Evaluation of Retrofits Concepts for Tank Cars in Ethanol and Crude Oil Service

For consideration relative to P-1577

August 23, 2012

Overview

- Description of approach
- Review of incidents
- Retrofit Considerations
- Operational Considerations
- Ranked Recommendations

Approach

- Derailment data
- Research performed for T87.6
- Flammable liquids require special consideration
  - Loss of containment of only a single tank car in a unit train derailment can result in self-"fueling" pool fire
  - Fire fighting strategy – let the fire exhaust its fuel
  - Principle vs practicality

Derailments

Incident	Date	# Cars derailed	Speed at derailment	Unit train	Product Loss (gal)	Cause of Derailment
Plevna, MT	8/12	17	25	No	Yes (TBD)	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

Summary of Incident Data

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	-----

There were numerous cars with damage from multiple categories.

Retrofit Considerations

- Top and Bottom Fittings protection
- Safety systems
  - PRV
  - Thermal protection
- Head protection system
- Shell protection

Top Fittings Protection

- Incident data

Number of incidents of top fittings damage	**34**
Volume lost from the cars	820,515 gallons
Number of incidents of only top fittings damage	**16**
Volume lost from the cars	317,913 gallons

- Roll-over protection
  - Current requirements of HMR (9 mph roll-over)
- Top fitting protection
  - Current requirements of M-1002 (1/2V down, 1W longitudinal, 1/2W lateral)

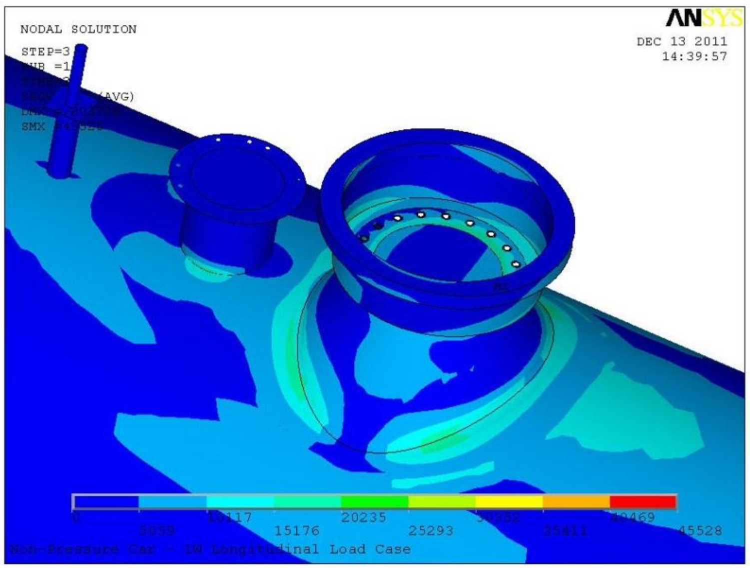
Top Fittings Protection vs Roll-over Protection

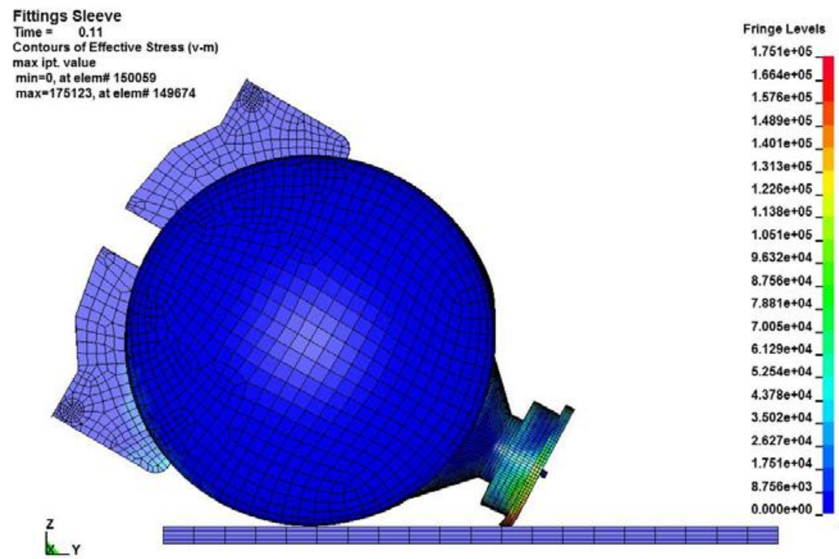
Top fittings protection

- Maximum stress is 45.512 psi
- Longitudinal Load case 1W

Roll-over protection

- Maximum stress is 175,123 psi





Performance requirements for roll-over protection result in a stress that is 4x the stress caused by loads of the performance requirements for top fittings protection.

Bottom outlet protection

- Incident data

Number of incidents of bottom outlet damage	**5**
Volume lost from the cars	136,113 gallons
Number of incidents of only bottom outlet damage	1
Volume lost from the cars	28,699 gallons

- AAR task force T10.7.5 charges
  - Evaluate shear plane design
  - Review strength of skid protection
  - Review operation of BOV operating mechanism

Safety System

- Thermal Protection and PRV
- Incident Data

Incidents of TC with no breach but loss of containment	**2**
Volume lost from cars	20,700 gallons
Incidents of TC with thermal tears	**14**
Volume lost from cars	207,329 gallons
Incidents of energetic ruptures	**5**
Volume lost from cars	142,471 gallons

- Note: The longitudinal tears in tank cars experiencing energetic rupture occurred at top of car (the car has not rolled over to one side).
- 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.

Safety System

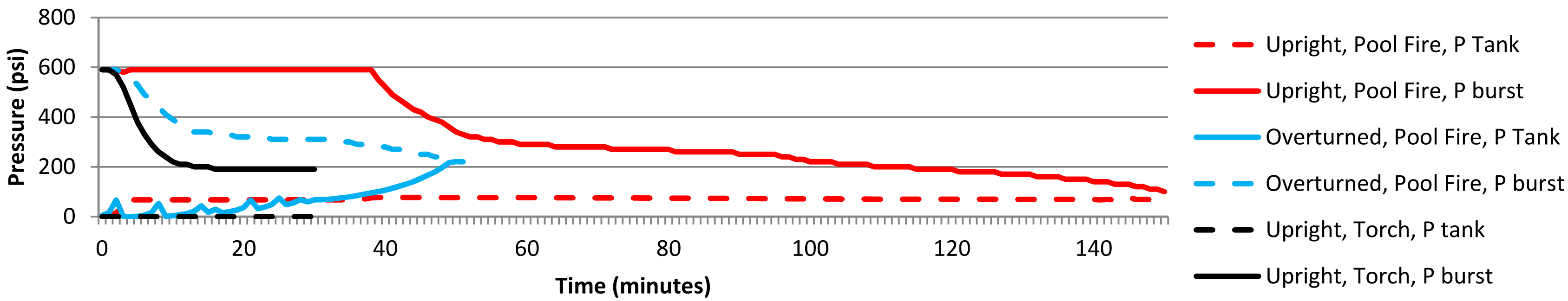
Regulatory requirement

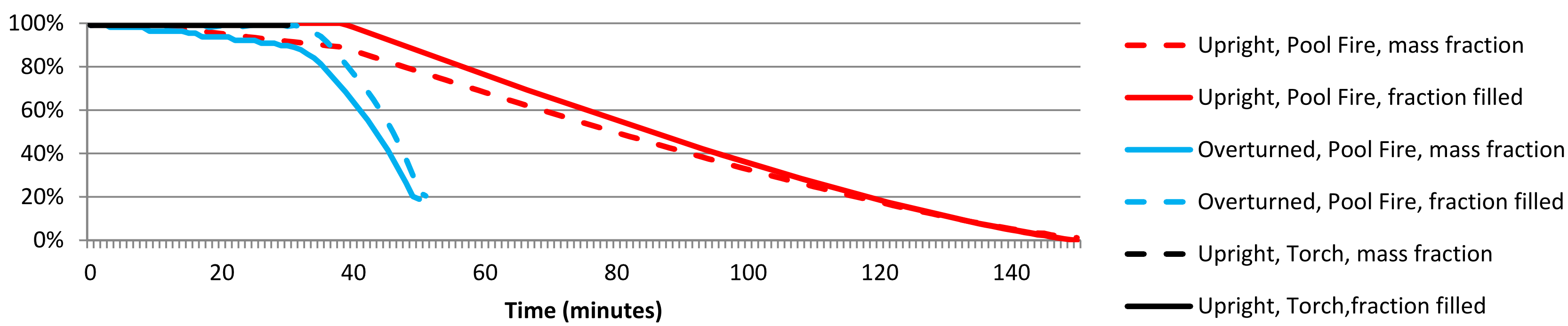
- Thermal protection
  - 100 minutes in a pool fire, 30 minutes in a torch fire without loss of product except from PRV
  - HM-144
    - Flammable gases in DOT 112 and 114 spec cars
    - 100 minutes – time required for liquid lading from 33,600 gallon tank car in a pool fire
- **Do unit trains of TC containing a flammable liquid require more stringent requirements than TC carrying flammable gases?**
  - **Current firefighting strategy is to allow fire to burn out.**
  - **Long pool fire times**

Safety System – Thermal Protection

Results of AFFTAC simulation of existing TC in pool fire

- The tank bursts at 50 minutes.
- 20% of liquid lading remains when tank bursts
  - Research indicates the severity of failure is directly related to the amount of liquid lading remaining at the time of failure

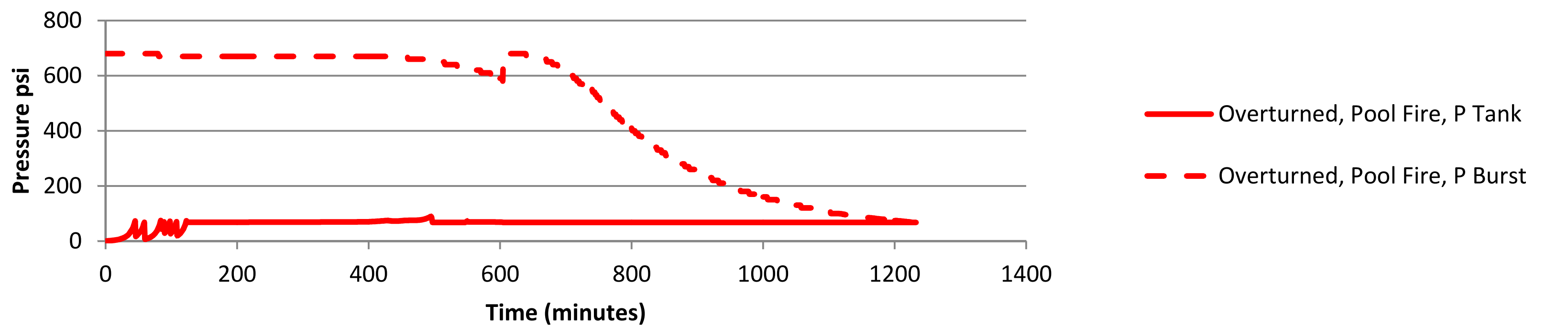


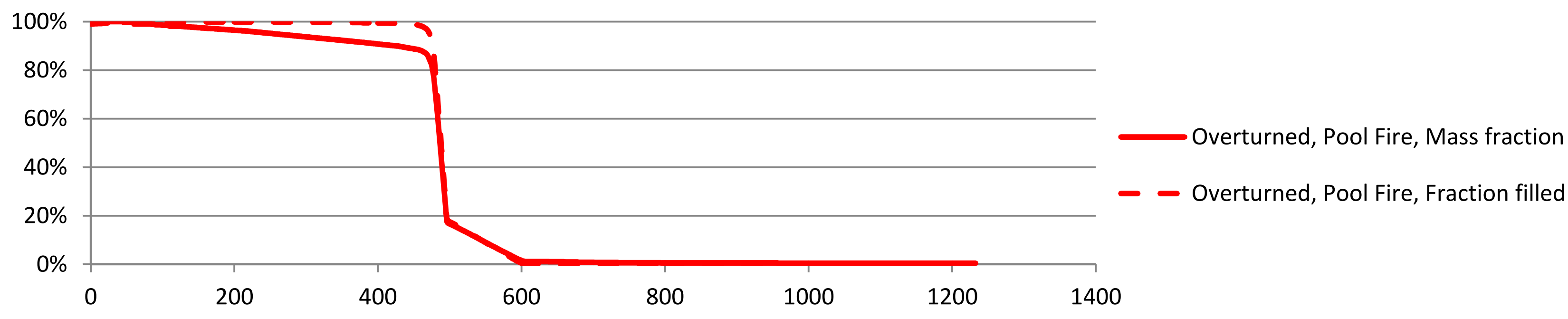


Safety System – Thermal Protection

Results of AFFTAC simulation of P-1577 TC with thermal protection in pool fire

- The tank bursts after 1,233 minutes
- Liquid lading expelled by 600 minutes



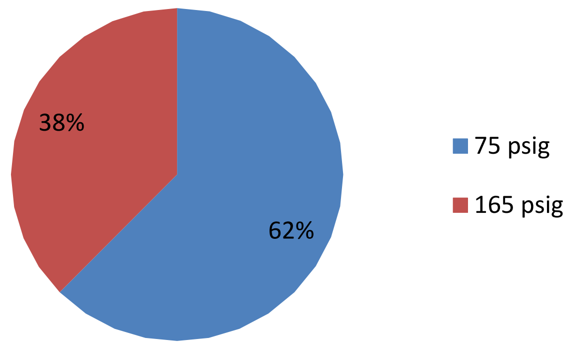


Thermal protection options

- Spray on thermal protection
  - maintenance problem – cracking caused by flexing to TCs.
  - corrosion
  - consistency in the tank structure will enable prediction of time to failure, corrosion will limit the predictability (Birk, 1995)
- Ceramic fiber and 11-gage jacket
  - Width limitation
  - Design modifications (fatigue)
  - Additional weight = more loaded trips
  - Maintenance/Inspection

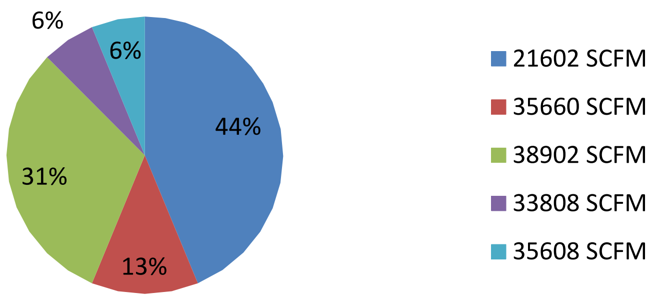
Pressure Relief Device

Thermal failures bsed on STD pressure



Set Pressure (psig)	% of population
165	36
76	64

Thermal failure based on PRV flow capacity



Flow capacity (SCFM)	% of population
20,555	2
20,605	3
21,602	49
33,808	1
35,608	13
35,660	17
38,902	14
41,016	2

Pressure Relief Device

- Recommendations of T87.6 Task force
  - 75 psig STD pressure
  - Minimum flow capacity of 27,000 SCFM
  - Single valve
- Based on AFFTAC modeling a tank car equipped with the PRV will survive 100 minutes in a pool fire.

Head Puncture Protection

- Incident data

Incidents of TC with head punctures	**41**
Volume lost	883,461
Incidents of TC with head puncture only	**22**
Volume lost	574,826
Incidents of top head puncture only	**6**
Volume lost	127,458
Incidents of bottom head puncture only	**16**
Volume lost	447,368

Head Puncture Protection

Regulatory history of half height head shield

- In 174 (HM-109)
  - requirements for head shields were introduced into the HMR (§179.100-23).
  - The requirements were for half head shields (on non-jacketed pressure cars) with specific minimum dimensions and performance requirements limited to the AAR impact test.
  - Based on three studies that indicate half height head shields were between 50% and 77% effective.

- In 1977 (HM-144)
  - introduced §179.105-5 Tank Head Puncture requirements which included performance standards and test requirements.
  - coupler restraint and thermal protection systems were also included.
  - Half height head shields were not precluded from use as long as the met the requirements in §179.100-23.

- In 1995 (HM-175A)
  - introduced the current §179.16 and removed §179.100-23 and §179.105-5.
  - for tank cars transporting all Class 2 materials.
  - In the preamble of the rule PHMSA states "research demonstrates that puncture resistance is an inter-related function of head thickness, insulation thickness, and jacket thickness, and the concept of "head protection" must include more than just traditional head shields."
  - The findings of a 2007 study of accident data by RSI which shows that a half height head shield would prevent between 60-70% of the head punctures supports this position.
  - The rule did not require retrofit of tank car equipped with half head shields but did require all new tank cars to be so equipped and a retrofit of tank cars without any type of head protection.

- No current standard for half head shield
- Does ½" thick half height head shield meet the performance requirements of Appendix A to part 179?

Head Puncture Protection

- Evaluation of benefits of head shield
- Methodology outlined in P-93-114 “Evaluation of the puncture resistance for stainless steel and carbons steel tank heads” (for DuPont)
- Assumptions
  - Material 516-70 steel
  - 4” standoff between 0.4375” head and 0.5” head shield
  - Gross rail load 286kips
- Puncture velocity of bare head – 9 mph
- Puncture velocity w/ head shield – 13.5 mph (15.1 mph if head is 0.4688” thick)

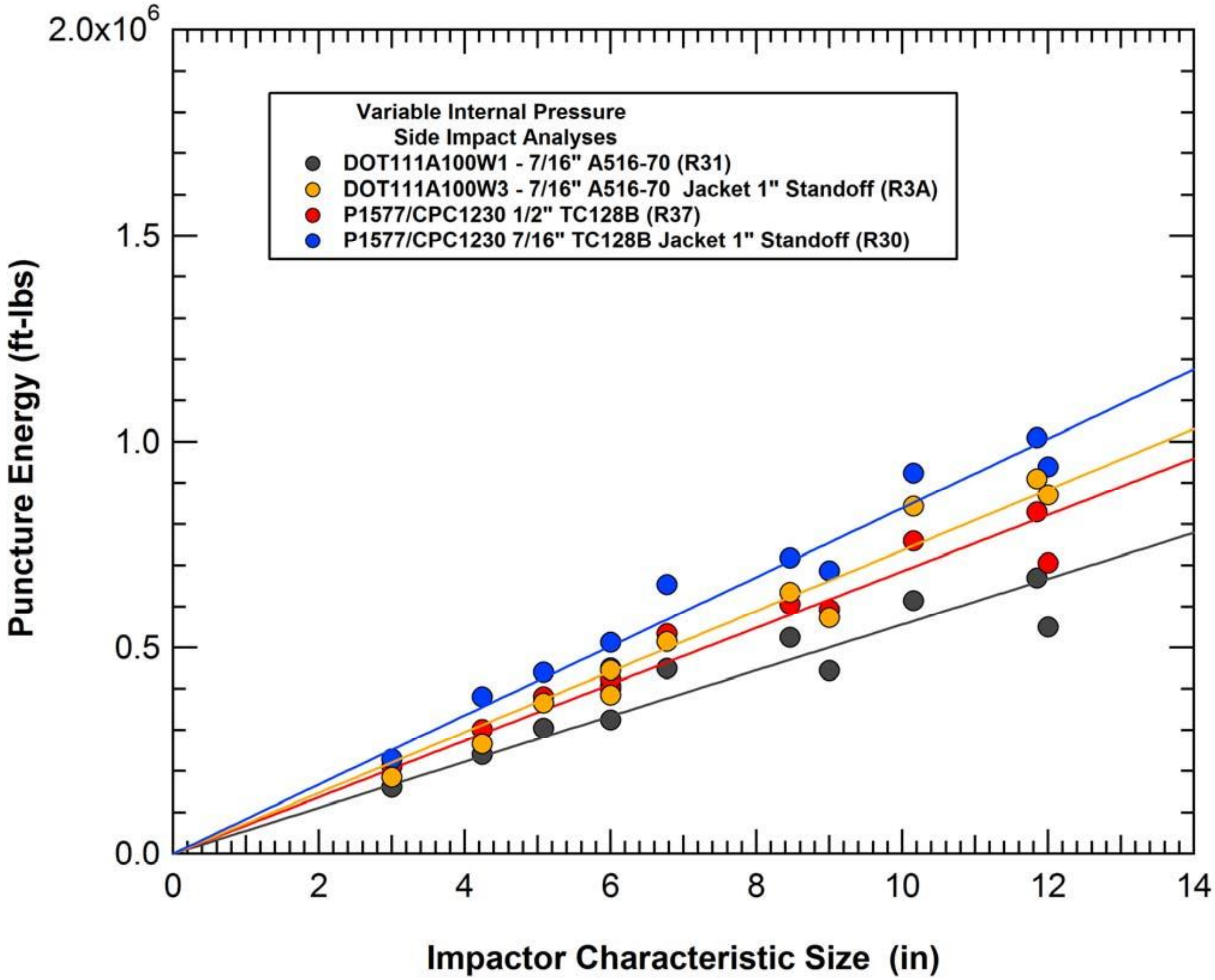
Shell puncture protection

- Incident data

Incidents of shell punctures	**30**
Volume lost	846,786 gallons
Incidents of shell punctures only	**12**
Volume lost	337,069 gallons

- Option for retrofit is an 11-gage jacket.
  - Improve puncture resistance
  - Provide thermal shield
  - Provision for thermal protection materials

Shell puncture protection



Comparison puncture energies of the DOT 111A100W1 and W3 tank car.

Source: Steve Kirkpatrick in support of T87.6

Shell puncture protection

- Estimated puncture resistance for different tank car configurations*

Case	Shell Thickness (in)	Shell material	Jacket thickness (in)	Jacket material	Puncture energy (10^6 ft-lb)	CPR
Reference	0.4375	A516-70	0.0000	None	0.550	0.1093
1	0.4375	TC-128B	0.0000	None	0.580	0.1093
2	0.500	TC-128B	0.0000	None	0.706	0.0886
3	0.4375	TC-128B	0.1196	A1011	0.871	0.0624
4	0.6250	TC-128B	0.0000	None	0.975	0.0568
5	0.3750	TC-128B	0.2500	TC-128B	1.020	0.0483

Source: “Puncture Resistance of different Tank Car configurations”, Volpe, 12/2011 in support of T87.6
* Assumes 12” x 12” indenter.

Operational Considerations

- Train Speed
- Brake Signal Propagation System
- Train Placement

Train Speed

- Incident data (range of speed)

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

- Range of damage through out derailed cars
  - Refer to slide 25

Brake Signal Propagation System

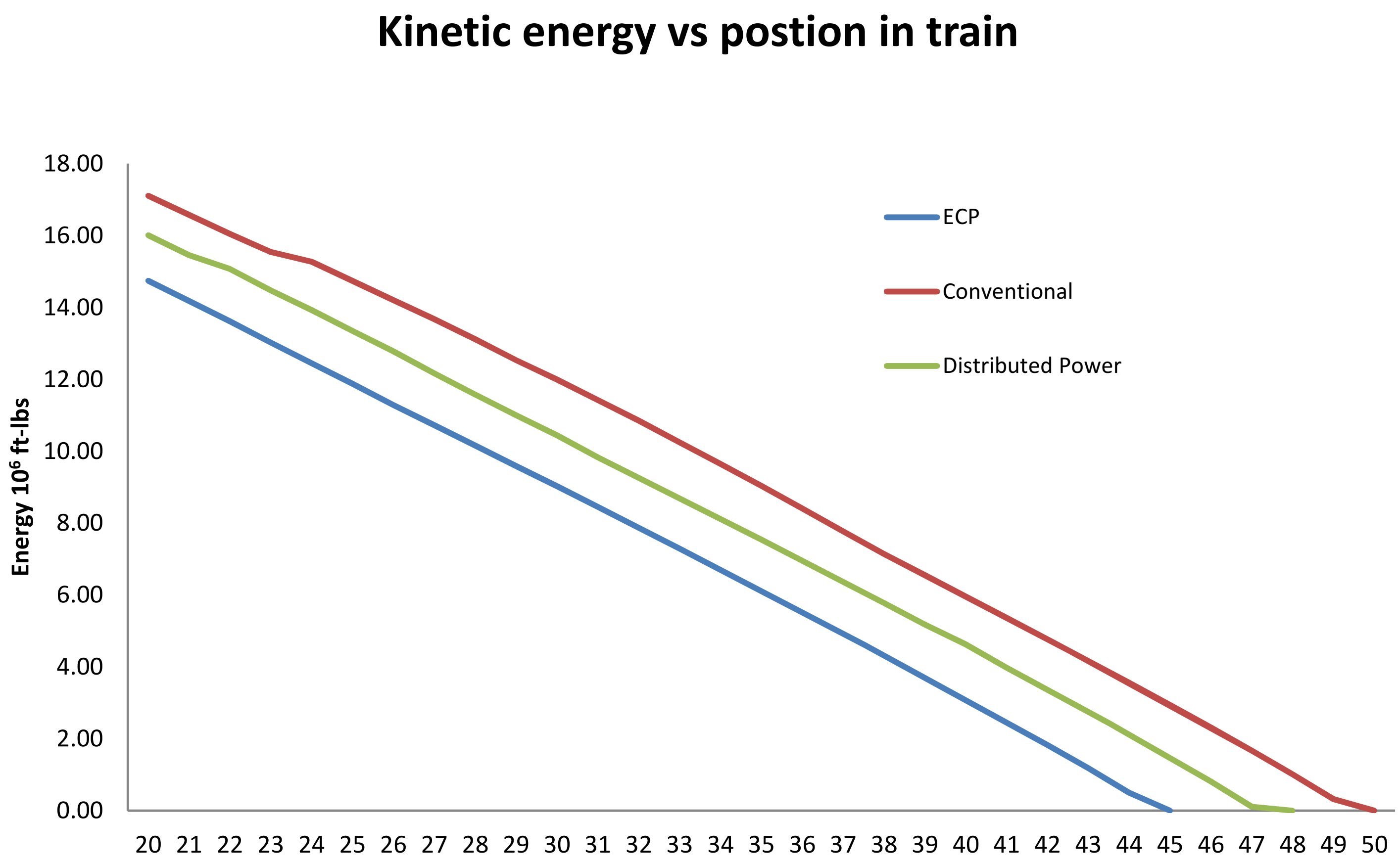
- Incident Data
  - Refer to slide 25
- How will this affect pile up
  - Overall arrangement will be the same
    - 1st cars not involved in pile up; limited damage
    - Last cars have lower energy; less damage
  - Number of cars in pile up will decrease
- By decreasing the available energy faster the number of cars damaged will decrease

Brake Signal Propagation

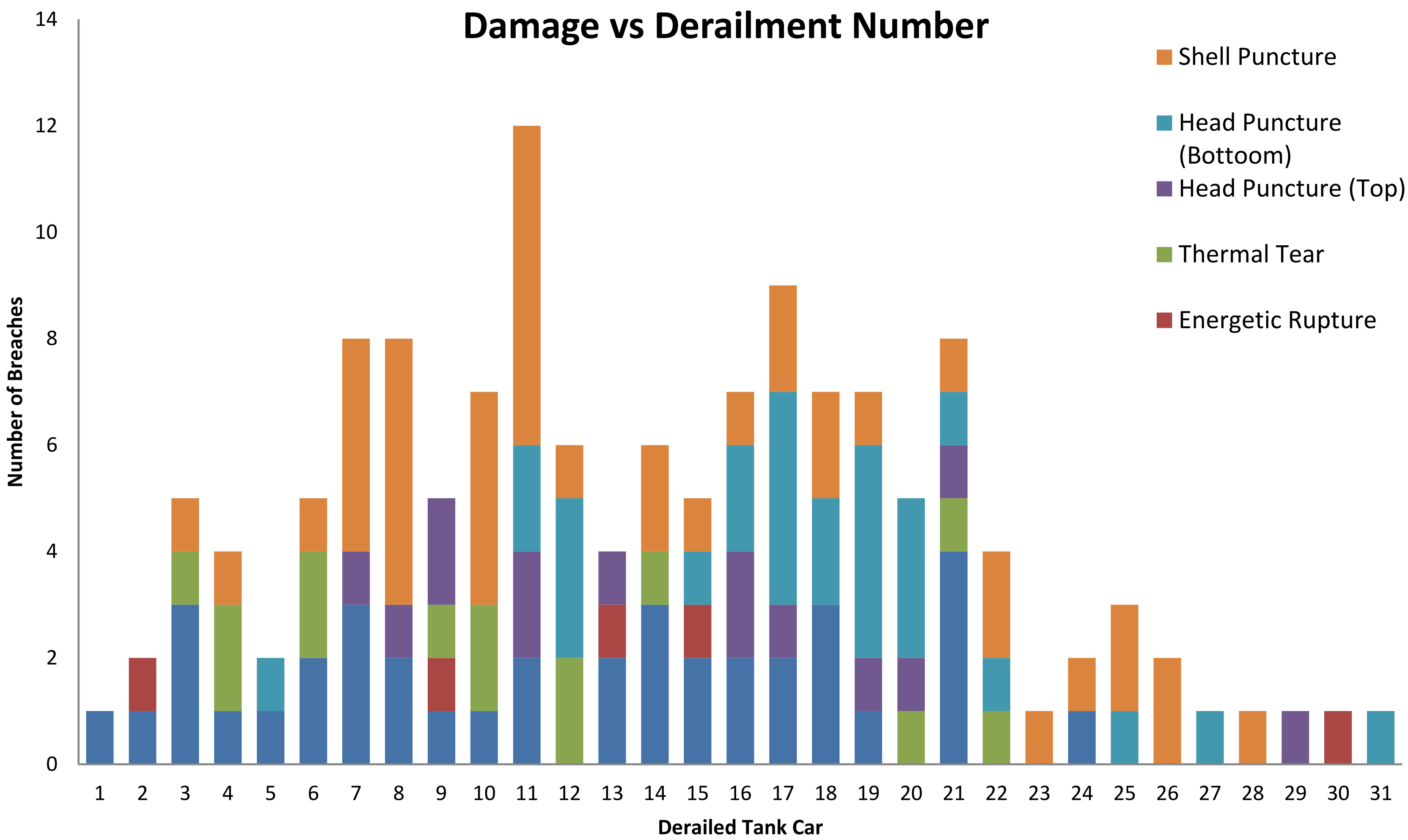
- Simulation by Sharma & Associates
  - 1st 20 cars have same energy at point of derailment regardless of brake propagation system
  - Benefits of DP and ECP brakes realized after 20th car (see slide 26)
  - Stopping distances of 100 car train with an initial velocity of 50 mph.

Brake propagation system	Stopping distance
Conventional	2,953 feet
Distributed power (front and rear)	2,793 feet
ECP brakes	2,656 feet

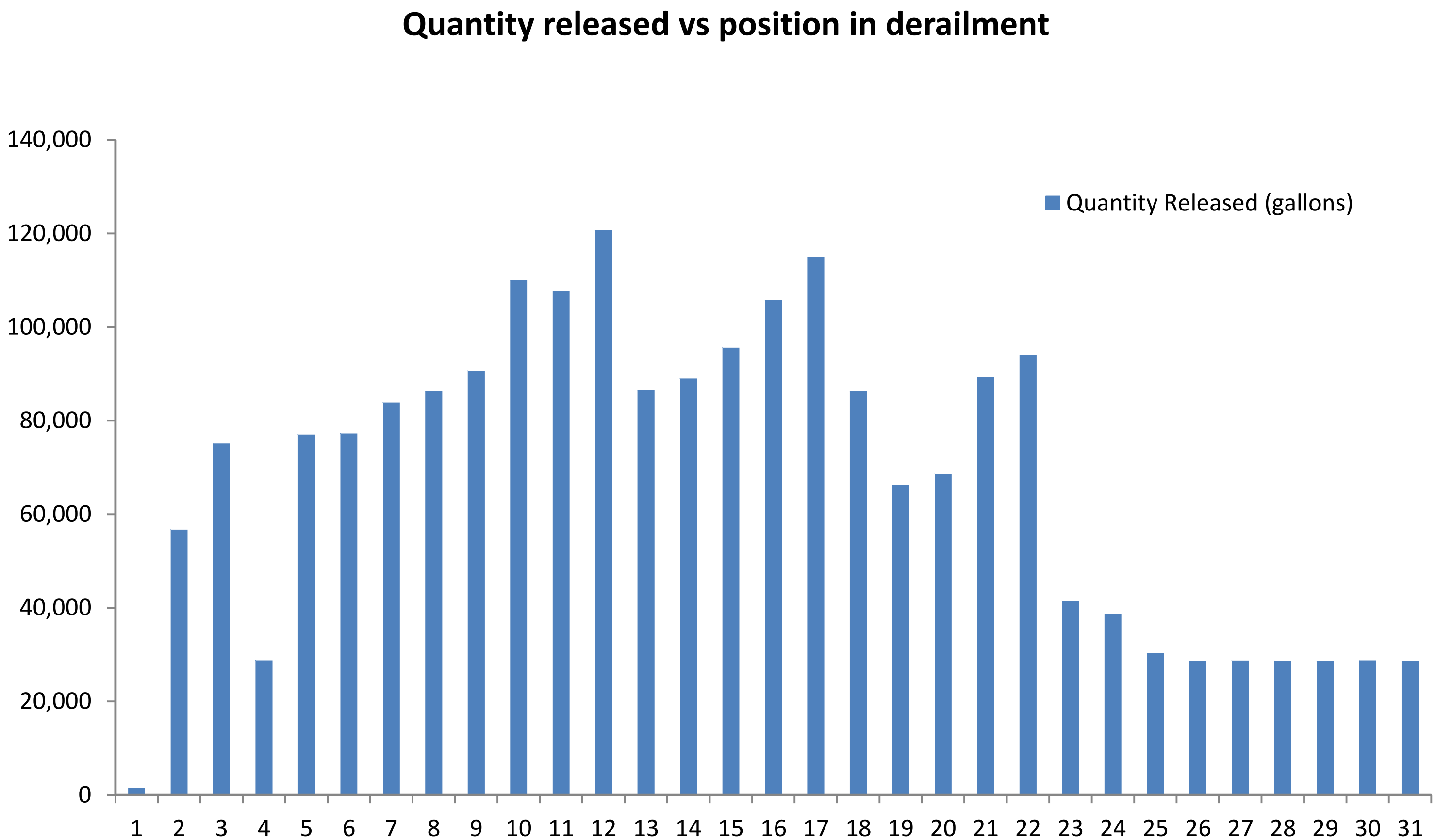
Brake Signal Propagation



Evaluation of Incident Data



Evaluation of Incident Data



Train Placement

- Location of 1st derailed car

Incident	# 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)

- Based on the spread of 1st car location, train placement requirements does not seem to be a solution.

Rank of Retrofit Options

Rank	Option	Reason
1	PRV per T87.6 recommendation for TCs equipped with a single nozzle for PRVs	The survivability of a tank car in a pool fire is a race between he decreasing tensile strength of the steel and the increasing hoop stress caused by the increasing pressure. The lower STD pressure will minimize the pressure at failure while the high flow capacity will evacuate the tank so at the time of failure less lading will be present to provide an energetic rupture.
2	Distributed power for unit trains or trains with blocks of FL greater than 20 cars	Provides improved brake signal propagation time. Lower cost than ECP brakes. Optimal location of DP unit at 2/3 back in the train.
3	ECP Brakes for unit trains	Install an overlay unit on existing tank cars. Offers the fastest brake signal propagation and associated decrease in energy of tank cars.
4	Half height head shield	Provide protection against 2/3 of the damage seen in the accidents evaluated. Securing a full head shield to the tank car is difficult. May cause more problems than it solves.
5	Top fittings protection per M-1002	Top fittings on the DOT 111A spec tank cars are vulnerable. Protection would help prevent shearing of the valves/nozzles and clogging or damage to the PRV. The roll-over protection may not be possible given the thickness of the tank shell.
6	BOV protection	Comply with recommendations of the AAR Task Force.
7	Evaluate spray on thermal protection	The industry should commit to evaluating new spray on thermal protection products. There is a long history of poor performance with existing products. At least one new product has been added to the list of those meeting the performance standard of Appendix B of Part 179.
8	Jacket and thermal protection material	Will add approximately 10,000 pounds of weight to the car. This will result is lower payload and more loaded trips to meet demand. Assuming probability of derailment remains the same, there will be more cars involved in derailments.
9	Train placement	Data indicates location of HM in train will have little effect on the consequences.