

Research Update Related to Cryogenic Tank Cars

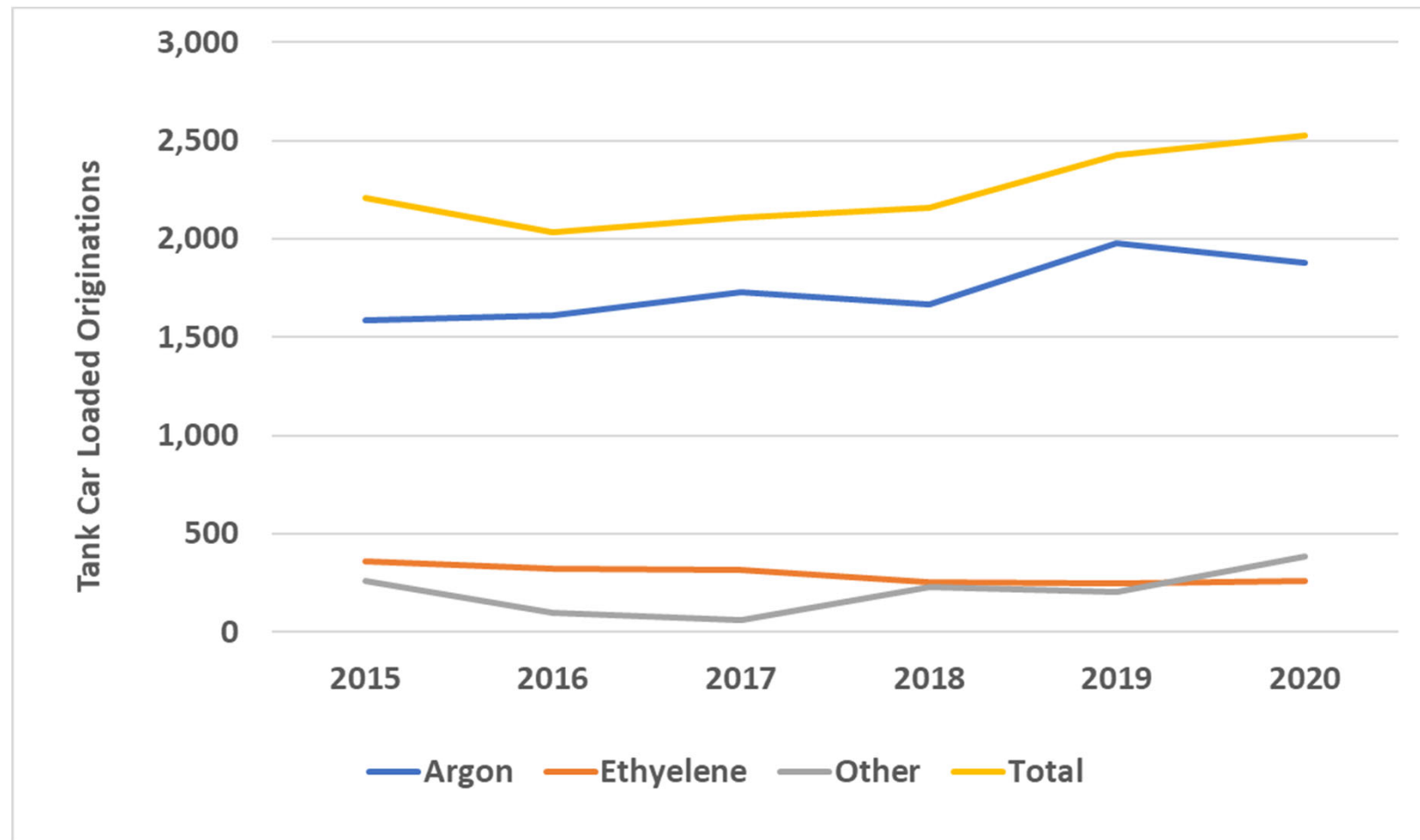
TRB Committee for the Safe Transportation of Liquefied Natural Gas
by Railroad Tank Car
Information-Gathering Meeting
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Topics

- Cryogenic tank car traffic
- Cryogenic tank car accident history
- Tank-within-tank cars in accident impact modeling
- Probability of lading loss – challenges
- Developments towards estimating probability of loss for new/uncommon tank car designs

Cryogenic Tank Car Traffic Volumes



US Loaded Originations Source: AAR

Cryogenic Tank Car Traffic Volumes

	Argon	Ethylene	Other	Total
2015	1,588	356	262	2,206
2016	1,611	321	100	2,032
2017	1,731	314	63	2,108
2018	1,669	255	231	2,155
2019	1,978	244	203	2,425
2020	1,879	262	384	2,525

US Loaded Originations Source: AAR

Cryogenic Tank Car Accident History

Cryogenic Cars Damaged in Accidents and Sources of Lading Loss 1980-2020

Car Specification	Damaged	Lost Lading from Tank	Lost Lading from Impact-Damaged Valves/Fittings	Lost Lading from Valves/Fittings Due to Fire Exposure	Lost Lading from Both Tank and Fittings	Unknown Source for Lost Lading	Total Lading Losses
113A90W	7	1	2	0	0	0	3
113A120W	1	0	0	0	0	0	0
113C120W	6	0	0	0	0	0	0
113D120W	3	2	0	1	0	0	3
204W	19	1	7	0	0	1	9
Total	36	4	9	1	0	1	15

Less than one car damaged per year

Source: RSI-AAR Tank Car Accident Database
Updated since 2019 memo to FRA, RA-19-03

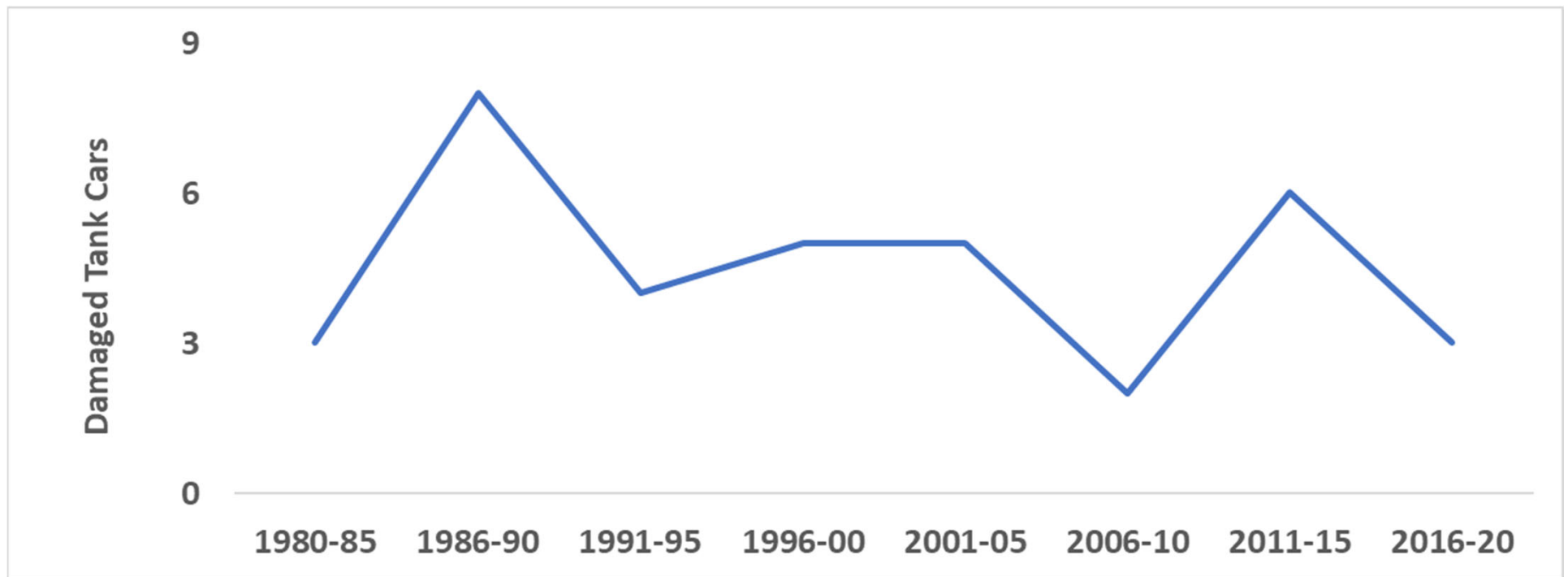
Cryogenic Tank Car Accident History

A complete list is available

	Date of Accident	Location	Track Type	Car Specification	Lading	Load/Residue	Gallons Lost	Source of Lading Loss
1	11/02/1983	Industrial, CA	Yard	204W	Argon	Load	None	n/a
2	04/22/1984	Marcel, CA	Main	204W	Oxygen	Residue	1	Fittings (top)
3	11/23/1985	La Porte, TX	Unknown	204	Argon	Load	None	n/a
4	04/28/1986	Conway, PA	Yard	113C120W	Ethylene	Load	None	n/a
5	06/18/1988	Westminster, VT	Main	204W	Nitrogen	Load	15,520	Fittings (top)
6	07/08/1988	Joliet, IL	Yard	113C120W	Ethylene	Load	None	n/a
7	02/02/1989	Muskogee, OK	Unknown	113C120W	Unknown	Unknown	None	n/a
8	03/16/1990	Glenwood, PA	Unknown	204W	Unknown	Unknown	None	n/a
9	03/21/1990	Sheridan, WY	Unknown	204W	Unknown	Unknown	None	n/a
10	08/31/1990	McConnell, BC	Unknown	204W	Argon	Load	None	n/a
11	08/31/1990	McConnell, BC	Unknown	204W	Argon	Load	None	n/a
12	09/22/1991	Boise, ID	Main	204W	Argon	Load	17,000	Fittings (bottom)
13	12/31/1992	Unknown	Unknown	204W	Unknown	Unknown	None	n/a
14	12/31/1992	Unknown	Unknown	204W	Unknown	Unknown	None	n/a
15	11/17/1995	Ft Worth, TX	Yard	204W	Argon	Load	12,817	Fittings (bottom)
16	04/08/1997	Bennington, VT	Unknown	204W	Unknown	Unknown	None	n/a

- “Top” and “bottom”, as used here to describe fittings, are not as well defined as for fittings on other types of tank cars. Generally, the tank car accident database will indicate “top” fittings for these cars if the damaged part of the system was closer to the top of the tank, and “bottom” if closer to the tank bottom. All types of fittings are lumped together in this summary, whether loading/unloading, pressure relief, or any other.
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Cryogenic Tank Car Accident History



Less than one car damaged per year

Source: RSI-AAR Tank Car Accident Database

Source for Accident History

- RSI-AAR Tank Car Accident Database (TCAD)
- Initiated 1970, continuously populated
- Includes all tank cars that experienced accident-caused damage to tank-car-specific features
 - Tank(s)
 - Fittings
 - Jacket
 - Head shield
- US and Canada, loaded or residue, hazmat or non-regulated, all accidents whether reportable to regulators or not

TCAD Fields

- Two files
 - Accident file - 38 fields
 - Car file - 78 fields
- Description of the car
 - specification, features, capacities, lading, load status
- Description of the accident
 - speed, track type, cars derailed, etc.
- Description of the damage and outcomes
 - types and locations of damage, lading lost, fire

Impact Modeling of Tank Cars

- Project TWP-14 under ATCCRP estimated impact resistance for a variety of conventional car types and impact types
 - Conducted by Applied Research Associates (ARA), funded by FRA
 - Final report 2013
- Project TWP-4 under ATCCRP modeled impacts on tank-within-tank designs
 - Conducted by ARA, funded by industry coalition
 - Final report 2017
- ARA and Volpe NTSC have supported FRA full-scale impact tests with similar modeling

Impact Modeling of Tank-Within-Tank Cars

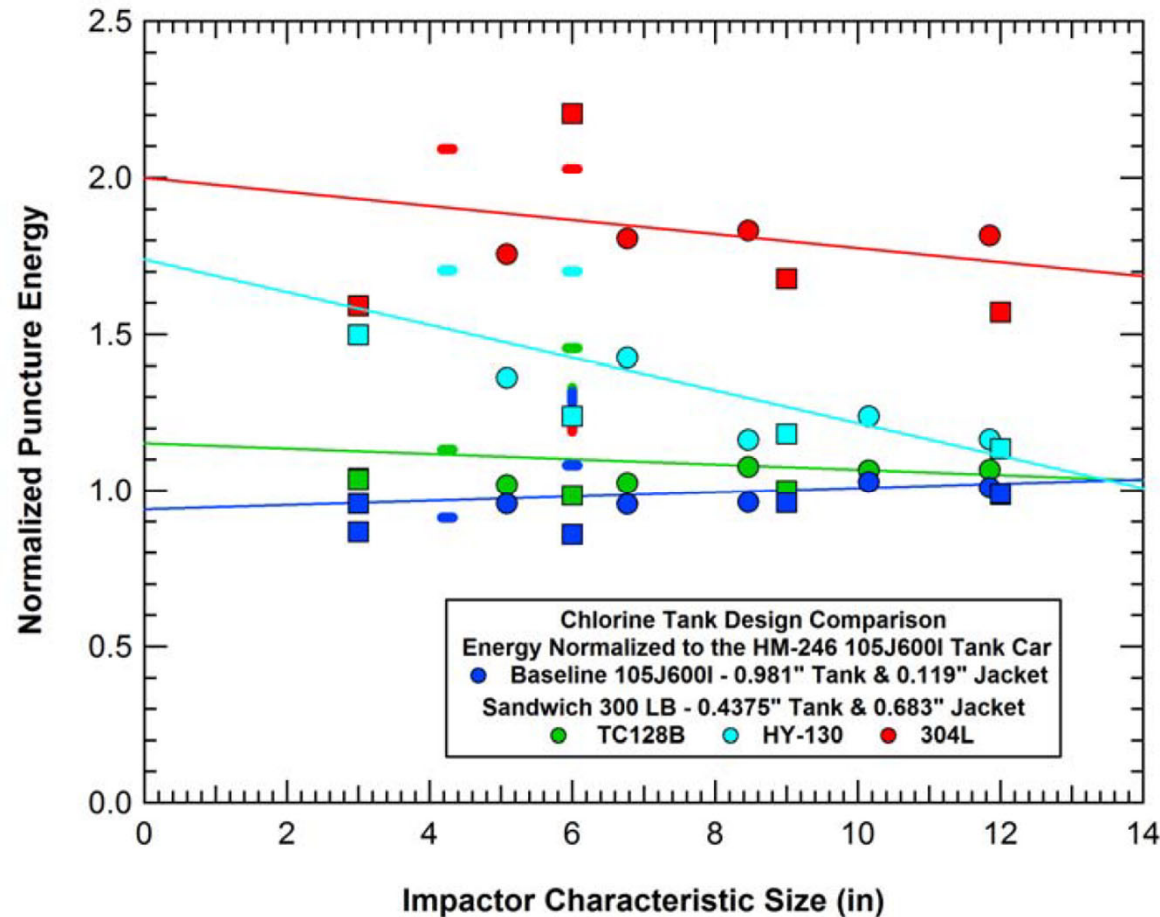


Figure 6. Relative side-impact puncture energies for Cl jacket materials

Source: ATCCRP Final Technical Report for Projects TWP-4, TWP-5 and TWP-22, 2017

Conditional Probability of Release from a Tank Car (CPR)

- CPR =
 - probability that a single tank car of a specified description loses any quantity of lading in an accident,
 - given a specified condition such as being derailed in an FRA-reportable accident
- RSI-AAR Tank Car Safety Research Project analyzes TCAD to produce CPR estimates and formulas for common tank car configurations and features
- 2019 report RA-19-01
- Updated study under final review now
- RSI-AAR CPR estimates exclude fire-caused losses

Conditional Probability of Release from a Tank Car (CPR)

Table E1
CPRs and CPR_{>100s} for Selected Tank Cars
Under Average Mainline Derailment Conditions¹

Car Specification	Head and Shell Thickness (in.)	Head and Shell Steel Type	Jacket	Head Shield	Top Fittings Protection	Bottom Fittings	Shell Inside Diameter (in.)	CPR	CPR _{>100} ²
111A100W1	0.4375	A516	No	No	No	Yes	119	0.274	0.200 ³
111A100W1/3	0.4375	A516	Yes	No	No	Yes	119	0.134	0.089
111A100W1/2	0.4375	A516	No	No	No	No	119	0.265	0.194
111A100W1/2/3	0.4375	A516	Yes	No	No	No	119	0.130	0.086
111A100W2	0.5625	A516	No	No	Yes	No	100.625	0.201	0.167
111A100W1	0.4375	TC128B	Yes	Full	Yes	Yes	119	0.064	0.046
111A/S100W1	0.500	TC128B	No	Half	Yes	Yes	119	0.132	0.103
117R100W	0.4375	A516	Yes	Full	No ⁴	Yes	119	0.126	0.081
117R100W	0.4375	TC128B	Yes	Full	Yes	Yes	119	0.064	0.046
117R100W	0.500	A516	Yes	Full	No ⁴	Yes	119	0.106	0.067
117R100W	0.500	TC128B	Yes	Full	Yes	Yes	119	0.052	0.037
117J100W	0.5625	TC128B	Yes	Full	Yes	Yes	119	0.042	0.029
112J340W	0.625	TC128B	Yes	Full	Yes	No	118.75	0.033	0.023
105J300W	0.562	TC128B	Yes	Full	Yes	No	118.75	0.040	0.028
105A500W	0.779	TC128B	Yes	No	Yes	No	102	0.040	0.030
105J500W	0.797	TC128B	Yes	Full	Yes	No	102	0.031	0.022
112J500I	H1.03 / S0.89	TC128B	Yes	Full	Yes	No	115.34	0.017	0.011
105J600I	H1.136/S0.98	TC128B	Yes	Full	Yes	No	106	0.016	0.011

Source: RSI-AAR Report RA-19-01, Conditional Probability of Release (CPR)
Estimates for Railroad Tank Cars in Accidents, 2019

CPR for Cryogenic Tank Cars

- CPR studies are based entirely on empirical data in TCAD
- Therefore, for designs and features that have rarely or never been derailed – which includes cryogenic cars - CPR estimates cannot be derived by the usual approach

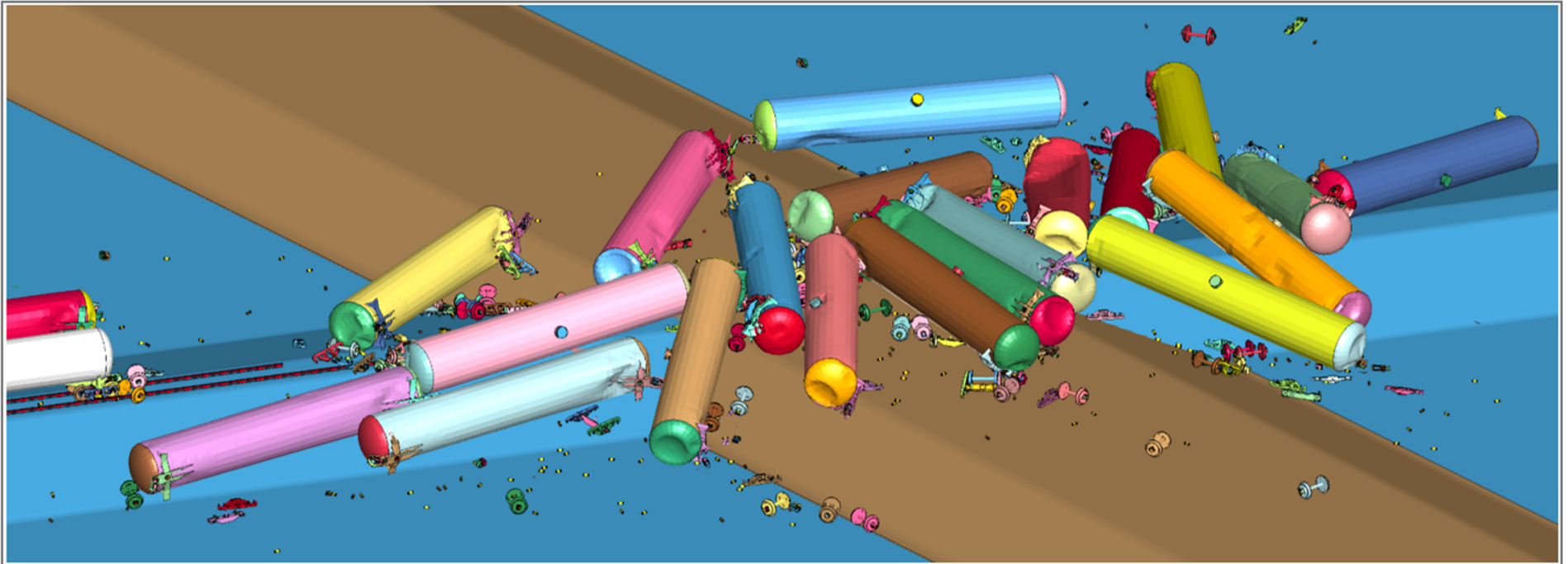
CPR for Cryogenic Tank Cars

- Even a very coarse-grained estimate for cryogenic cars requires strong assumptions, including:
 - the performance of two tanks is equal to, or bounded by, the performance of a single tank and jacket that have the same combined steel thickness
 - $\text{CPR}(\text{tank-within-tank}) = \text{CPR}(\text{tank} + \text{jacket})$ if $(\text{thickness}_{\text{outer tank}} + \text{thickness}_{\text{inner tank}}) = (\text{thickness}_{\text{tank}} + 0.118")$
 - the lading affects tank performance exactly as compressed gas in pressure cars does
 - there is effectively no difference in performance among stainless steel, carbon steel and jacket steel
- CPR estimate for a conventional tank car with a tank that resembles the outer tank of a cryogenic car might be a reasonable estimate of the probability of loss of vacuum

TWP-11: CPRs for Uncommon or Untried Designs

- But a need exists for CPR-type information for uncommon and new tank car designs
 - Comparisons among design options
 - Risk studies
- TWP-11 project aims to provide a means to estimate CPR from test and modeling results
- Begun under ATCCRP by coalition of RSI, AAR and shippers; now continuing under AAR sponsorship
- Goal is a method for estimate CPRs for these cars

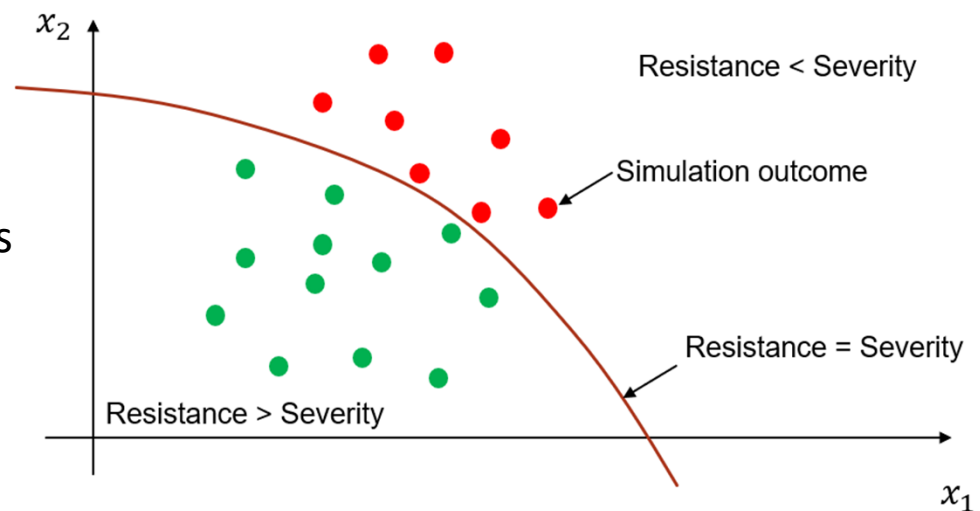
TWP-11



Simulated derailments → Impact Force Distributions

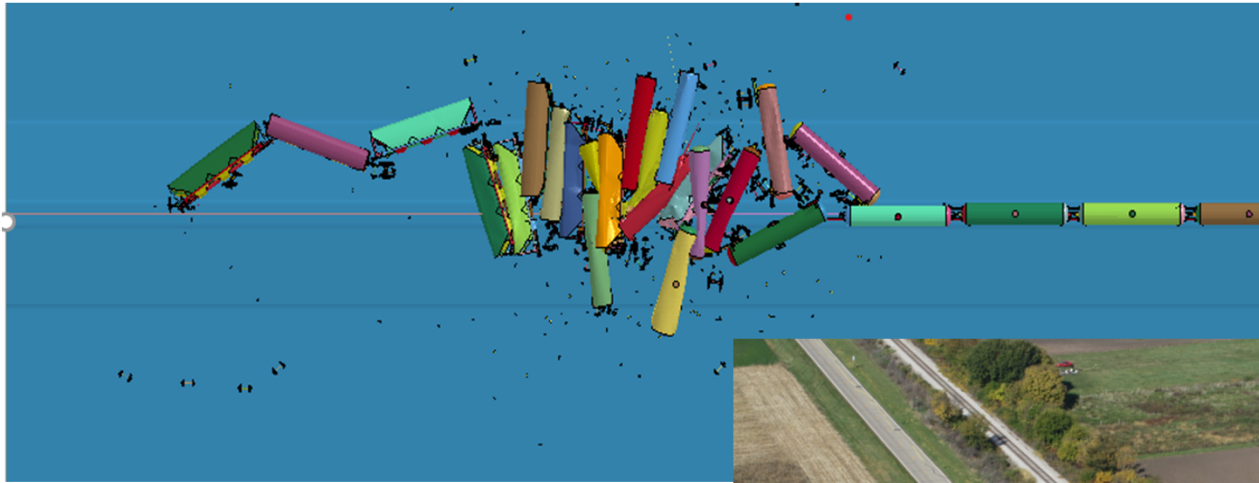
Checked against impact resistance of cars

Percent exceeding puncture force compared to CPRs



11/9/21

TWP-11



Validated against actual accidents with various characteristics

Developed quantitative system for measuring and comparing derailments



TWP-11

- Matrix of simulation runs, with key factors varied by experimental design, generates impact force distributions for different locations on the car
- Comparison to estimated puncture force F_{pi} for each location i yields
 - estimated percentage of cars that lose lading
 - mathematical relationship $CPR = f(F_{pi})$, which can be applied to untried designs if impact modeling or testing for puncture force has been done
- Current phase will be completed Summer 2022
- Final Phase - ??