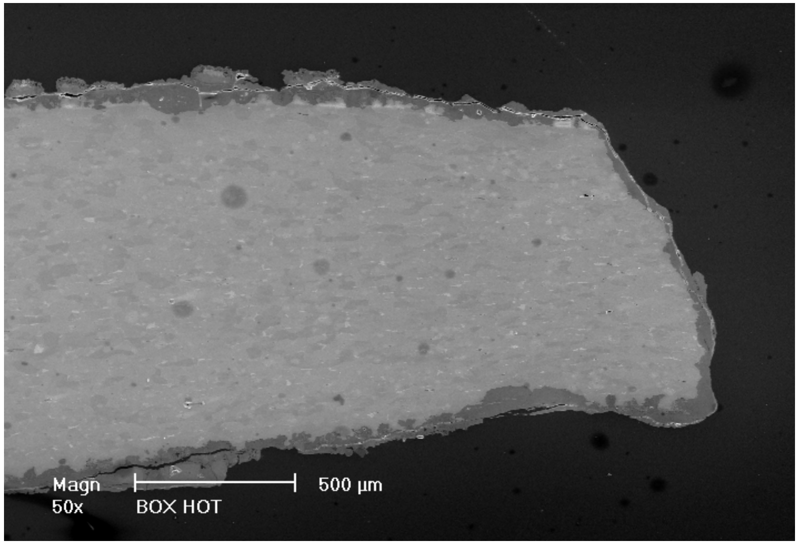
and X is thickness

Rate constants for Fe-2$^1/_4$Cr-1Mo from Simms and Little (1987)

Rate constants for Fe from Kubaschewski and Hopkins (1962)

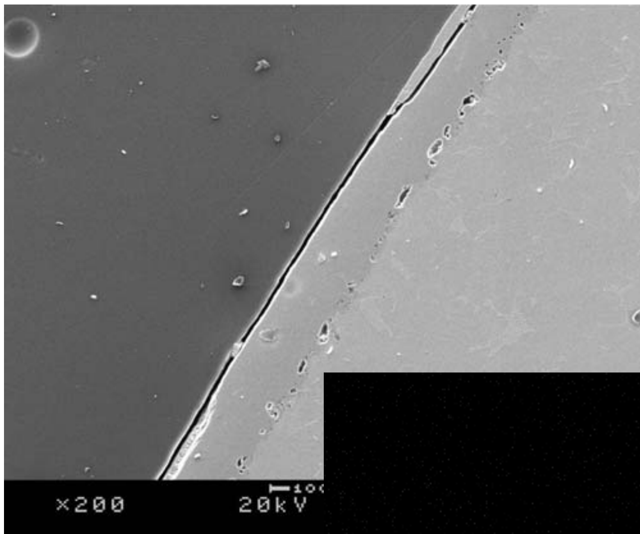
# Analyses of Steel Components



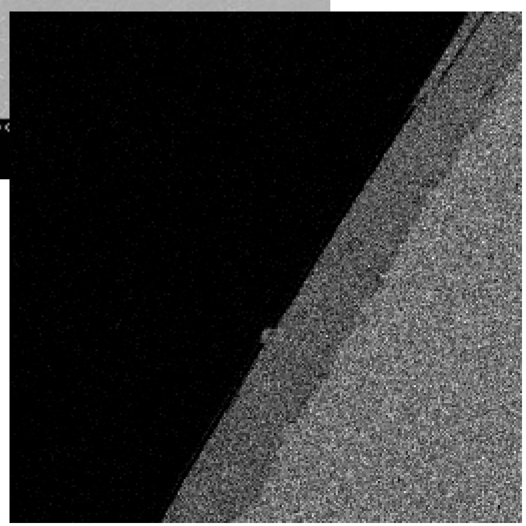




- Sections of Roof of Rail Car 50
- Thickest section: 1,761 micrometers [0.069 in]
- Thinnest section: 829 to 930 micrometers [0.033 to 0.037 in]
- Metal Loss: 148 to 466 micrometers [0.006 to 0.018 in]
  4 hours at 750 to 850 $^{o}$C [1,382 to 1,562 $^{o}$F]
- Secondary Paper Fire

# Analyses of Steel Components (cont.)



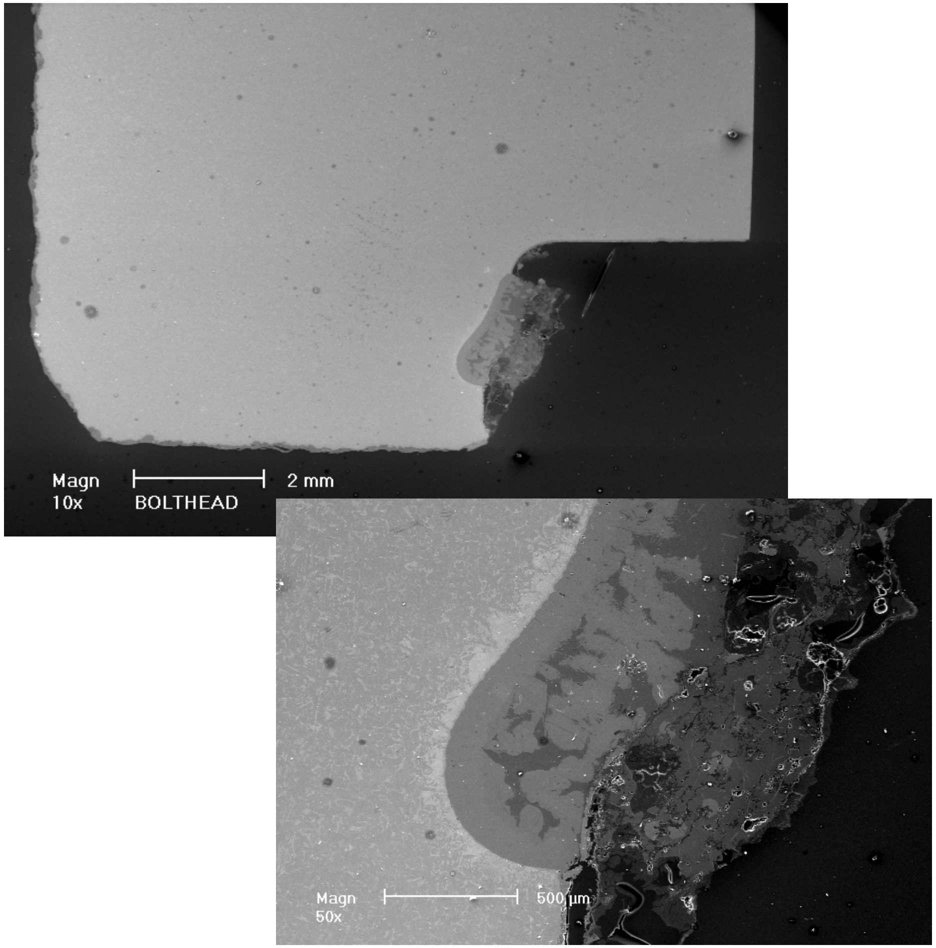

Secondary Electron Image



Iron image

- Oxide layer on steel bolt found on air brake valve of Rail Car 52
- Aluminum Air Brake Valve Cover melted as a result of the fire
- Oxide layer thickness 53 micrometers [0.0021 in] with no evidence of spalling
- Oxide could be expected from an exposure at 627 $^{o}$C [1,160 $^{o}$F] for 4 hours

# Analyses of Steel Components (cont.)

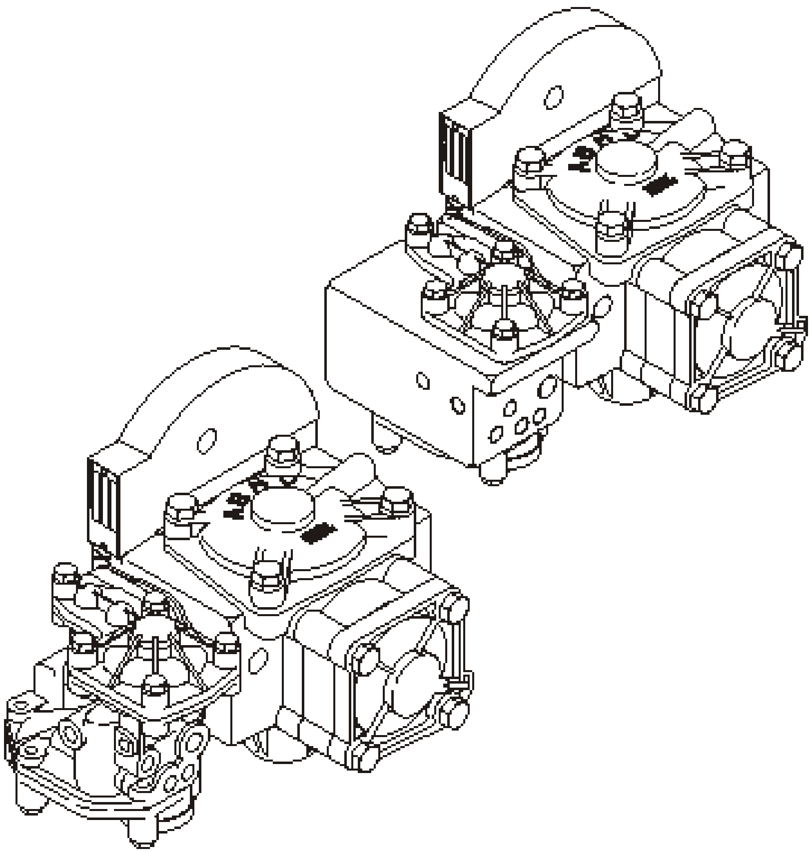



- Small Area of an observed phase on the underside of one ABDX Brake valve

  66Al-4Si-30Fe (atomic percent)
- Composition not likely to have been formed by melting or diffusion

# ***Empirical/Computational Analyses***

# Analysis of Air Brake Valves



- Air brake valves used on rail cars
- Cast iron valve body with aluminum covers
- Aluminum covers located 10 m [33 ft] from fire source melted
- Aluminum melting temperature 600 $^{o}$C [1,112 $^{o}$F]

# Computer Model

- Transient heat transfer model
- Convective and radiative heat transfer

$$\dot{q}'' \bullet F \Delta t = \rho_{Al} \bullet c_{Al} \bullet V \bullet \Delta T_{Al}$$

*and*

$$\dot{q}'' = h_c \left( T_f - T_{Al} \right) + \sigma \varepsilon \left( T_f^4 - T_{Al}^4 \right)$$

# Assumptions

- Lumped Mass
  - Whole mass behaves as one, no partial melting
  - Full volume of aluminum was considered
- Radiative exposure from luminous flames not considered
  - Typically 30% of the total heat release
  - Good assumption for "obstructed targets"

***Both delay estimated melting time***

# Assumptions (cont.)

- No conduction into adjacent steel or other materials
  - Negligible effect since adjacent materials are assumed to be heated during the fire as well

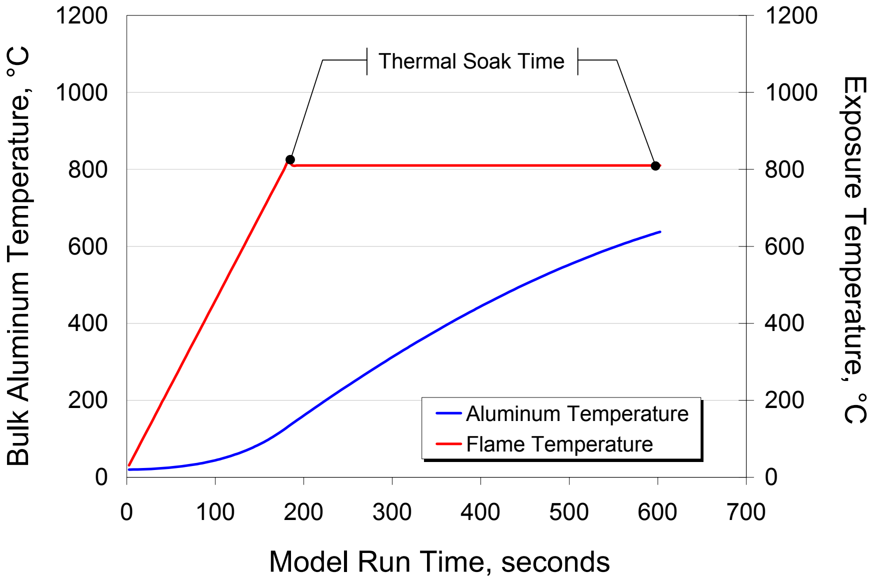
***Could accelerate estimated melting time***

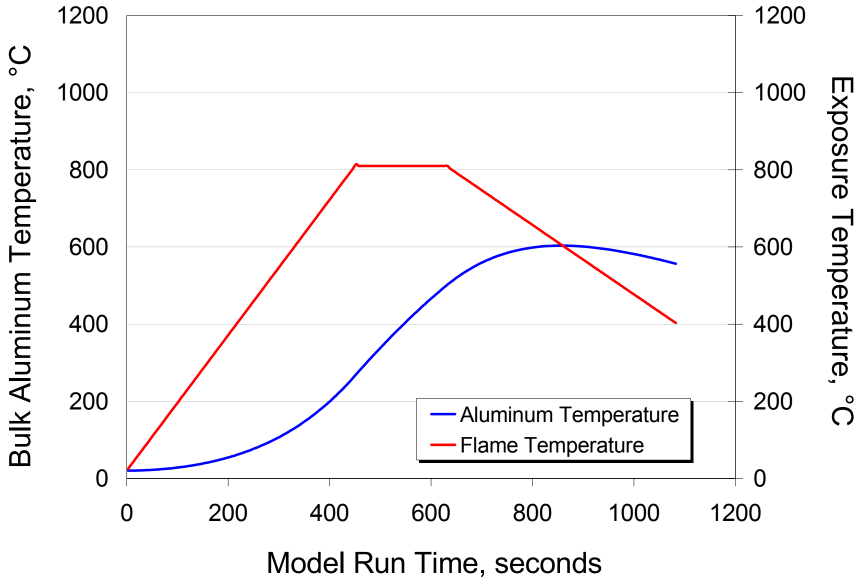
# Assumptions (cont.)

- Convective heat transfer coefficient of 50 kW/mK
  - Applicable when calculating the exposure of steel elements in a hydrocarbon fire

- Varying fire exposure profiles
  - Immediate growth (common for hydrocarbon fires)
  - Ramp-to-plateau
  - Ramp-plateau-decay (most realistic)

# Typical Output



# Empirical Validation

- Irradiation Method
  - ASTM E1354-99, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*
- Heat Flux Chosen was 150 kW/m²
  - ASTM E1529-93, *Standard Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies*

*Melted in a little over 6 min*

# Aluminum Air Brake Valve Cover


Aluminum covers from ABDX valve from Car 52

New aluminum cover for ABDX valve after testing

# Analysis of Air Brake Valves

Air brake valve on Rail Car 52 located approximately 10 m [33 ft] from fire source

Air brake valve on Rail Car 51 located approximately 20 m [66 ft] from fire source

# ***Summary of Analyses***

# Summary of Analyses

- Temperature estimation from aluminum air brake components
  - ≥ 600 $^{o}$C [≥ 1,112 $^{o}$F] 10 m [33 ft] from fire source
  - = 600 $^{o}$C [= 1,112 $^{o}$F] 20 m [66 ft] from fire source
  - < 600 $^{o}$C [< 1,112 $^{o}$F] 40 m [131 ft] from fire source
- Temperature estimation from steel components
  - 750 to 850 $^{o}$C [1,382 to 1,562 $^{o}$F] for 4 hours, roof of Rail Car 50 that also had secondary paper fire
  - 627 $^{o}$C [1,160 $^{o}$F] for 4 hours, bolt on Rail Car 52
- Temperature estimation from rail car paint
  - ≥ 700 $^{o}$C [1,292 $^{o}$F] within 15 m [49 ft] from fuel spill

# Summary of Analyses (cont.)

- Model calculations indicate that the assumed “hot fire” environment in the tunnel would have melted solid cores of aluminum in as little as 300 seconds

- The ease of melting was verified during an empirical test, where melting was observed in 365 sec

# Summary of Analyses (cont.)

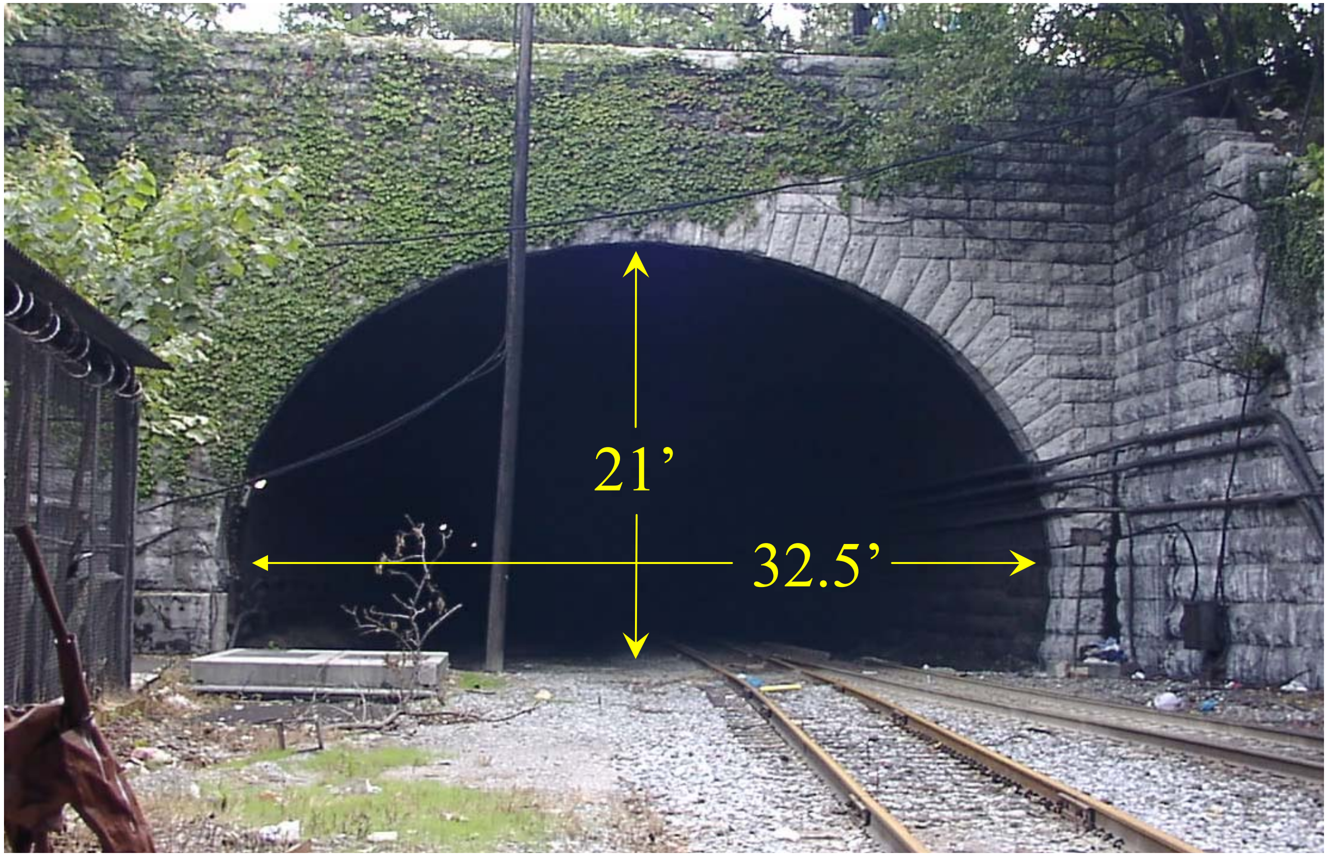
***The fact that aluminum covers remained intact elsewhere in the tunnel indicates lower temperatures were observed only a short distance from the spill source.***

***Questions/Break?***

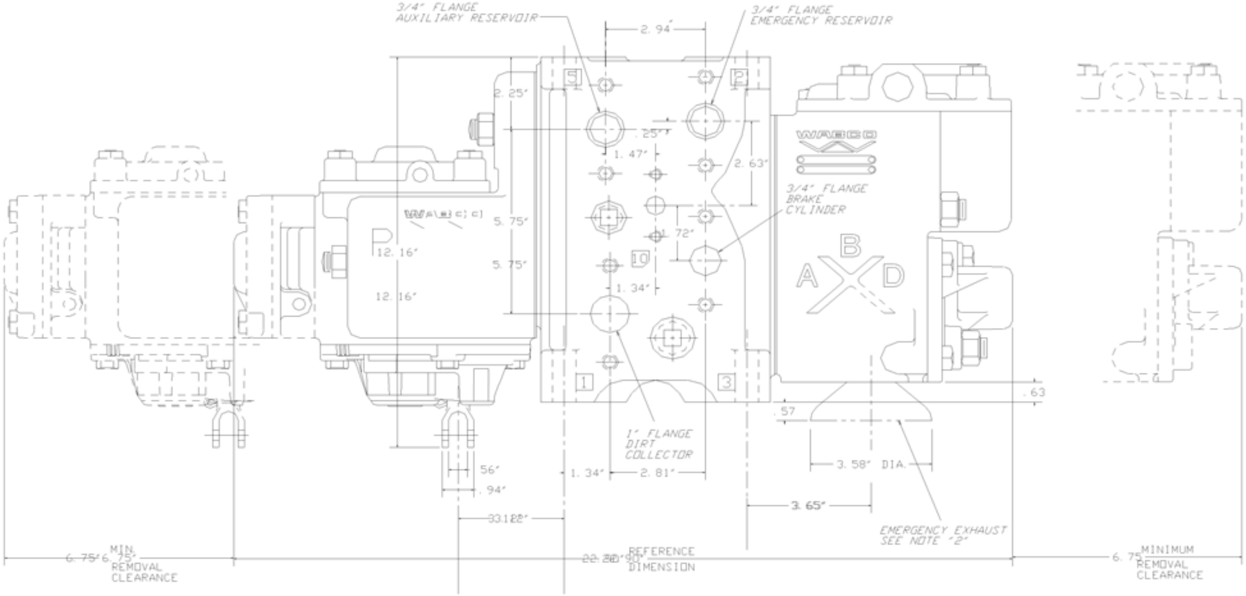
# Backup

# Railcars (cont.)

# Baltimore Tunnel



# Air Brake Schematic



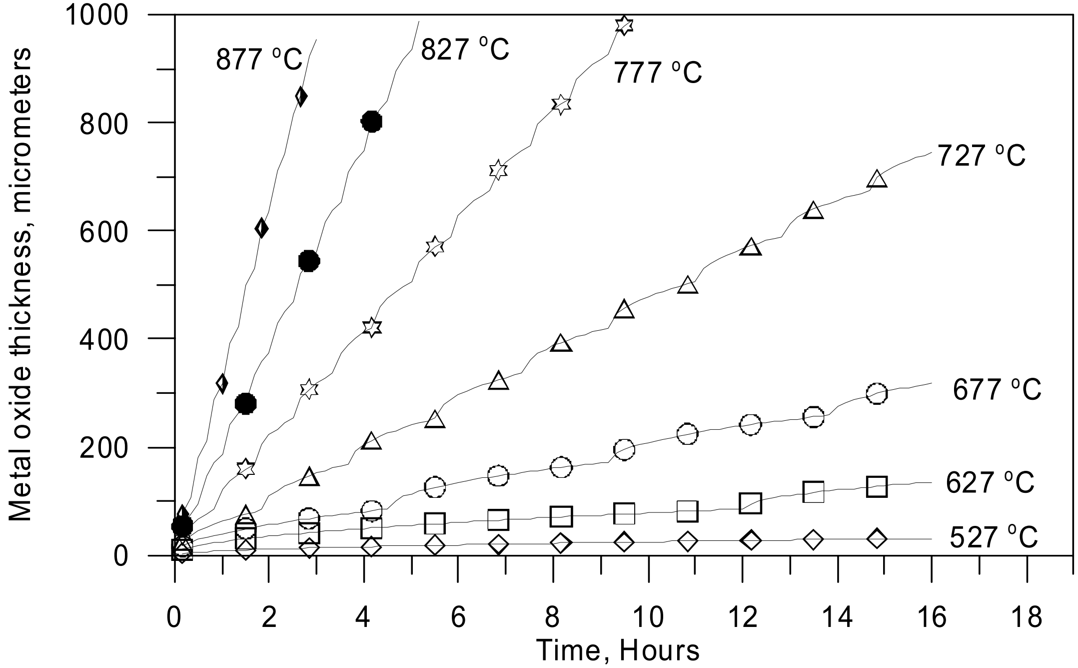
# Tunnel Fire Fuel Sources

- Tripropylene fuel spill ($C_9H_{18}$)
  - Approximately 28,700 gal
  - Spilled from a ~3 in. diameter, irregular hole
- Adjacent cars containing paper products
  - Standard "Box" Cars

# Data Collection

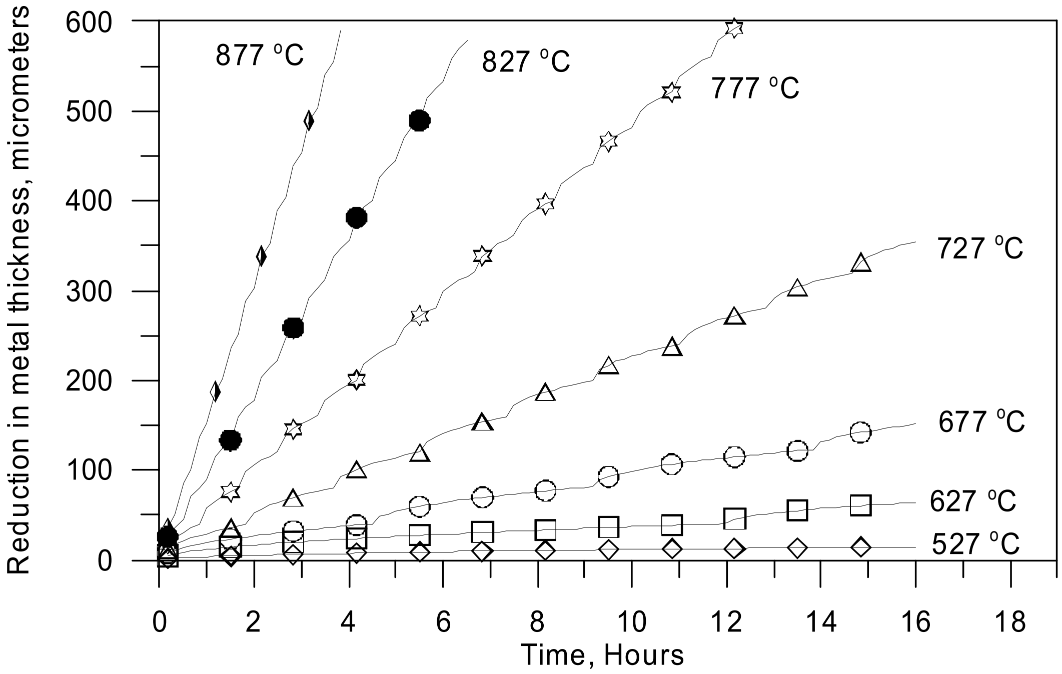
- Anecdotal Evidence
  - Photographs, News reports, etc.
- Site Visit (September 16 and 17 , 2002)
  - Visited Tunnel to better understand the scale
  - Visited two railcar storage sites to make observations and identify samples for collection
  - Visited National Transportation Safety Board to collect additional data on the actual rails from the tunnel

# Oxide Layer Thickness




- Based on oxidation kinetics of iron
- Spalling of oxide assumed when oxide reaches a thickness of 85 micrometers
- Total oxidized layer thickness

# Reduction in Metal Thickness




- Based on oxidation kinetics of iron
- Spalling of oxide assumed when oxide reaches a thickness of 85 micrometers
- Total reduced metal thickness