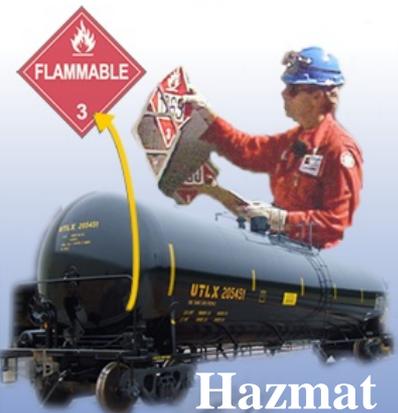




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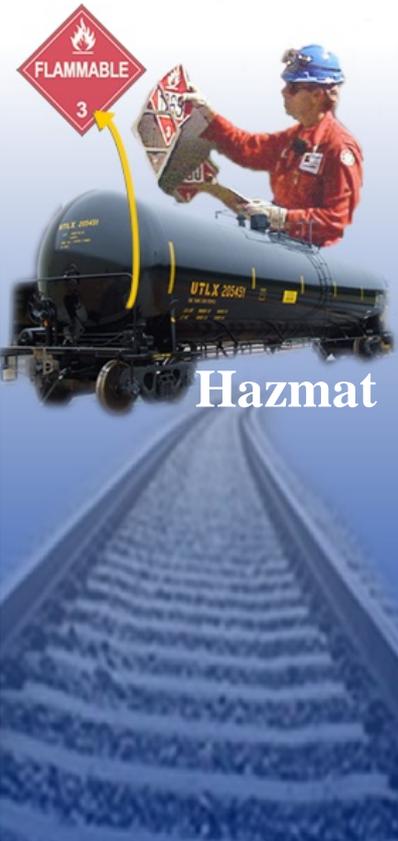
# Federal Railroad Administration Hazmat Seminar Reno, NV

June 25-27, 2013

# Tank Car Forensics



# Railroad Safety

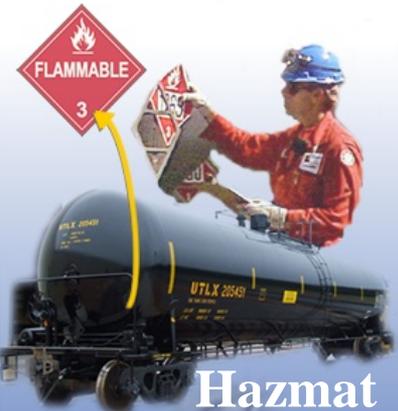


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# Introduction

- Karl Alexy, Staff Director – Hazardous Materials Division, FRA.
- HM Division
  - HQ
    - *Specialists and Engineers*
  - Field
    - *HM Specialists*
    - *Federal/Regional Inspectors*
    - *State Inspectors*
- Support
  - Attorneys
  - Economists
  - Research and Development

# Railroad Safety



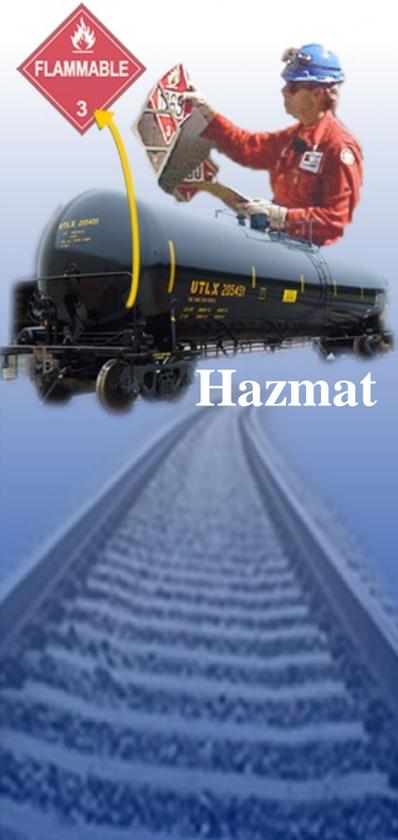
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# Overview

- What is a forensic analysis?
- Application
- Components of analysis
- Methodology
- How is information used?
- Examples
- Translation to NARs



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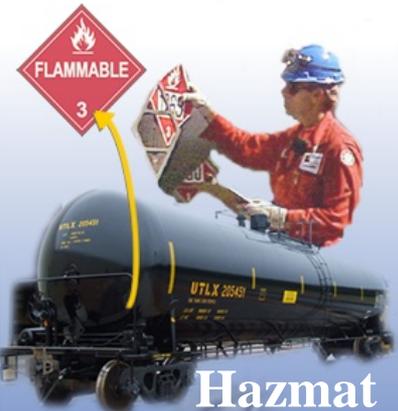


# Tank Car Forensic Analysis

- Application of a broad spectrum of sciences and technologies to investigate and establish facts of interest in relation to tank cars involved in a derailment.
  - What happened
  - When it happened
  - Why and How it happened



# Railroad Safety



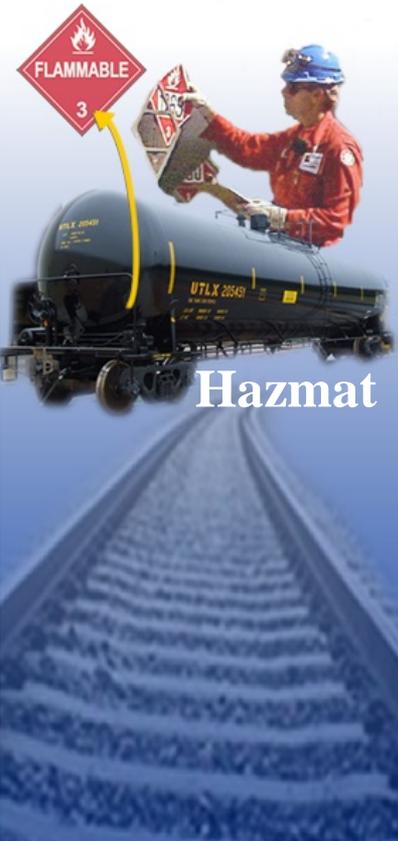
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# Application

- Accidents
  - Derailments
  - Collisions
- Non-Accident
  - Releases
  - Non-Compliance (One Time Movement Approvals)



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# Components of Forensic Analysis

- What failed (and did not fail!)
- Why and How failure occurred
  - Mode – observable consequence of failure
  - Mechanism – physical process which caused failure
- When did failure occur
  - Rupture
  - NARs

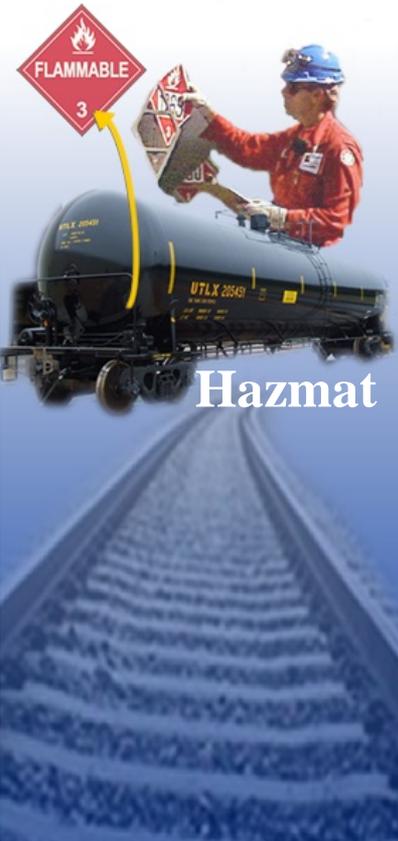


# Methodology

- Preliminary
- On-site
- Information compilation and review
- Reconstruct derailment
- Comparison to similar incidents to identify similar issues or trends



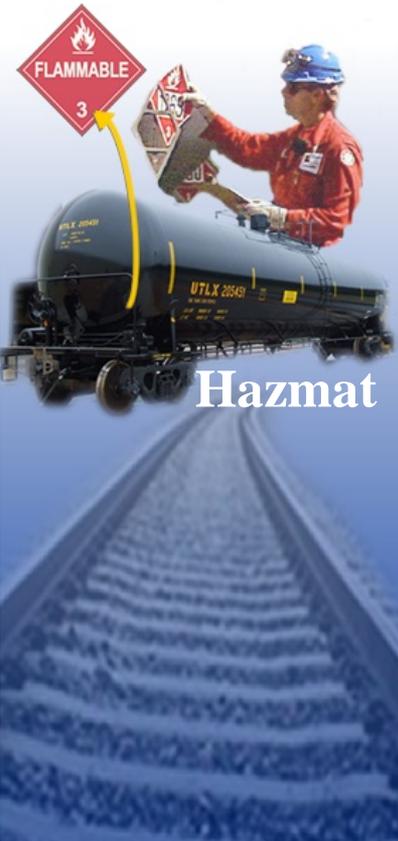
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# Preliminary Data

- Information
  - Consist/location/orientation of HM cars
  - Loaded/Residue/Contents
  - Specification of TCs involved
  - Builder and owner of tank car
  - Inspection records
  - Direction of travel
  - Speed at time of derailment

## Railroad Safety



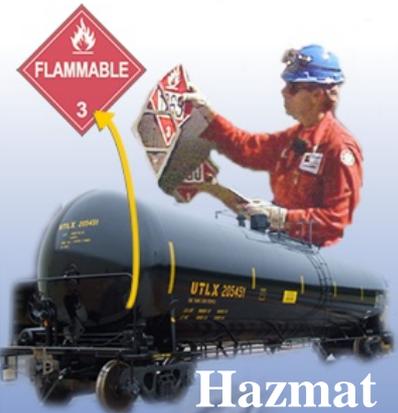
# On-Site Analysis

- Photographs/Video
  - General
    - *Final resting location*
    - *Surrounding area/debris*
    - *Aerial Photographs*
    - *Security cameras/YouTube*
  - Individual cars
    - *Entire tank car*
    - *Service Equipment*
    - *Damage to tank shell and appurtenances*
    - *Classify and quantify damage*
      - » Size, location, type
- Written Documentation





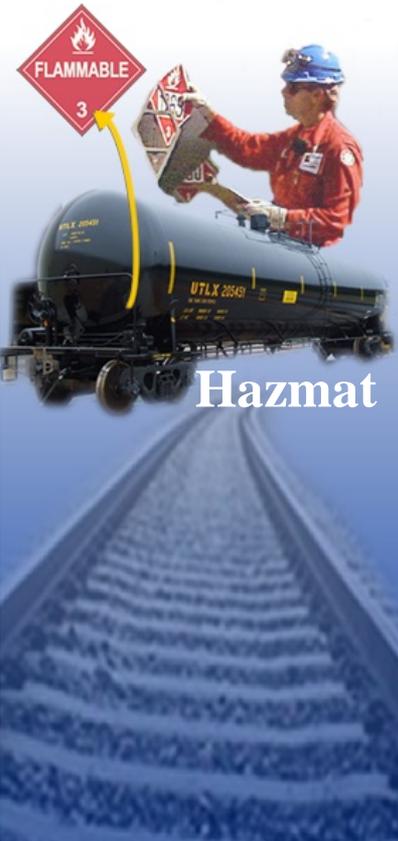
## Railroad Safety



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# Compilation and Review

- Sources
  - Fire Department
  - First Responders
  - Railroads
  - National Transportation Safety Board
  - FRA
- Media
  - Video
  - Photographs
  - Interviews

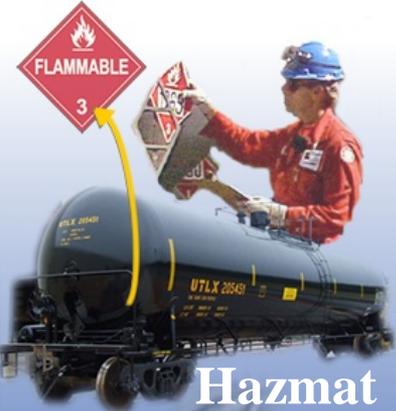


# Comparison to similar accidents

- Summarize accidents
  - Speed at derailment
  - Number of cars
  - Damage to cars
  - Quantity released
  - Location of first derailed car
  - Analysis of components
- Examples on following slides



# Railroad Safety

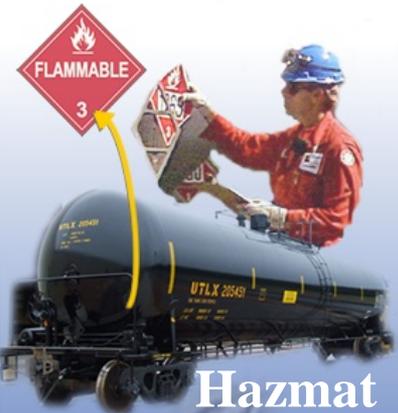


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# Summary of Incidents

Incident	Date	# Cars derailed	Speed at derailment	Unit train	Product Loss (gal)	Cause of Derailment
Plevna, MT	8/12	17	25	No	245,336	Undetermined
Columbus, OH	7/12	3	23	No	53,347	NTSB Investigation
Tiskilwa, IL	10/11	10	34	No	143,534	NTSB Investigation
Arcadia, OH	2/11	31	46	Yes	834,840	Rail
Rockford, IL	6/09	19	34	No	232,963	Washout/Rail
Painesville, OH	10/07	6	48	No	76,153	Rail
New Brighton, PA	10/6	23	37	Yes	485,278	Rail

# Railroad Safety



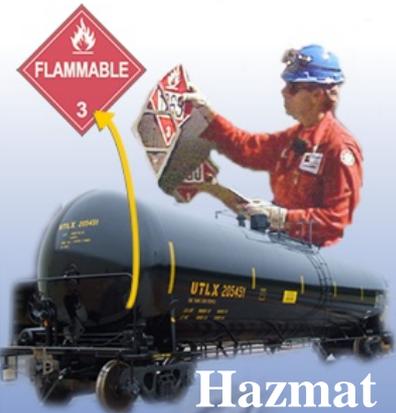
Hazmat

# Speed at derailment

Incident	Speed at derailment	# of cars derailed
Plevna, MT	25	18
Columbus, OH	23	3 TCs , 17 overall
Tiskilwa, IL	34	10 TCs, 19 overall
Arcadia, OH	46	31
Rockford, IL	24	19
Painesville, OH	48	6 TCs, 28 overall
New Brighton, PA	37	23



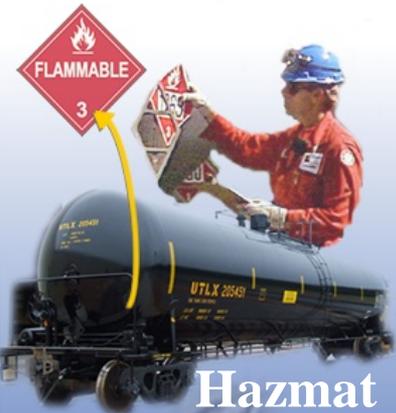
# Railroad Safety



# Location of first derailed

Incident	Location in train of first car derailed
Plevna, MT	19 (106 car train)
Columbus, OH	3 (98 car train)
Tiskilwa, IL	2 (131 car train)
Arcadia, IL	2 (64 car train)
Rockford, IL	57 (114 car train)
Painesville, OH	31 (112 car train)
New Brighton, PA	23 (86 car train)

# Railroad Safety



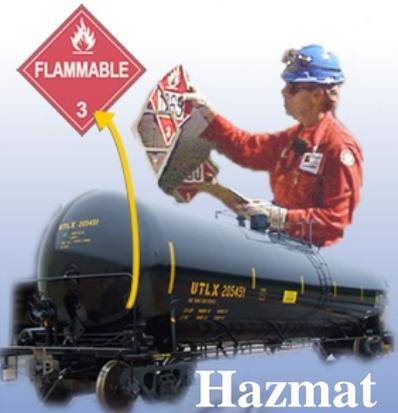
# Location of first derailed of incidents since 2008

Location of first car derailed



- All trains
  - 40% of all derailments occur in the first 5 railcars (including locomotives)
  - 50% in the first 10 railcars,
  - 75% within the first 35 railcars.
- Freight trains
  - 21% of derailments occur in the first 5 railcars
  - 50% in the first 25 railcars
  - 75% in the first 55 railcars.

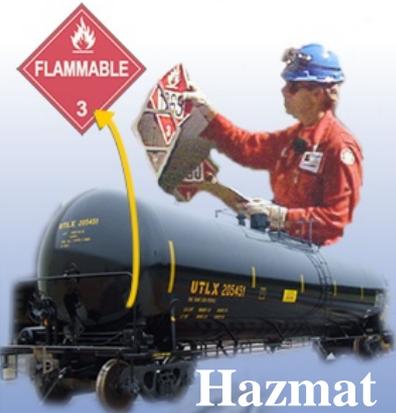
# Railroad Safety



# Summary of Damage

Damage	Number of Incidents	Occasions of only damage
Top Fittings	34	16
Bottom Outlet Valve	5	1
Thermal Tear	14	13
Energetic Rupture	5	5
Top Head Puncture	14	6
Bottom Head Puncture	27	19
Shell Puncture	42	12
Total Volume Lost	2,161,807 gallons	-----

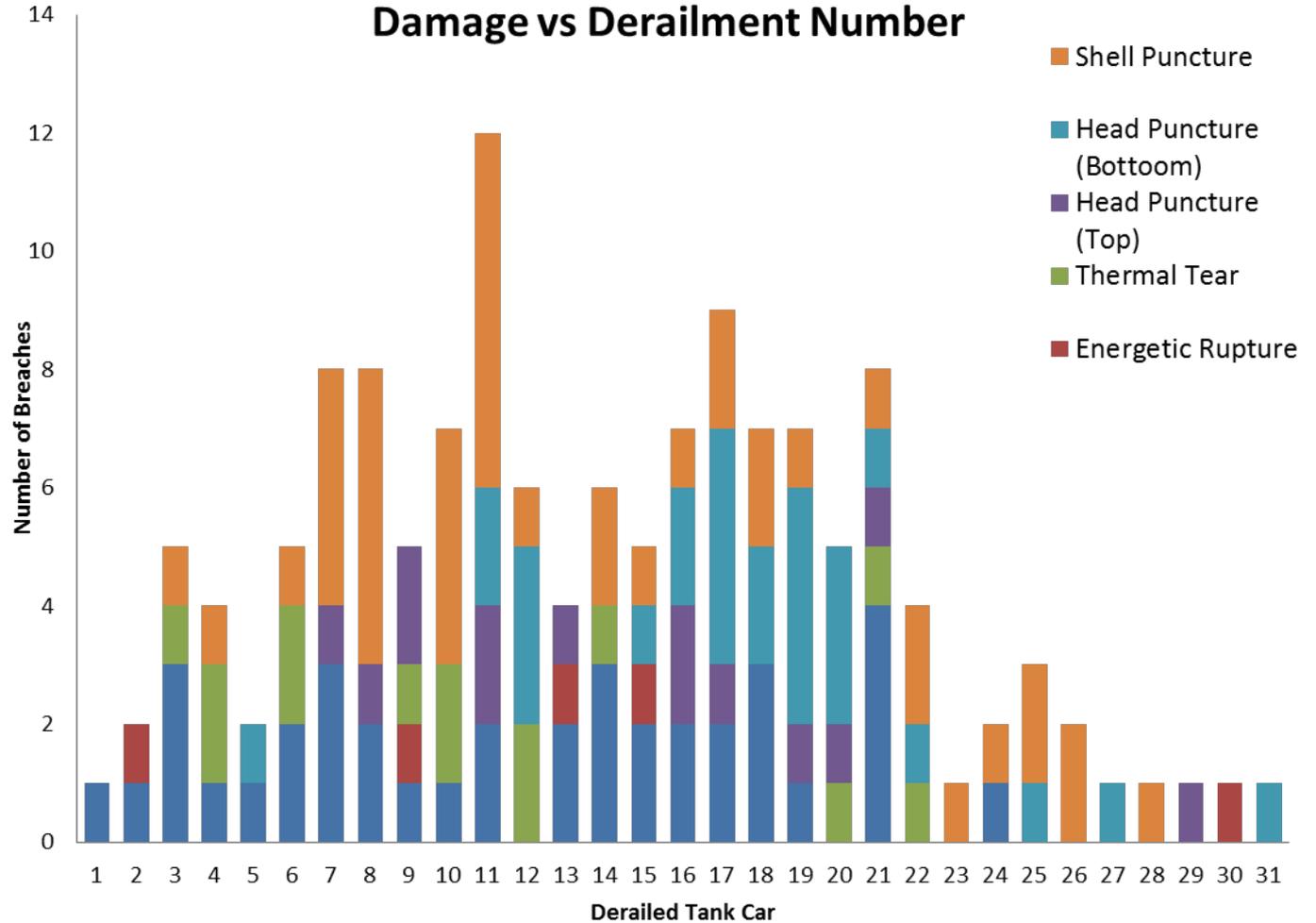
# Railroad Safety



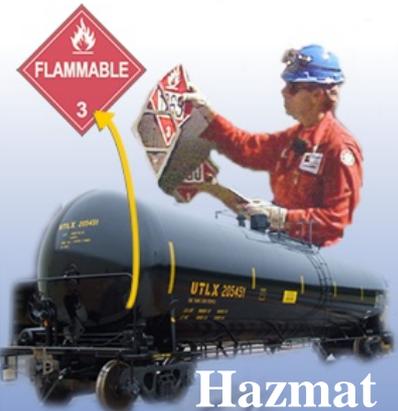
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# Damage to cars

Damage vs Derailment Number



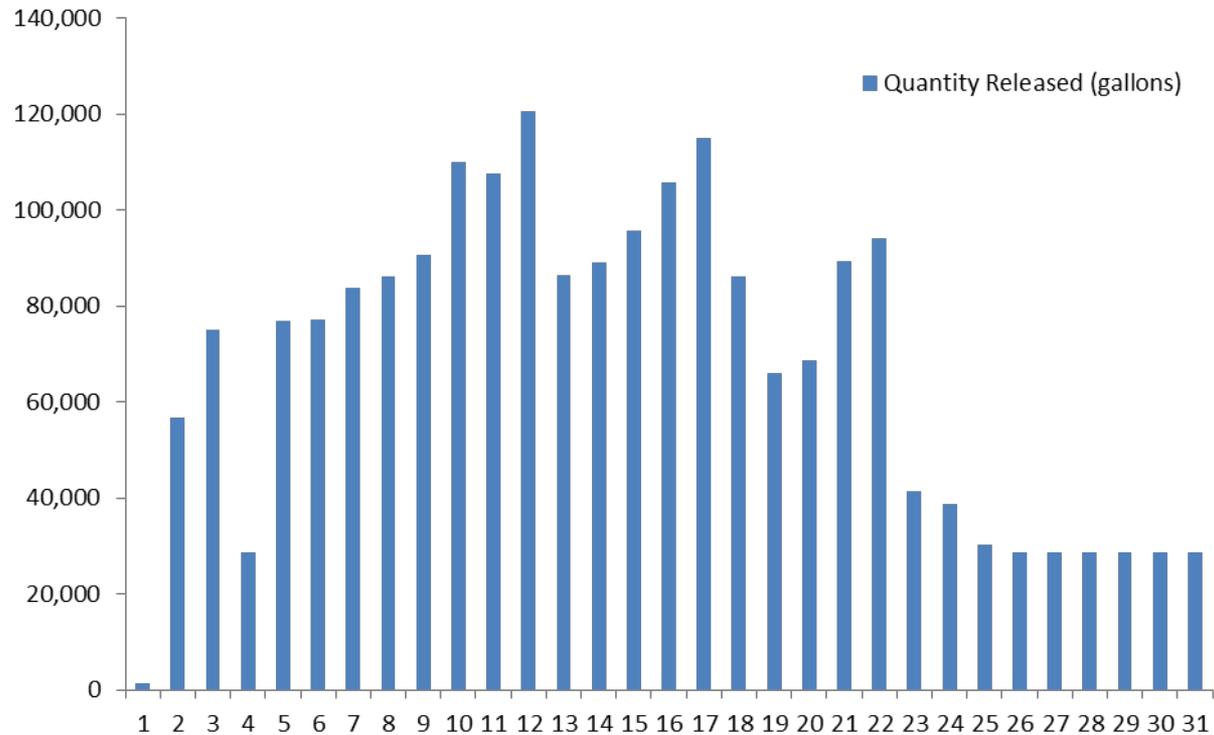
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# Quantity of Material Lost

Quantity released vs position in derailment



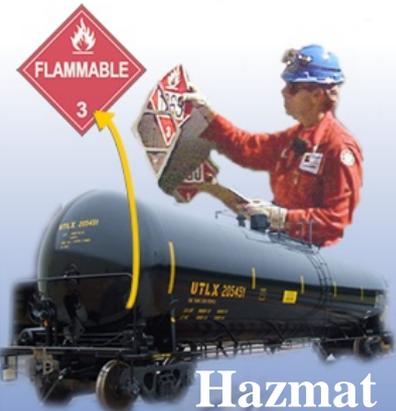


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# Use of Results of Forensic Analysis

- Advanced Tank Car Collaborative Research Project
  - Modeling (AFFTAC)
  - Statistical Analysis (CPR)
- Identify vulnerabilities and strengths of designs
- Inform Research
- Safety in reclamation efforts (AAR)
- **How can we protect against future occurrences without increasing risk?**

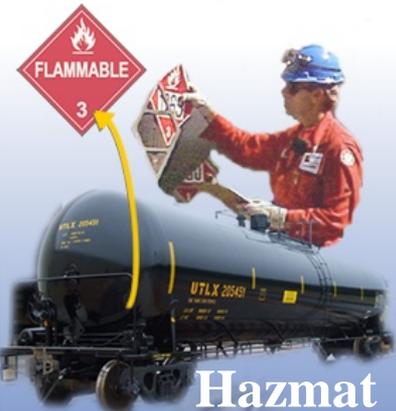


# Case Studies

- Columbus, OH
  - Derailment Reconstruction
- Cherry Valley, Arcadia, Tiskilwa
  - Standards/Requirements issues
- Arcadia, Plevna, Tiskilwa, New Brighton, Columbus
  - Thermal tears and BLEVEs?
- Rosedale, MD
  - Determination of train dynamics



# Railroad Safety



# Columbus, OH

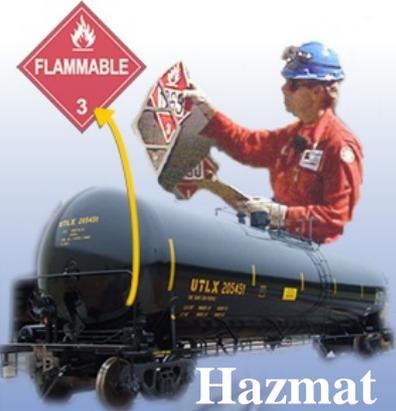


## Statistics

7/11/12	3 tank cars	23 mph	Not a unit train	53,347 gallons
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# Railroad Safety



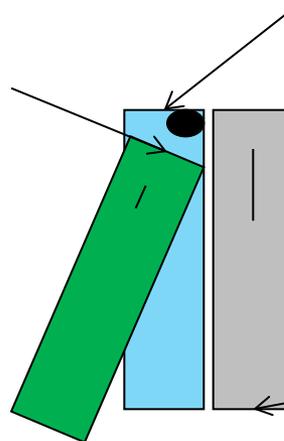
Hazmat

# Columbus, OH Post-Derailment



NATX364118 B-end  
Heat Induced Tear

NATX364083 B-end  
(Puncture in B-end)



NATX364017 A-end  
Heat Induced Tear



# Railroad Safety



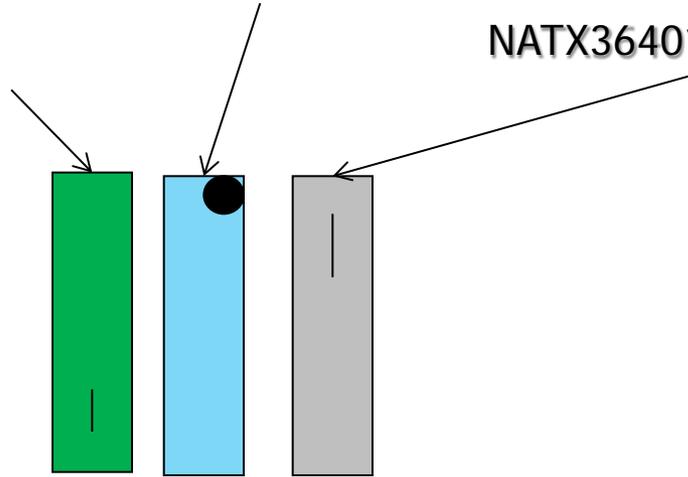
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# Columbus, OH Staging Area

NATX364083 B-end

NATX364017 A-end

NATX364118 A-end

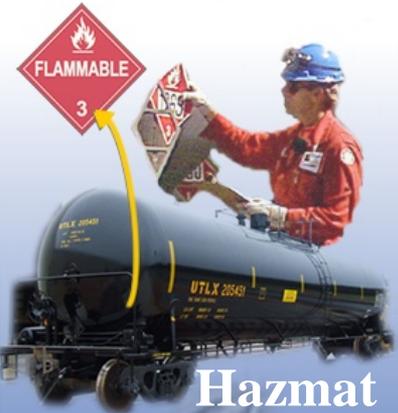


- Inspection preformed at staging area
- No indication of post-derailment orientation
- Difficult to determine puncture scenario



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# Columbus, OH NATX364118

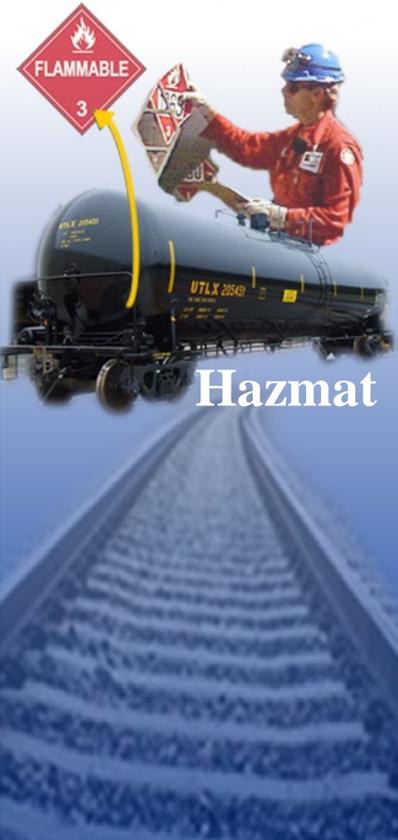


- Vapor space during pool fire
- Race between pressure increase and decreasing steel strength.
- PRV below liquid line



- 3' tear, B-end 11 o'clock
- In longitudinal weld

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# Columbus, OH NATX364017



- B-end draft gear
- Broken coupler



15' tear, B-end 3 o'clock



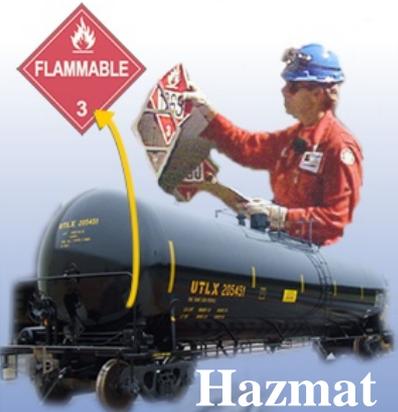
A-end inboard draft sill



ACF300 Underframe



# Railroad Safety



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# Columbus, OH NATX364017

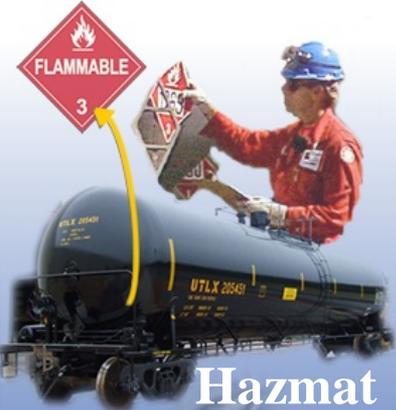
- Vapor space
- PRV below liquid line





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# Columbus, OH NATX364083

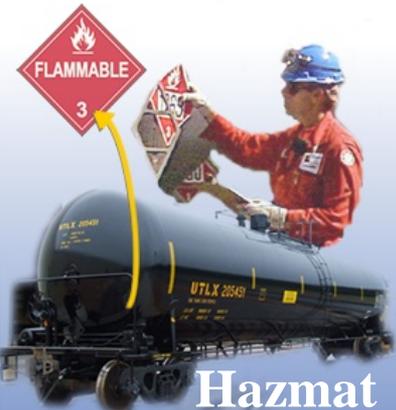


- Puncture B-end head and ring 1
- Gouge above hand brake pads



- Broken B-end shelf coupler
- Suggests significant upper motion of connected coupler
- Initially thought B-end coupler of 017 punctured 083

# Railroad Safety

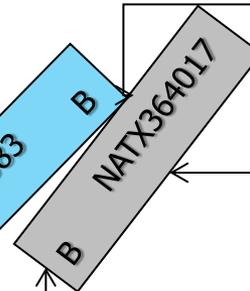
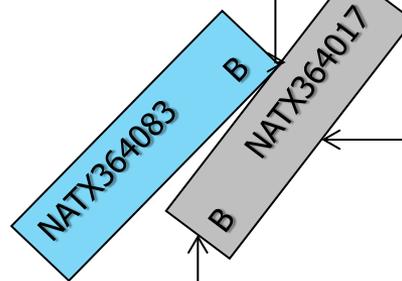
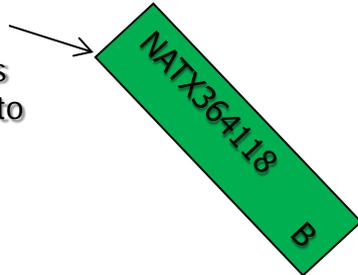


# Columbus, OH

At time of derailment – arrows indicate initial forces



Trailing cars  
continuing to  
push along  
tangent of  
track

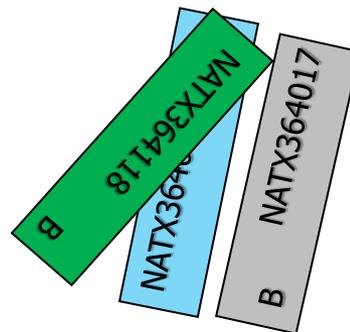


Head of 083 slides into  
the inboard termination  
of the draft sill

017 rotates 90°  
clockwise exposing  
the draft sill to 083

Broken coupler

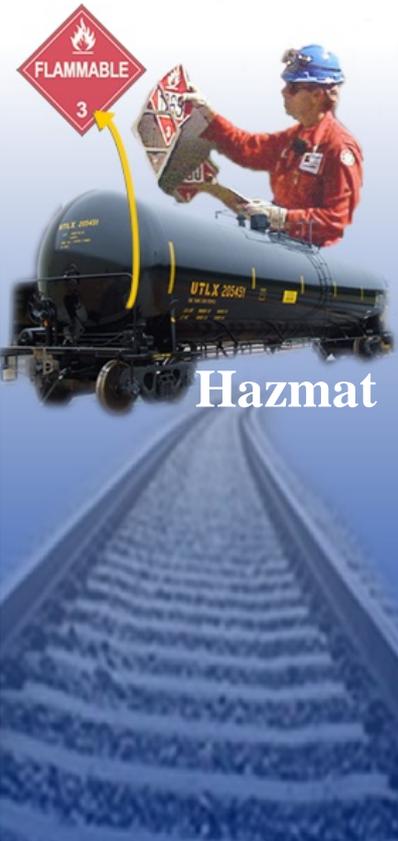
Less than 1 minute  
after derailment a fire  
was started. A steady  
pool fire after two  
minutes



Approximately 36  
minutes after derailment  
there was an explosion



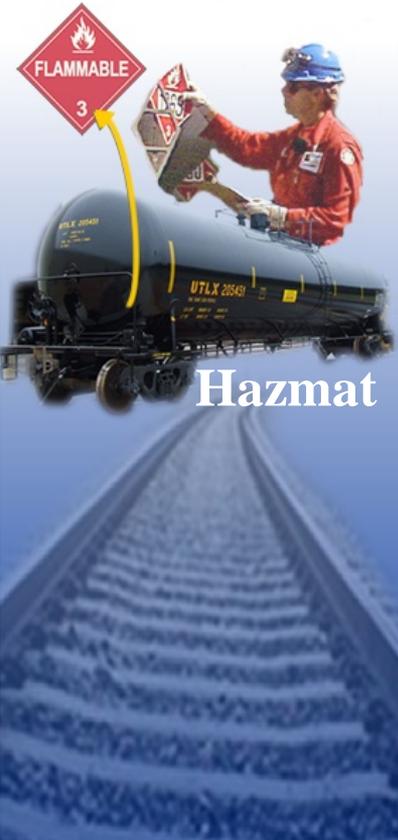
## Railroad Safety



# Columbus, OH

## Safety Concerns

- Puncture (center of shell)
  - 3"x3" rigid punch - 180,000 ft-lbs (TC-128)
  - 6"x6" rigid punch – 360,000 ft-lbs (TC-128)
  - 9"x9" rigid punch – 500,000 ft-bls (TC-128)
  - 12"x12" punch – 580,000 ft-lbs (TC-128)
- Explosion
  - AFFTAC indicates tank cars should last nearly 100 minutes
  - Thermal protection
    - *Protect car from long duration fire?*
  - Flow capacity of PRV (liquid flow)
    - *Empty car prior to failure of shell, no explosion (HM-144)*



# Sill Issues

- Similar failures identified in three derailments
  - Cherry Valley, IL
  - Arcadia, OH
  - Tiskilwa, IL
- Sill Designed to meet all AAR standards
- Subject of NTSB Recommendation
  - Proximity of transverse welds
- Ongoing FRA Investigation



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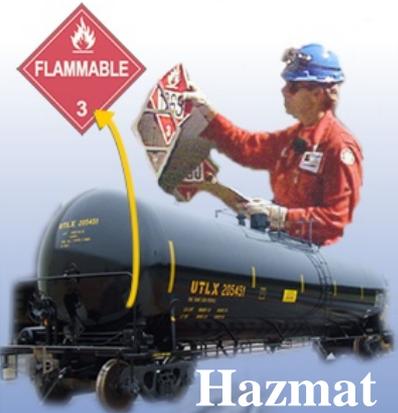
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# Cherry Valley



# Railroad Safety



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# Arcadia, OH



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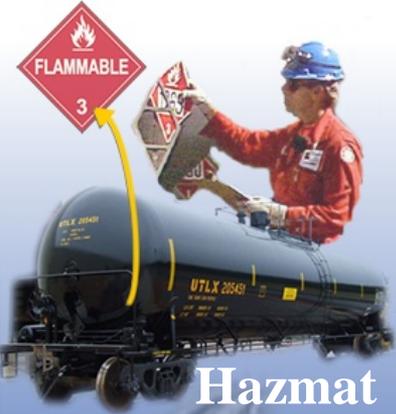


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# Tiskilwa, IL

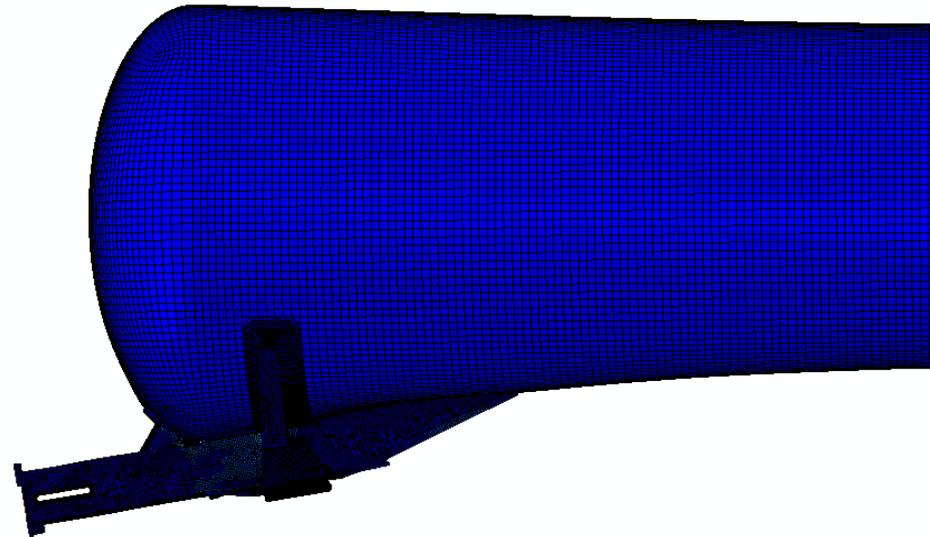
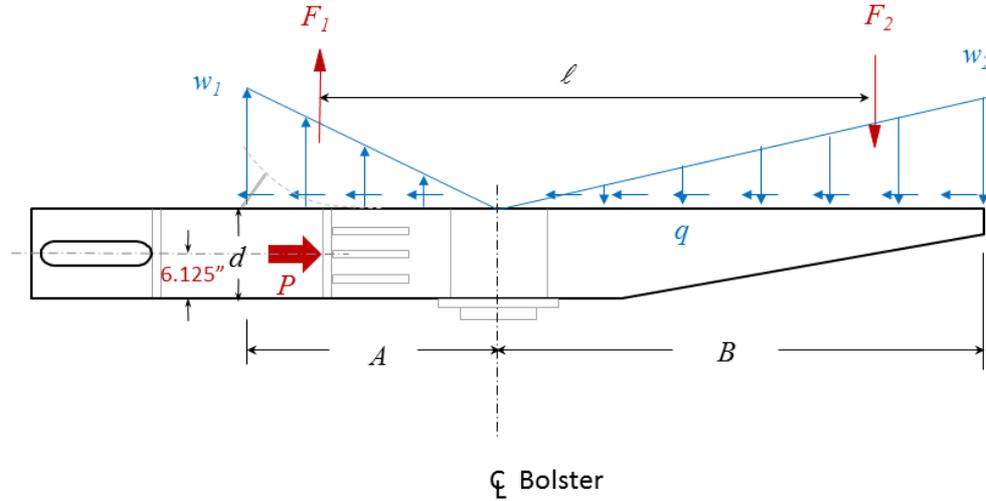


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# Analysis of Sill Behavior





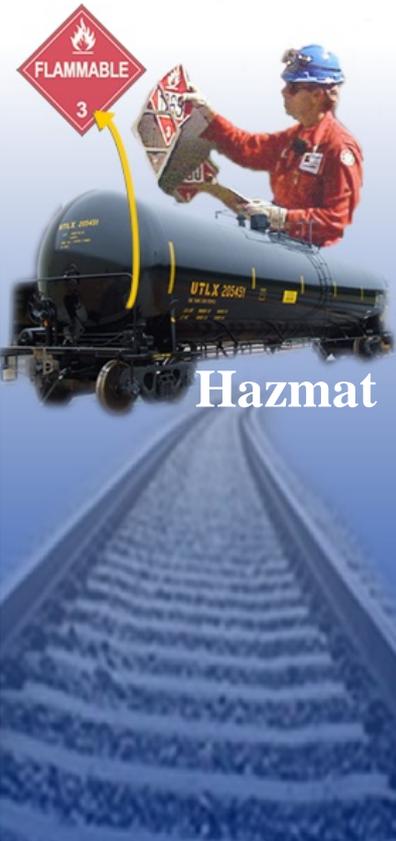
## Railroad Safety



# FRA Investigation

- AAR M-1001 and M-1002
- 85% throat rule
- Sills designed in accordance with standards
- Local vs global
- Qualify Assurance
  - Design vs As-Built Weld Sizes
  - Weld procedures

# Railroad Safety



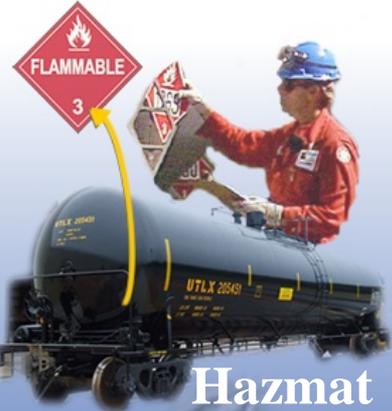
# Explosions

- Large explosions resulting in classic tank destruction (BLEVEs) occurred in two derailments
  - Arcadia (3)
  - Plevna (2)
- Large explosion with limited tank damage (thermal tears) occurred in five derailments
  - Arcadia (2)
  - Tiskilwa (3)
  - Columbus (2)
  - Plevna (6)
  - New Brighton (1)
- Birk (1995) found that in cases where a fissure (tear) are similar in length to the tank diameter the resulting release and fireball was virtually identical to a BLEVE.



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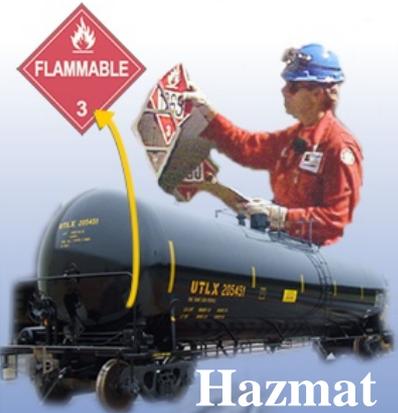


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# Thermal Tear



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# Explosions





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# Arcadia, OH





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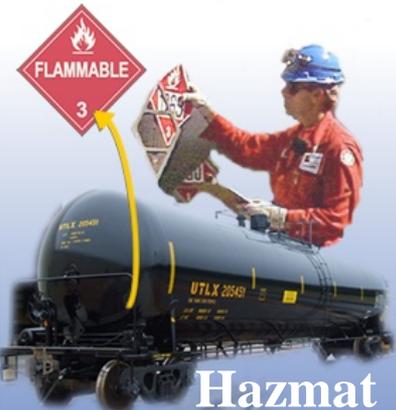


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# Plevna, MT



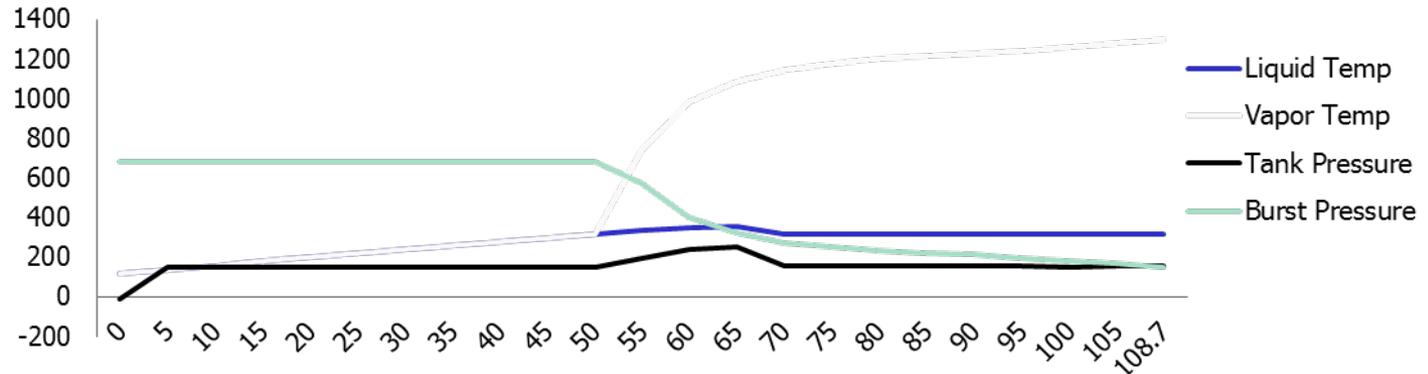
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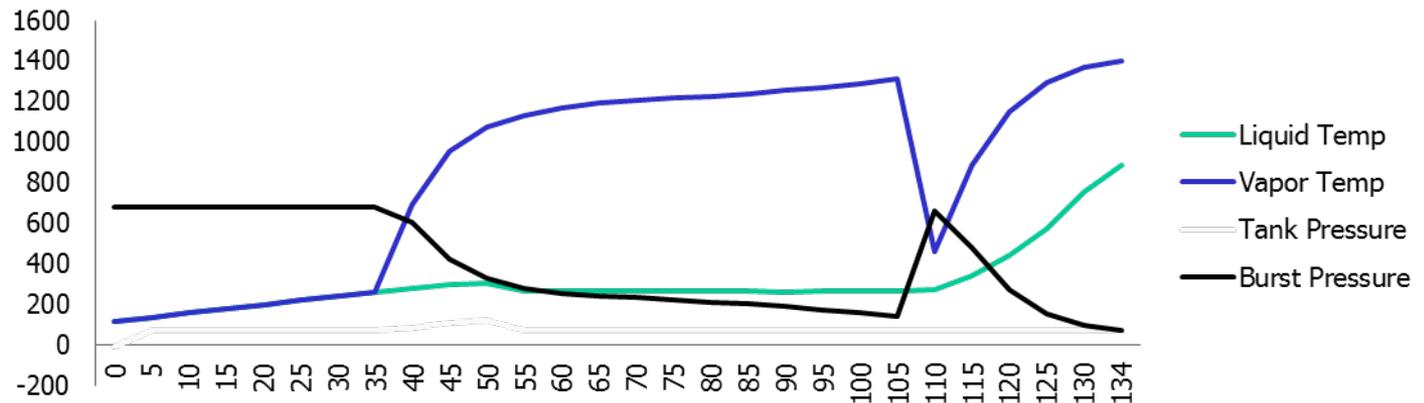
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# Model Validation

## AFFTAC Simulation (165 psig STD)



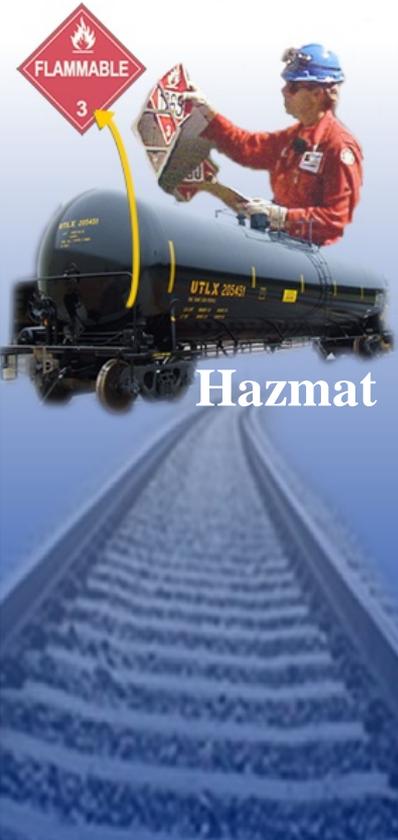
## AFFTAC Simulation (75 psig STD)



- Video from Columbus – rupture at ~34 min
- Anecdotally, all ruptures within one hour.



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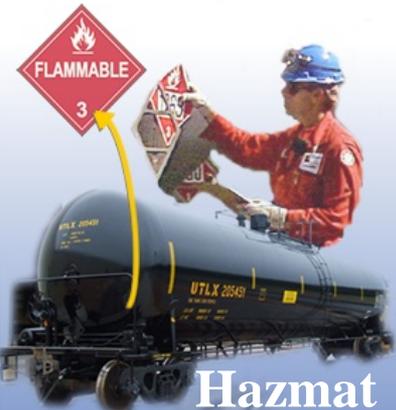


# Rosedale, MD

- Train, 2 locomotives and 45 rail cars, collided with a loaded dump truck at a private grade crossing
- 15 cars derailed, 9 empty and 6 loaded cars
- Estimated speed of 48 mph when it struck the dump truck.
- Covered hopper car was breached allowing its contents, Sodium chlorate, to mix with Terephthalic acid from an adjacent covered hopper car.
- Mixture caught fire and exploded, damaging two metal warehouse buildings and shattering windows in a three block area.
- An initial evacuation was ordered forcing the closure of several major interstate highways.



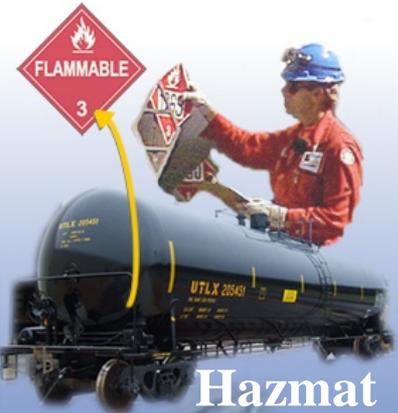
# Railroad Safety



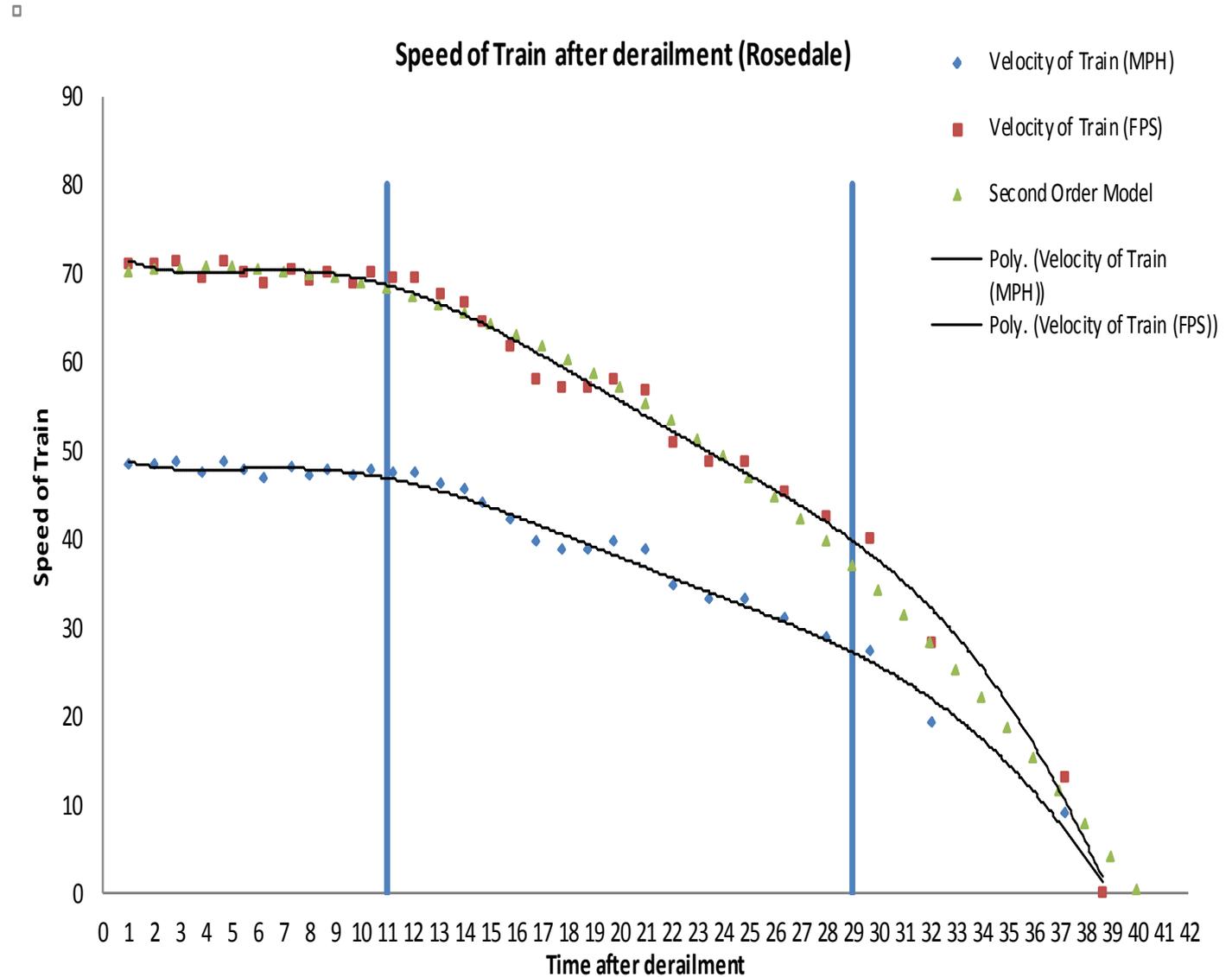
# Rosedale, MD

Number in consist	Car number	Loaded/Empty/Type
1	CSXT135017	Empty/A
2	TTPX82350	Empty/F
3	EEC1095	Empty/A
4	CSXT130476	Empty/A
5	CSXT141318	Empty/A
6	TTPX811227	Empty/F
7	UNPX128076 (Sodium chlorate)	Loaded/CH
8	GATX61416 (Fluorosilicic Acid)	Empty/T
9	ACFX67747 (Terephthalic Acid)	Loaded/CH
10	ACFX66451 (Terephthalic Acid)	Loaded/CH
11	ACFX68042 (Terephthalic Acid)	Loaded/CH
12	ACFX67966 (Terephthalic Acid)	Loaded/CH
13	NOKL725103	Empty/F
14	AEX12778	Empty/CH
15	HOKX111773	Loaded/T
16	ATW140155	Loaded/A

# Railroad Safety



# Rosedale, MD





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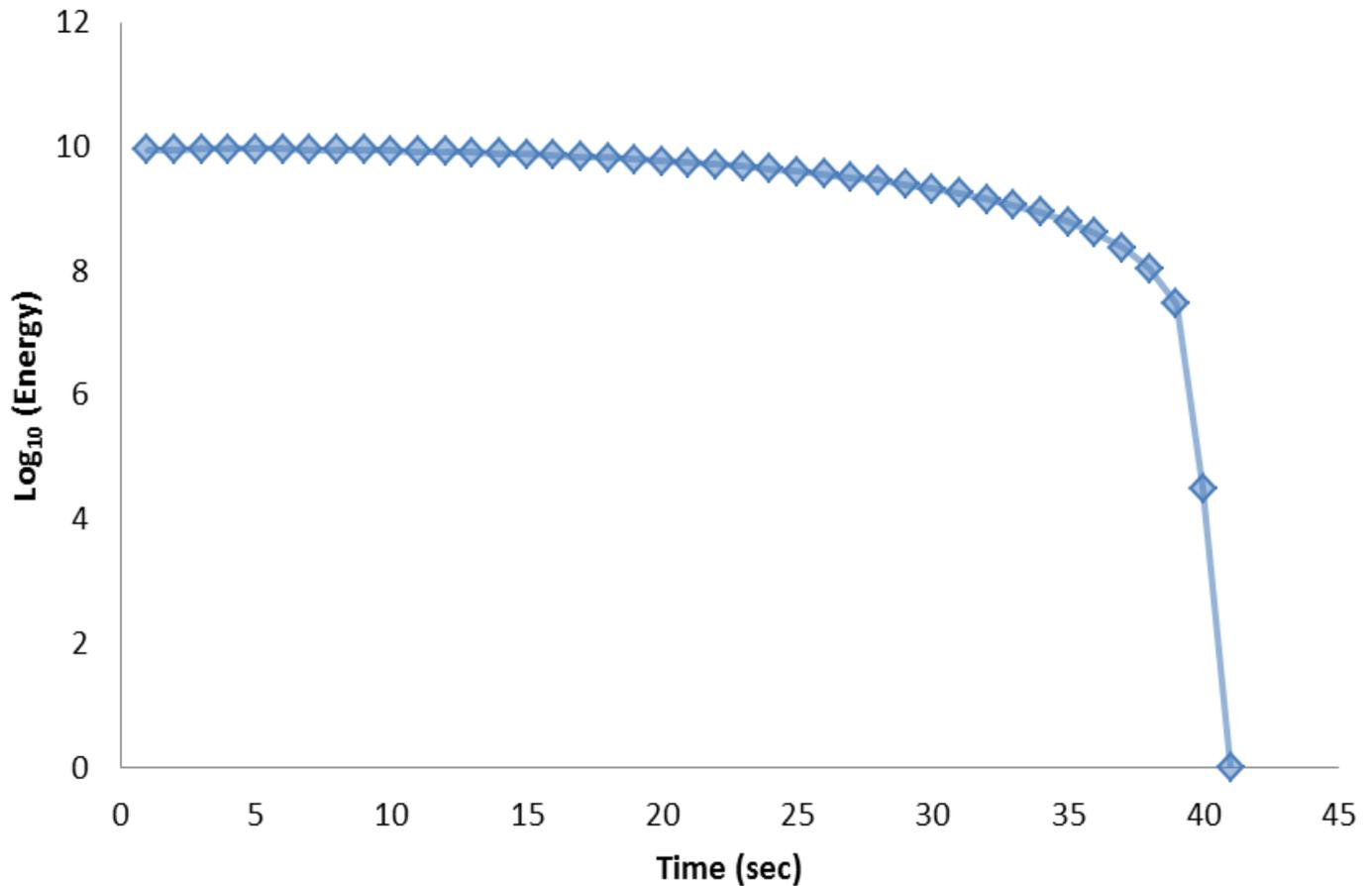
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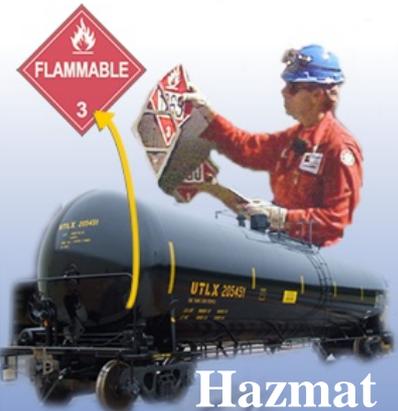


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# Rosedale, MD

Log of the kinetic energy of train behind ATW140155  
(last car derailed)

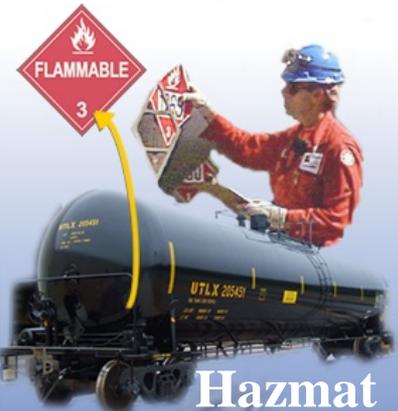




## Rosedale, MD

- Train placement - Regulations do not prohibit placing cars containing an oxidizer and a non-regulated combustible solid.
- Empty railcars as buffers between cars containing incompatible materials..
- Performance standards specific to hopper cars.
- Rail cars containing hazardous material positioned at the front of a train consist are more likely to be involved in the wreckage than those at the rear of the consist.

# Railroad Safety

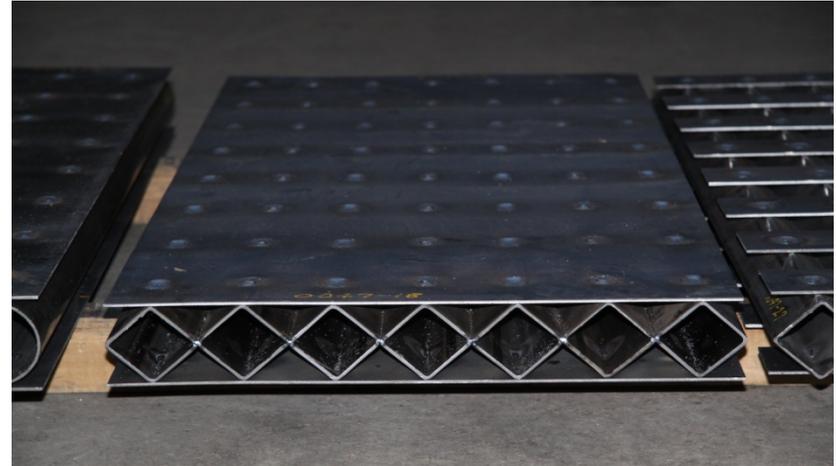


Hazmat

# Research

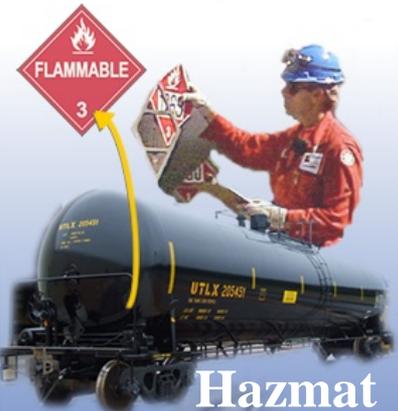
## FRA Research

- Tank Car survivability
  - ATCCRP
  - Sandwich panels
  - Puncture scenarios
  - Puncture tests
- Roll-over protection
- Liquid flow through relief valves (AFFTAC)
- Environmental Factors related to PRV behavior
- PRV stem failures
- Risk analysis
- Tank car operating environment/Coupling speed
  - Informed by previous TC research





## Railroad Safety



# Translation to NARs

- Root Cause Analysis
  - A detailed statement of the problem;
  - Factor(s) contributing to the problem, including photographs and drawings
  - The cause of the factor(s), if a cause can be determined;
  - Steps taken to prevent future occurrence.
- HM-216B
  - Qualification Procedures
  - Inspection/Test methods, frequency, acceptance criteria



US Department of  
Transportation  
Federal Railroad  
Administration

# Railroad Safety



Hazmat

## Questions?



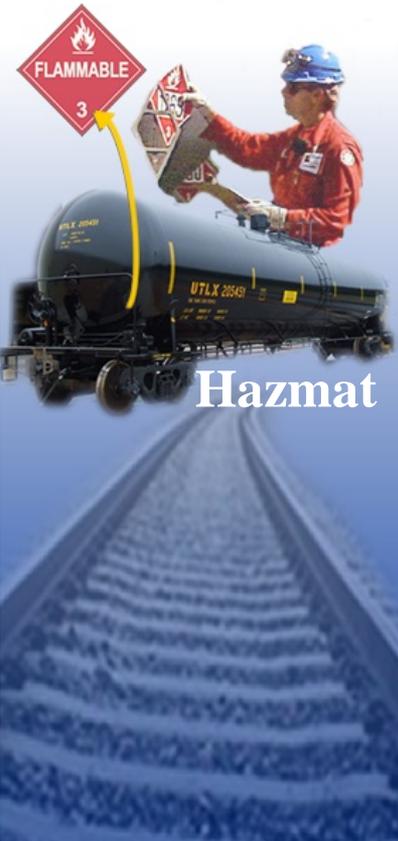
## Still have Question?

- Contact me at 202.493.6245
- E-mail me at [karl.alex@dot.gov](mailto:karl.alex@dot.gov)
- E-mail hmassist at [hmassist@dot.gov](mailto:hmassist@dot.gov)

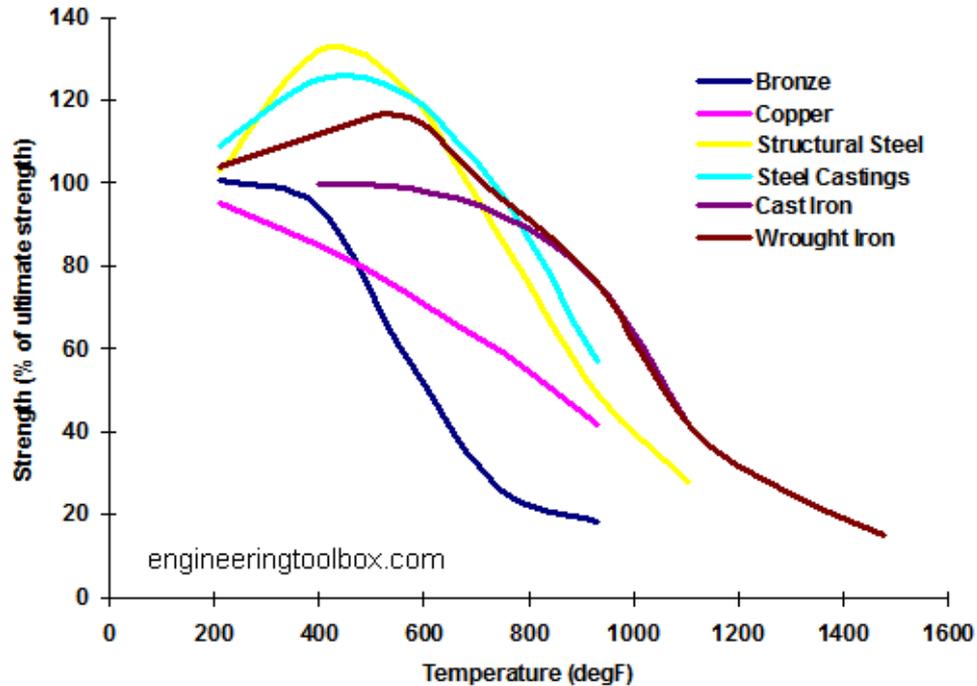
# Analysis of ruptures

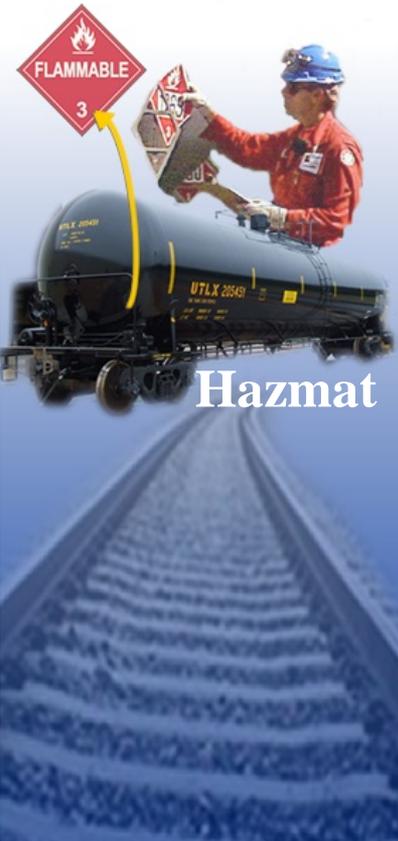


**Railroad  
Safety**



Car Number	Thickness at fracture	Material	Tensile strength	Diameter	STD Pressure
UTLX211623	0.180"	TC-128	81,000 psi	120"	165 psig
UTLX204101	0.213"	TC-128	81,000 psi	120"	165 psig
GATX263706	0.144"	TC-128	81,000 psi	120"	75 psig





# Analysis of Rupture

Car Number	Thickness at fracture	Pressure at Rupture	Strength at rupture	Temp of steel at rupture	Time to reach temperature
UTLX211623	0.180"	245 psi	55,000 psi	850	15.76 min
UTLX204101	0.213"	289 psi	46,480 psi	950	18 min
GATX263706	0.144"	195 psi	31,250 psi	1100	20.7 min

- $t = \frac{Pd}{2SE}$

- Heat Flux from fire – 34,500 btu/hr-ft<sup>2</sup>
- Specific heat of carbon steel - 0.12 btu/lbm-°F
- Area of impingement =  $A^{0.82}$