Cryogenic Tank Cars for LNG Transportation - Design Features

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TrinityRail Products




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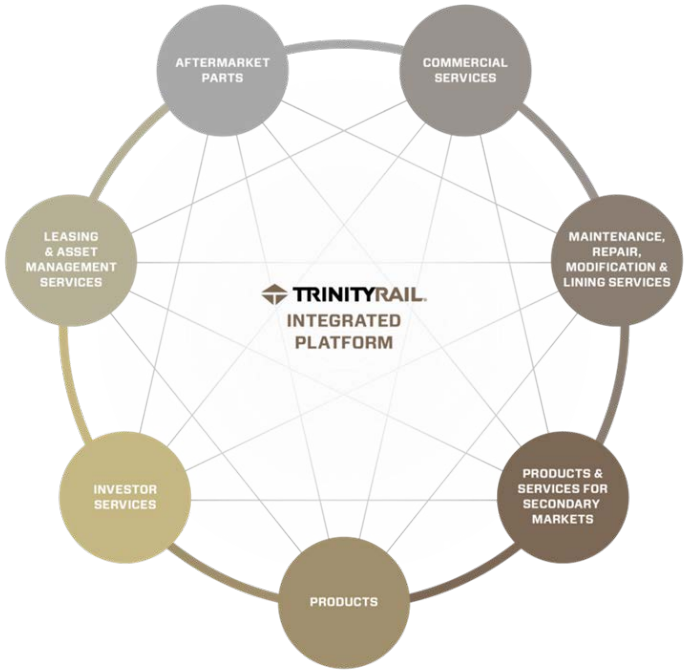
- **Largest Manufacturing Capacity in North America**
- **Most Complete and Extensive Product Line in North America**
- **Unmatched Operational and Manufacturing Flexibility**
- **Dedication to Quality Products and Processes**
- **Responsible Care Management System (RCMS) Partner**



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SAFETY

QUALITY

VALUES

CUSTOMER EXPERIENCE

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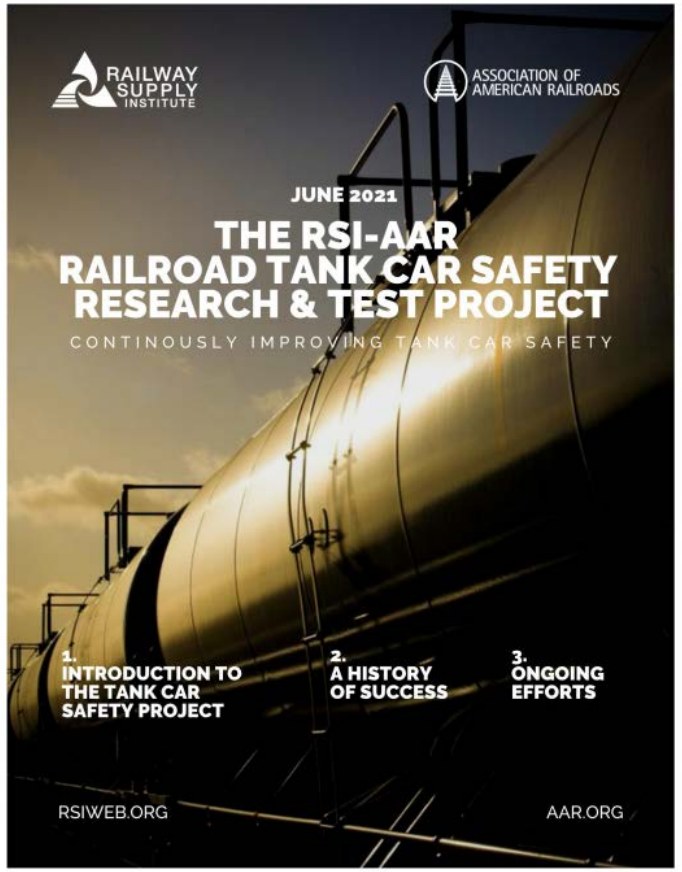
RSI-AAR Tank Car Safety and Research Project

- 50th Anniversary

- Propane/LPG Incidents late 1960's and early 1970's
- HM-144 (1977)
  - Class 2 Commodities
- Continued Research and Safety Improvements
  - Bottom Fittings Protection
  - Top Fittings Protection
  - Improved Steels
- Tank Car Accident Database (TCAD)
- Additional Commodity Classes
  - PIH Cars (HM-246 2009, HM-219C 2020)
  - Ethanol and Crude Oil Cars (HM-251 2019)
- Design Features
  - Mechanical Protection – Commodity Containment
  - Thermal Protection – Pressure and Temperature Control



Tank Car Safety Systems

- 49 CFR 173.31(b)

(1)Coupler Vertical Restraint

(2)Pressure Relief Devices

(3)Tank-head Puncture-resistance Requirements

(4)Thermal Protection Requirements

(5)Bottom-Discontinuity Protection Requirements

Design Features – Mechanical Protection
- Commodity Containment

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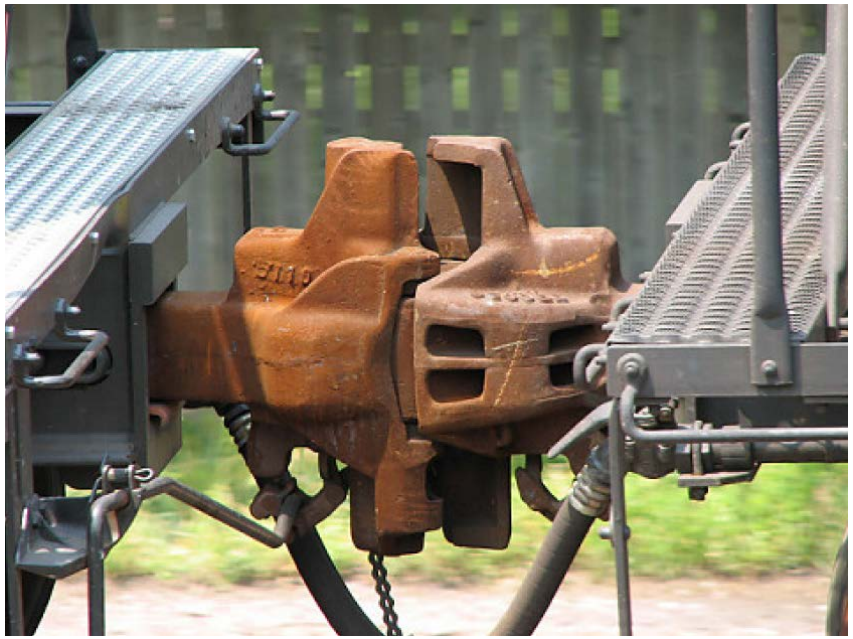
Shelf Couplers

(1)Coupler Vertical Restraint
(2) Pressure Relief Devices
(3) Tank-head Puncture-resistance Requirements
(4) Thermal Protection Requirements
(5) Bottom-Discontinuity Protection Requirements

Prevent Coupler Override

- Top-shelf couplers

§179.14 Coupler vertical restraint system. (a) Performance standard. Each tank car shall be equipped with couplers capable of sustaining, without disengagement or material failure, vertical loads of at least 200,000 pounds (90,718.5 kg) applied in upward and downward directions in combination with buff loads of 2,000 pounds (907.2 kg), when coupled to cars which may or may not be equipped with couplers having this vertical restraint capability.



Head Shields

Protect Tank Head

- Full and half-height designs

§179.16 Tank-head puncture-resistance systems. (a) Performance standard. When the regulations in this subchapter require a tank-head puncture-resistance system, the system shall be capable of sustaining, without any loss of lading, coupler-to-tank-head impacts at relative car speeds of 29 km/hour (18 mph) when:

(1) The weight of the impact car is at least 119,295 kg (263,000 pounds);

(2) The impacted tank car is coupled to one or more backup cars that have a total weight of at least 217,724 kg (480,000 pounds) and the hand brake is applied on the last "backup" car; and

(3) The impacted tank car is pressurized to at least 6.9 Bar (100 psig).

(b) Verification by testing. Compliance with the requirements of paragraph (a) of this section shall be verified by full-scale testing

(1) Coupler Vertical Restraint
(2) Pressure Relief Devices
(3)Tank-head Puncture-resistance Requirements
(4) Thermal Protection Requirements
(5) Bottom-Discontinuity Protection Requirements

Bottom Fittings Protection

Bottom Skid

- 3:1 slope

9.0 PROTECTION OF BOTTOM AND TOP DISCONTINUITIES ON NONPRESSURE TANK CAR TANKS

9.1 Bottom Protection

9.1.1 On new nonpressure stub sill tank cars and on nonpressure stub sill tank cars converted or altered to add bottom fittings, an approved method of protection against impact shall be provided for bottom discontinuities that project beyond the shell envelope, such as bottom outlets, washouts, blind flanges, or sumps, but excluding those discontinuities that have the following characteristics:

- Extend 1 in. (25.4 mm) or less beyond the shell envelope, measured on the longitudinal bottom centerline.
- Support safety or brake appliances or other appurtenances.
- Incorporate a continuous longitudinal slope at a 1:3 ratio or shallower in the portion extending beyond 1 in. (25.4 mm) from the shell envelope, measured on the longitudinal bottom centerline.
- Are capable of resisting the design conditions specified in paragraphs 9.1.2.1, 9.1.2.2, and 9.1.2.3 below, without rupturing the tank.

(1) Coupler Vertical Restraint
(2) Pressure Relief Devices
(3) Tank-head Puncture-resistance Requirements
(4) Thermal Protection Requirements
(5)Bottom-Discontinuity Protection Requirements

Top Fittings Protection

Interchange Requirement

- PG I and II

Regulatory for DOT 117’s

9.2 Top Protection

9.2.1 When top fittings discontinuity protection is specified for nonpressure cars, the following requirements must be met:

9.2.1.1 The protective structure must be as tall as the tallest fitting involved, must provide protection for those fittings, without overstressing the tank shell and nozzles, when subjected to forces of 1/2W in the vertical downward direction, 1W horizontal in the longitudinal direction, and 1/2W horizontal in the lateral direction.

- W is defined as the designed gross rail load of the car, less trucks.
- The forces are applied separately and uniformly over the projected plane of the protective structure perpendicular to the direction of the force.
- For horizontal loads, the projected plane extends from the top of the tank to the top of the protective structure.
- In the case of multiple nozzles, the forces are applied uniformly over their combined projected area if the reinforcement zones of the nozzle, as defined in paragraph 2.3.1 of this appendix, have a positive overlap. If there is no overlap of the reinforcement zones, each nozzle must be protected so that it can withstand the applied loads independent of the other nozzles.

Fittings Cabinet Protection

Proposed CGSB Requirement

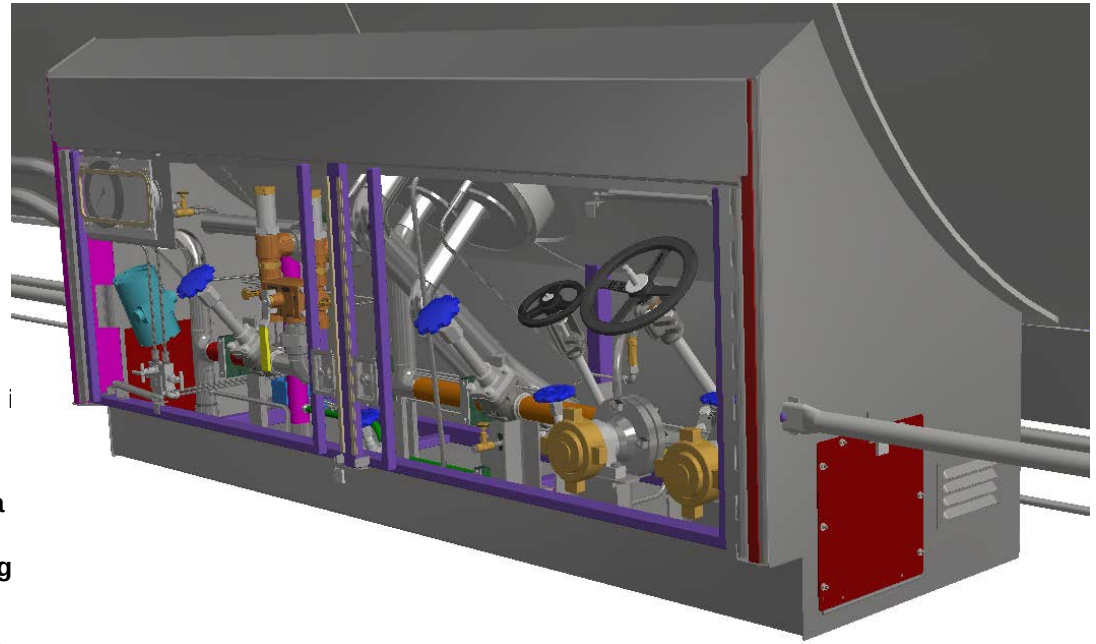
Incorporate top and bottom fittings protection lessons learned

8.2.3.3.11 The protective housing shall provide protection for the enclosed components when subjected to forces equal to the designated gross rail load of the car, less trucks, applied i the following manners:

a. The load distributed, in an orientation parallel to the longitudinal axis of the jacket, over a 76 mm (3 in.) wide area along the entire longitudinal length of the protective housing, centered approximately at the vertical midpoint of the protective housing

b. The load distributed, in an orientation perpendicular to the longitudinal axis of the jacket, over a 76 mm (3 in.) wide area along the entire vertical height of the protective housing, centered approximately at the longitudinal midpoint of the protective housing; and

c. For analysis purposes, rotations can be resisted at the centerplates.



General Puncture Resistance

- Research Success

TrinityRail R&D for Chlorine cars (2005)

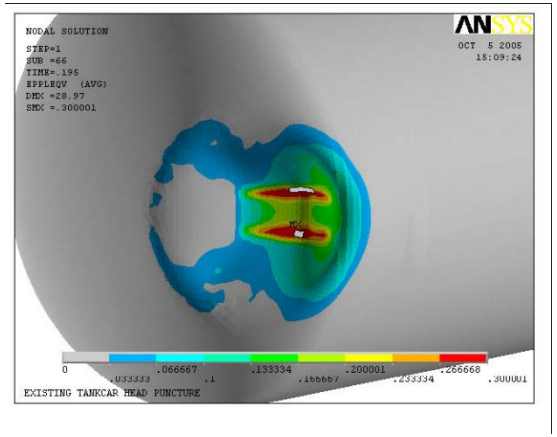
Advanced Tank Car Collaborative Research Program

HM-246 (2009)

FRA/TTCI Testing

- Standardized impact test methods

HM-219C (2020)



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Tank Car Accident Database

- Conditional Probability of Release

RSI/AAR Tank Car Safety and Research Project

Safety Project CPR Reports

- RA-05-02
- RA-19-01

Logistic Regression Model

$$CPR = 1 - (1 - P_H)(1 - P_S)(1 - P_T)(1 - P_B)$$

$$P_i = \frac{e^{L(X_i)}}{1 + e^{L(X_i)}}$$

$L(X_{HEAD}) = -0.4492 - 1.1672\ HST - 1.9863\ HMT - 0.9240\ INS - 0.4176\ SHELF - 0.4905\ YARD$

$L(X_{SHELL}) = 0.4425 - 0.6427\ INS - 4.1101\ STS - 1.5119\ YARD$

$L(X_{TOP\ FITTINGS}) = -1.0483 - 0.8354\ PRESS - 0.8388\ INS + 0.1809\ SHELF - 0.3439\ YARD$

$L(X_{BOTTOM\ FITTINGS}) = -1.4399 - 0.3758\ INS - 0.5789\ SHELF - 1.4168\ YARD$ (See Note 1 below.)

Jacket Conditional Probability of Release

- Equivalent head and shell thickness
- Probability of outer jacket breach

Spec	113C120W	113C120W9	113C120W9	113C120W9	112J340W
Commodity	Ethylene	Ethylene	Ethylene	LNG	LPG
Comment	Current Fleet	HM-264	286 GRL	286 GRL	Head Shields
Head Thickness	.5	.5625	.6875	.8125	.608
Shell Thickness	.4375	.5625	.6875	.8125	.608
CPR- Head	7.18%	7.18%	5.16%	4.12%	2.00%
CPR - Shell	19.94%	7.12%	4.5%	2.79%	6.04%
CPR - Net	17.33%	13.79%	9.43%	6.79%	7.93%

Design Features – Thermal Protection
- Pressure and Temperature Control

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Thermal Protection Systems – HM-144

- Class 2 Materials

(1) Coupler Vertical Restraint
(2) Pressure Relief Devices
(3) Tank-head Puncture-resistance Requirements
(4)Thermal Protection Requirements
(5) Bottom-Discontinuity Protection Requirements

Prescribed Maximum Conductance or §179.18

Thermal Analysis

- Procedures outlined in DOT/FRA/OR&D-84/02

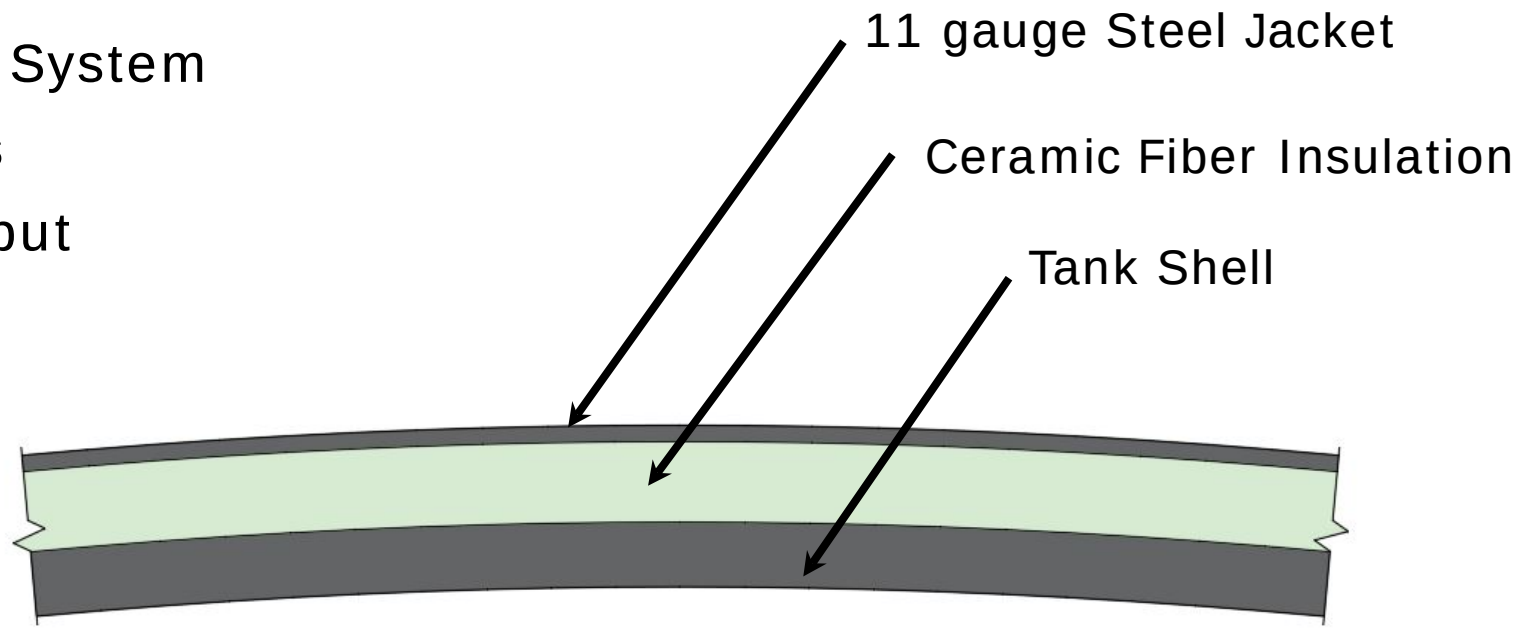
Performance Test Verification of System

- List of pre-approved Systems

Basic Principle - Reduce heat input

- Control tank temperature
- Minimize pressure buildup

Very Effective System



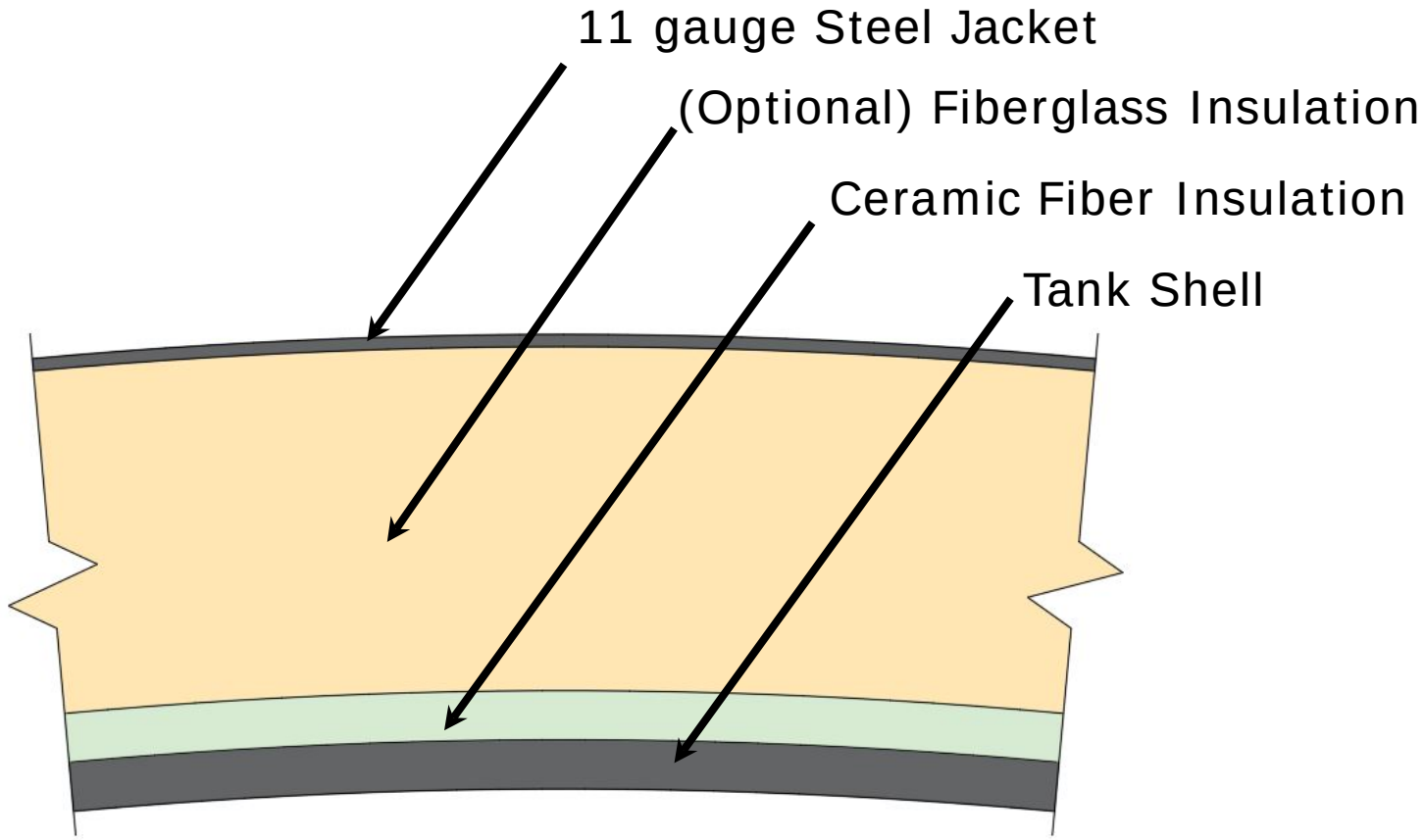
Thermal Protection Systems – HM-246

- Class 3 Materials

Prescribed System §179.202

References §179.18

Very Effective System



Thermal Protection Systems – DOT-113

- Cryogenic Materials

Prescribed System

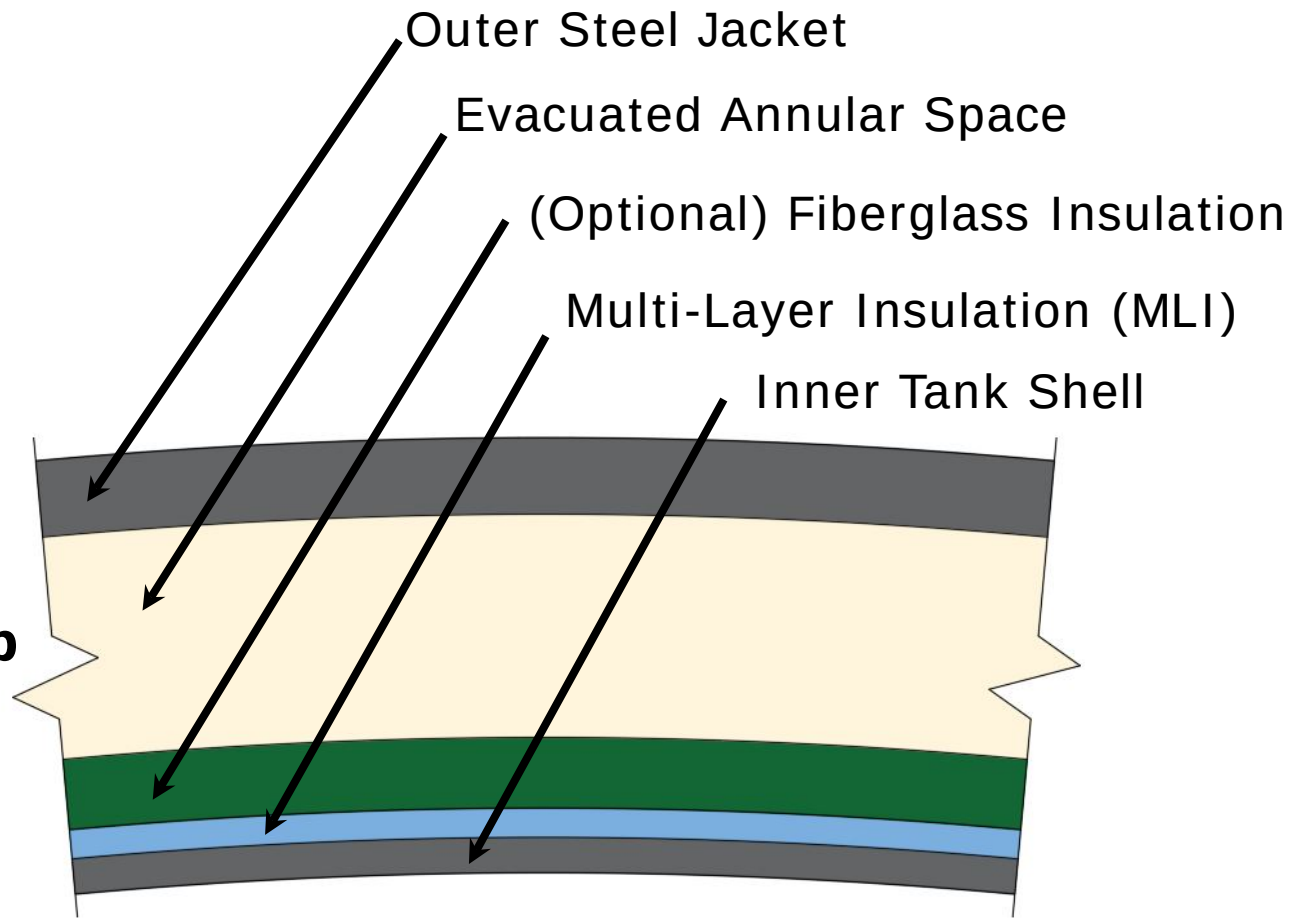
- §179.400-3

Performance Requirement

- §179.400-4

Same Principles

- **Control tank temperature**
- **Minimize pressure buildup**



Pressure Relief Device Requirements

(1) Coupler Vertical Restraint

(2)Pressure Relief Devices

(3) Tank-head Puncture-resistance Requirements

(4) Thermal Protection Requirements

(5) Bottom-Discontinuity Protection Requirements

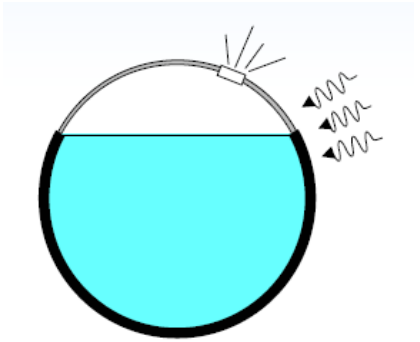
PRD required in addition to TPS

Limit tank internal pressure

Transient analysis (Class 2, 3)

Steady-state analysis (Class 2, 3, Cryogenic)

- Hand calculations
  - AAR MSRP C-III Appendix A
  - CGA Similarity
- Minimum flow rate required

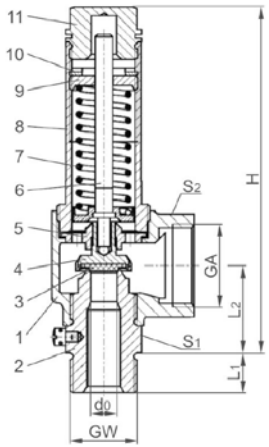


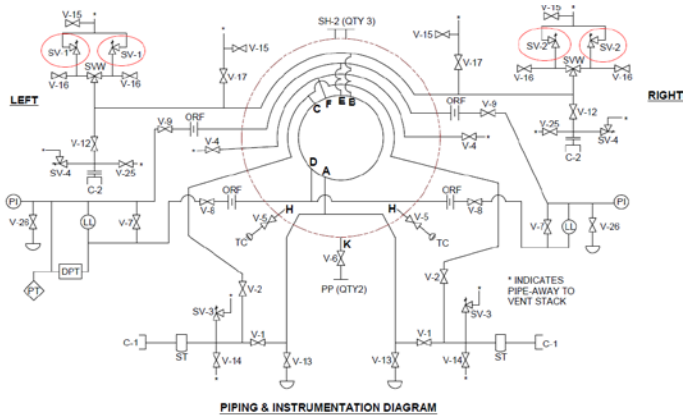
$$Q_a = \frac{(130 - t_2)}{4(1{,}200 - t_2)} G_i U_c A$$

Safety Relief Valve Flow Requirements

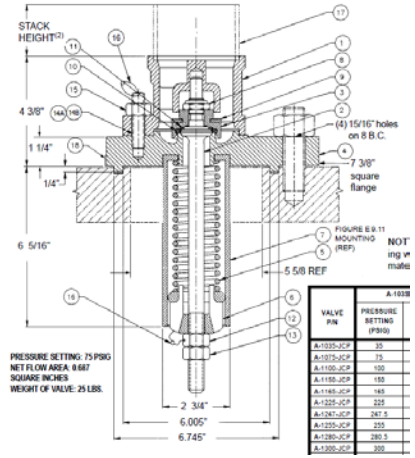
- Propane/LNG

Commodity	Specification	Capacity	Devices	STD	Method	Required	Actual	S.F
Propane	112J340W	33,690 gal	1	280.5 psig	AAR	3237 SCFM	3576 SCFM	1.1
LNG	113C120W9	34,500 gal	2	75 psig	CGA	238 SCFM	1528 SCFM	6.4





PIPING & INSTRUMENTATION DIAGRAM



Summary

50 year history of tank car safety research

Initial research intended for LPG/Propane cars

Safety systems developed and successfully applied

- Mechanical Protection – prevent puncture
- Thermal Protection – prevent overpressure/tank rupture

Developed for Class 2 and Class 3 commodities

Applicable to cryogenic commodities

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