Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

OPERATIONAL SERVICES BRANCH

ENGINEERING LABORATORY REPORT

LP149/2013

Field Examination of Tank Cars

Montreal, Maine & Atlantic Railway, Train MMA-002

Date of Occurrence: 06-Jul-2013

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1.0 INTRODUCTION

1.1 Description of Occurrence

1.1.1 On 05 July 2013, at about 2250 Eastern Daylight Time, Montreal, Maine & Atlantic Railway (MMA) freight train MMA-002 (the train), en route from Montréal, Quebec, to Saint John, New Brunswick, was stopped at Nantes, Quebec (Mile 7.40 of the Sherbrooke Subdivision), the designated MMA crew change point. The train, consisting of 5 head-end locomotives, 1 VB car (special purpose caboose), 1 box car, and 72 Class 111 tank cars carrying flammable liquids (petroleum crude oil, UN 1267, Class 3), was then secured on the main track on a descending grade.

1.1.2 Shortly before 0100 on 06 July 2013, the unattended train started to move and gathered speed as it rolled uncontrolled down the descending grade towards the town of Lac-Mégantic, Quebec. Sixty-three (63) tank cars and the box car derailed near the centre of the town. The 9 tail-end tank cars had not derailed and were subsequently pulled back to Nantes as part of the emergency response.

1.1.3 As a result of the derailment, about 6 million litres of petroleum crude oil spilled. The released product ignited almost immediately, resulting in a large pool fire that burned for more than a day. The petroleum crude oil that did not burn permeated and contaminated the downtown soil, with some crude oil reaching the river and Mégantic Lake.

1.2 Engineering Services Requested

1.2.1 A request was received from the Transportation Safety Board of Canada (TSB) Eastern Regional Operations - Rail/Pipeline office to conduct a field examination of the derailed tank cars.

2.0 EXAMINATION

2.1 Tank Car Information

2.1.1 The information pertinent to the 63 derailed tank cars is summarized in Table 1. The derailed tank cars were manufactured by Trinity Tank Car (34 cars), Gunderson (9 cars), American Railcar Industries (9 cars), American Car & Foundry (7 cars), and Union Tank Car (4 cars).

2.1.2 The oldest tank car was built in 1980 and the most recent in 2012; thus the derailed tank cars were 1 to 33 years old. All had been ordered before 01 October 2011. Consequently, none were subject to the requirements of the Association of American Railroads (AAR) circular letter CPC-1232 identifying new construction standards for DOT-111 general service tank cars ordered after October 1, 2011. CPC-1232 pertains to cars built for the transportation of Packing Group I and II

materials with the proper shipping name Petroleum Crude Oil, Alcohols, NOS (denatured ethanol) and ethanol/gasoline mixtures in Packing Group I and II.[1]

2.1.3 The initial commodities noted on the certificate of construction (COC)[2] of the derailed tank cars are listed in Table 2. These cars were intended to transport products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car. Some cars were also intended to transport Class 3 flammable liquids with Packing Groups II and/or III.

2.1.4 It was noted that 11 cars manufactured by Trinity Tank Car under COC L116012A had been remarked WFIX under a memorandum of lease between First Union Rail and Western Petroleum Company. The original TILX car initial and number for each of the WFIX cars is indicated in Table 1 for ease of reference.

2.1.5 All of the derailed cars were Department of Transportation (DOT) specification 111A100W1 tank cars of non-insulated, stub sill design. Each tank car was fitted with a bottom outlet valve (BOV), multiple top fittings within a protective housing, a hinged and bolted manway, and 1 or 2 pressure relief devices. None of the cars were equipped with head shields, jackets, or thermal protection.

2.1.6 General specifications applicable to the DOT-111 tank car are found in 49 CFR 179.200. [3] 49 CFR 179.200-17 requires that DOT-111 cars equipped with bottom outlets must also be equipped with protection of bottom discontinuities that is designed to prevent damage to the valve and loss of lading during a derailment. The valve operating mechanism must also be equipped with a locking arrangement to ensure positive closure during transit. Approved methods of bottom protection such as breakaway design for structures that extend below the valve and skid protection structure are specified in Appendix E of the AAR Specifications for Tank Cars. Various fittings and devices can be located on the top of tank cars such as loading and unloading valves, pressure relief device (PRD), vacuum relief device, and manway. The protection of top discontinuities is optional for DOT-111A100W1 tank cars.

2.1.7 The minimum head and shell thickness requirement specified by 49 CFR 179.201-1 is 7/16-inch. Plate material used to fabricate the tank must be AAR TC128 grade B or ASTM A516 grade 70 steels. [4] Table 3 summarizes the tank material requirements indicated in the COCs of the derailed tank cars. The shells were made of 7/16 inch thick AAR TC128 Grade B non-normalized (52 cars) or normalized (11 cars) steel. The nominal thickness of the head materials ranged from 7/16 to 15/32 inch. The heads were made of ASTM A515 Grade 70 non-normalized steel (6 cars), ASTM A516 Grade 70 non-normalized (38 cars) or normalized (17 cars) steel or AAR TC128 Grade B normalized steel (2 cars).

[1] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 2.7
[2] AAR Application for Approval and Certificate of Construction
[3] U.S. Code of Federal Regulations Title 49 Part 179 Specifications for Tank Cars
[4] 49 CFR 179.200-7

Table 1: Derailed Tank Car Information

Position in consist	Car initial	Car number	COC	Builder[5]	Month-year ordered	Month-year built	Car age (y)	Owner reporting mark	Field car no.
3	TILX	316547	L116012A	Trinity	Feb-11	Jul-11	2	TILX	1
4	WFIX	130608	L116012A	Trinity (TILX 316400)	Mar-11	Jul-11	2	FURX	2
5	TILX	316359	L116012A	Trinity	Mar-11	Jul-11	2	FURX	3
6	TILX	316338	L116012A	Trinity	Mar-11	Jul-11	2	TILX	4
7	NATX	310428	L114001	Gunderson	Dec-09	Aug-11	2	NATX	5
8	CTCX	735541	F111018	ARI	Jun-11	Jan-12	1	CEFX	6
9	DBUX	303879	F071004C	ARI	Oct-06	Dec-07	6	CEFX	7
10	WFIX	130682	L116012A	Trinity (TILX 316486)	Mar-11	Jul-11	2	FURX	8
11	TILX	316641	L116012A	Trinity	Mar-11	Jul-11	2	TILX	9
12	TILX	316570	L116012A	Trinity	Mar-11	Jul-11	2	TILX	10
13	NATX	310457	L114001	Gunderson	Dec-09	Aug-11	2	NATX	11
14	WFIX	130638	L116012A	Trinity (TILX 316430)	Mar-11	Jul-11	2	FURX	12
15	NATX	310473	L114001	Gunderson	Dec-09	Aug-11	2	NATX	13
16	TILX	316379	L116012A	Trinity	Mar-11	Jul-11	2	TILX	14
17	ACFX	79709	A811019A	ACF	Sep-79	Dec-81	32	NATX	15
18	TILX	316333	L116012A	Trinity	Mar-11	Jul-11	2	TILX	16
19	TILX	316549	L116012A	Trinity	Mar-11	Jul-11	2	TILX	17
20	CTCX	735527	F111018	ARI	Jun-11	Jan-12	1	CEFX	18
21	NATX	310477	L114001	Gunderson	Dec-09	Aug-11	2	NATX	32
22	WFIX	130603	L116012A	Trinity (TILX 316395)	Mar-11	Jul-11	2	FURX	33
23	TILX	316556	L116012A	Trinity	Mar-11	Jul-11	2	TILX	23
24	CTCX	735629	F111018	ARI	Jun-11	Jan-12	1	CEFX	19
25	ACFX	76605	A841016	ACF	Apr-84	Sep-84	29	NATX	24
26	PROX	44293	F067034B	Union Tank Car	Feb-06	Apr-07	6	PROX	20
27	NATX	310581	L114001	Gunderson	Dec-09	Nov-11	2	NATX	21
28	PROX	44202	F067034B	Union Tank Car	Feb-06	Feb-07	6	PROX	22
29	TILX	316234	L116012A	Trinity	Feb-11	Jul-11	2	TILX	25
30	TILX	316584	L116012A	Trinity	Mar-11	Jul-11	2	TILX	26
31	WFIX	130571	L116012A	Trinity (TILX 316362)	Mar-11	Jul-11	2	FURX	34
32	TILX	316330	L116012A	Trinity	Feb-11	Jul-11	2	TILX	27
33	NATX	310412	L114001	Gunderson	Dec-09	Jul-11	2	NATX	35
34	TILX	316317	L116012A	Trinity	Feb-11	Jul-11	2	TILX	28

[5] Trinity: Trinity Tank Car Inc.; ARI: American Railcar Industries; ACF: American Car & Foundry.

Position in consist	Car initial	Car number	COC	Builder[5]	Month-year ordered	Month-year built	Car age (y)	Owner reporting mark	Field car no.
35	WFIX	130545	L116012A	Trinity (TILX 316310)	Feb-11	Jul-11	2	FURX	29
36	ACFX	79698	A811019A	ACF	Sep-79	Dec-81	32	NATX	31
37	NATX	302784	L066085	Trinity	Jan-07	Feb-07	6	NATX	30
38	ACFX	71505	A861020	ACF	Jun-86	Oct-86	27	NATX	36
39	ACFX	71121	A851028	ACF	Jun-85	Aug-85	28	NATX	37
40	CTCX	735537	F111018	ARI	Jun-11	Jan-12	1	CEFX	38
41	NATX	303128	L066085	Trinity	Jan-07	Mar-07	6	NATX	39
42	CTCX	735572	F111018	ARI	Jun-11	Jan-12	1	CEFX	40
43	WFIX	130616	L116012A	Trinity (TILX 316408)	Mar-11	Jul-11	2	FURX	60
44	WFIX	130664	L116012A	Trinity (TILX 316456)	Mar-11	Jul-11	2	FURX	42
45	WFIX	130630	L116012A	Trinity (TILX 316422)	Mar-11	Jul-11	2	FURX	43
46	TILX	316523	L116012A	Trinity	Mar-11	Jul-11	2	TILX	44
47	TILX	316613	L116012A	Trinity	Mar-11	Jul-11	2	TILX	45
48	TILX	316616	L116012A	Trinity	Mar-11	Jul-11	2	TILX	46
49	TILX	316206	L116012A	Trinity	Feb-11	Jul-11	2	TILX	47
50	TILX	316319	L116012A	Trinity	Feb-11	Jul-11	2	TILX	48
51	CTCX	735617	F111018	ARI	Jun-11	Jan-12	1	CEFX	49
52	TILX	316572	L116012A	Trinity	Mar-11	Jul-11	2	TILX	63
53	CTCX	735526	F111018	ARI	Jun-11	Jan-12	1	CEFX	50
54	TILX	316622	L116012A	Trinity	Mar-11	Jul-11	2	TILX	62
55	WFIX	130585	L116012A	Trinity (TILX 316376)	Mar-11	Jul-11	2	FURX	41
56	NATX	310508	L114001	Gunderson	Dec-09	Sep-11	2	NATX	61
57	CTCX	735525	F111018	ARI	Jun-11	Jan-12	1	CEFX	51
58	ACFX	79383	A801029A	ACF	May-79	Oct-80	33	NATX	59
59	PROX	44428	F067036B	Union Tank Car	Dec-08	May-07	6	PROX	52
60	PROX	44150	F067040A	Union Tank Car	Feb-06	Jan-07	6	PROX	53
61	TILX	316533	L116012A	Trinity	Mar-11	Jul-11	2	TILX	54
62	ACFX	94578	A911018B	ACF	Aug-91	Mar-92	21	NATX	55
63	NATX	310515	L114001	Gunderson	Dec-09	Oct-11	2	NATX	58
64	TILX	316528	L116012A	Trinity	Mar-11	Jul-11	2	TILX	56
65	NATX	310470	L114001	Gunderson	Dec-09	Aug-11	2	NATX	57

Table 2: Intended Products for Derailed Tank Cars

Builder	No. of cars	COC	Initial commodity noted on COC
Trinity	32	L116012A	Petroleum crude oil (packing group II) and products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
	2	L066085	Ethyl alcohol and products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
Gunderson	9	L114001	Ethanol (non-regulated) and products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
ARI	8	F111018	Petroleum crude oil – Packing group III and products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
	1	F071004C	Ethanol and products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
ACF	1	A801029A	Commodities authorized for this class car by part 173 of the DOT hazardous material regulations for which there are no special commodity requirements and non-regulated commodities compatible with design of tank (initial commodity: alcohol)
	2	A811019A	
	1	A841016	Toluene and products authorized in DOT Part 173 for which there are no special commodity requirements and non-regulated commodities compatible with this class of car
	1	A851028	Light naphta and products authorized in DOT Part 173 for which there are no special commodity requirements and non-regulated commodities compatible with this class of car
	1	A861020	Alcohol and products authorized in DOT Part 173 for which there are no special commodity requirements and non-regulated commodities compatible with this class of car
	1	A911018B	Methanol and products authorized in DOT Part 173 for which there are no special commodity requirements and non-regulated commodities compatible with this class of car
Union Tank Car	2	F067034B	Products authorized in DOT Part 173 for which there are no special commodity requirements, and non-regulated commodities that are compatible with this class of car
	1	F067036B	
	1	F067040A	

Table 3: Tank Material Requirements for Derailed Tank Cars

Builder	No. of cars	COC	Heads material type & grade	Heads material thickness (in.)	Shell material type & grade	Shell material thickness (in.)
Trinity	32	L116012A	ASTM A516 Grade 70 non-normalized	7/16	AAR TC128 Grade B non-normalized	7/16
	2	L066085	AAR TC128 Grade B normalized	7/16	AAR TC128 Grade B normalized	7/16
Gunderson	9	L114001	ASTM A516 Grade 70 normalized	0.443	AAR TC128 Grade B normalized	0.438
ARI	8	F111018	ASTM A516 Grade 70 normalized	7/16	AAR TC128 Grade B non-normalized	7/16
	1	F071004C	ASTM A516 Grade 70 non-normalized	7/16	AAR TC128 Grade B non-normalized	7/16
ACF	1	A801029A	ASTM A515 Grade 70 non-normalized	15/32	AAR TC128 Grade B non-normalized	7/16
	2	A811019A				
	1	A841016				
	1	A851028				
	1	A861020				
	1	A911018B	ASTM A516 Grade 70 non-normalized	7/16	AAR TC128 Grade B non-normalized	7/16
Union Tank Car	2	F067034B	ASTM A516 Grade 70 non-normalized	15/32	AAR TC128 Grade B non-normalized	7/16
	1	F067036B				
	1	F067040A				

2.2 Field Examination

2.2.1 Aerial photo-documentation of the derailment zone was completed as soon as the fire was extinguished and while some tank cars were still being cooled by firefighters (Figure 1).

2.2.2 Wreckage clearing operations began after the fire was extinguished and while part of the scene was still under investigation by the police and the coroner, thus partially accessible to TSB personnel. Consequently, it was not possible to conduct a comprehensive photo-documentation of the derailed tank cars in-situ.

2.2.3 Each derailed tank car was assigned a field car number by the remediation contractor. These field car numbers were spray painted onto each car and are listed in Table 1 for ease of reference. The cars were emptied of remaining product and moved to a staging area for examination and photo-documentation by the TSB investigation team. The remediation contractor indicated that approximately one quarter of the cars were emptied through the manway. For 26

of the 63 derailed tank cars, an access hole was cut in the tank using water-jet equipment to empty the tank's content. The last tank car to derail (NATX 310470, consist no. 65) was lightly damaged and it was re-railed and pulled back from the pile-up during the wreckage clearing operations.

2.2.4 TSB's inspection of the tank cars was conducted during daylight hours as equipment was unavailable for photo-documentation during nighttime. A few tank cars were inadvertently disposed of during night operations without having been inspected by the TSB investigation team. Fortunately, these cars had been examined by the RSI-AAR Safety Project team who agreed to share their photos with TSB.

2.2.5 TSB inspection of the derailed tank cars was completed from 15 to 26 July 2013. If no further examination was required, the cars were marked "BST" and immediately released for disposal. Cars selected for three-dimensional (3D) laser scanning were marked "3D Hold". Coupons were obtained from 9 derailed tank cars during the field examination. The location of the coupons was marked using spray paint on the selected cars. Once the 3-D scanning and/or recovery of coupons were accomplished, these cars were also released for disposal.

2.2.6 The detailed inspection results for the 63 derailed tank cars are presented in Appendix A (refer to Tables A-1 through A-63 and to Figures A-1 through A-63, respectively). In-situ photographs showing the orientation and relative position of selected tank cars are presented in Appendix B.

2.3 Identification of Derailed Tank Cars

2.3.1 The exterior finish and stenciling of many tank cars was damaged during the post-derailment fire precluding identification of the cars' reporting mark and number. Some cars were identified from stamped markings on their stub sill, top fitting pressure plate and/or heads. Representative examples of such markings are presented in Figure 2. Figure 2a shows a stamped marking "TILX 316395" on the stub sill of field car no. 33, identifying this tank car as WFIX 130603 (this was one of the re-marked cars, see paragraph 2.1.3 and Table 1). Figure 2b shows a stamped marking "NATX 310412" on the top fitting cover plate of field car no. 35, identifying this tank car as NATX 310412. Figure 2c shows a stamped serial number "R50175-182" on the head of field car no. 21, identifying this tank car as NATX 310581 (consist no. 27).

2.3.2 The AAR Manual of Standards and Recommended Practices requires that "All tank cars ordered after December 31, 2003, must be equipped with two identical stainless steel identification plates. Plates must be at least 3/32 in. thick and permanently affixed by welding or mechanical fasteners in a visible location to the inboard surfaces of the AR and BL body bolster webs". [6] Figure 3a shows an example of an AAR identification plate observed on a relatively undamaged car. Figure 3b shows a representative example of an identification plate affixed by welding – the text was still legible even though the car was significantly fire-damaged. On some cars the identification plates were affixed with fasteners made

[6] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Appendix C 4.0 Tank Identification Plates

of a low melting point material. Most of these identification plates had separated from the car during the post-derailment fire (a representative example is shown on Figure 3c). One identification plate was missing the items of text required by the AAR (Figure 3d).

2.4 Description of the Derailment Zone

2.4.1 The main track intersected with Frontenac Street just west of the Mégantic West turnout. The Mégantic West turnout was a No. 11, 115-pound, left hand-operated turnout designed for a maximum speed of 15 mph. It was located at Mile 0.23 with the switch points facing west. The turnout was in the entry spiral of a 4.25° right-hand curve in the direction of movement. The derailment zone started at Mile 0.23, just east of the Frontenac public grade crossing and covered the main track, 3 adjacent yard tracks and the west leg of the wye. The different tracks are indicated by red dashed lines on Figure B-1. At the time of the accident, there were 2 cuts of box cars in the adjacent yard tracks. Figure B-2a is an aerial view of the derailment zone showing the orientation of the A and B ends of each tank car as it came to rest and the direction of the end leading prior to the derailment (indicated by red arrows on Figure B-2a). Thirty-two (32) cars came to rest on their side, 18 cars were upright and 13 cars upside down (Figure B-2b).

2.4.2 The box car and the first 8 derailed tank cars (consist no.3 through 10) came to rest between the main track and the west leg of the wye track (Figure B-3a). Consist no.3 came to rest with its B end adjacent to a box car parked on yard track 2 (Figure B-3b). Figure B-3c is an in-situ photo showing a ground mark originating from the top fittings of consist no.5. The ground mark suggests that this car slid on its side for some distance before coming to rest. Figure B-3d shows the condition of yard tracks 1 and 2 looking back along the direction of this ground mark. The rail was broken in several places and one piece was bent back 180 degrees. Figure B-3e is an in-situ photo showing a ground mark and trail of debris originating from consist no.8 and 9. This suggests these cars followed a trajectory situated roughly between yard tracks 2 and 3 before coming to rest. Consist no.10 came to rest with its leading end closest to the trailing end of consist no.9 (Figure B-2a). This suggests that consist no.10 remained attached to the two other cars for some distance and that its trailing end swung out when the car became uncoupled.

2.4.3 The next 2 derailed cars (consist no.11 and 12) came to rest on their side, approximately parallel to the west leg of the wye. The AR bolster of consist no.12 was pierced by two rails from a switch (see Figures A-10e, A-10f, B-4a and B-4c). It is considered most probable that these rails acted as an anchor for the derailed car. The car was likely pushed a short distance in the direction of movement, before the rails embedded in the bolster prevented further movement. Figure A-10d is an in-situ photo showing a pile-up of ballast at the leading end of the car created by this forward motion. Figure A-10d also shows the severe impact damage sustained by the trailing end of consist no.12 when it was hit by consist no.13.

2.4.4 Most of the derailed tank cars located to the rear of consist no.12 were jackknifed[7] towards the wye track (Figures B-4b and B-4c). As the number of cars in the pile-up increased, some cars were forced into the ground while others were projected to the side and eventually on top of the pile (Figures B-4b, B-5a and B-5b). Thus consist no.21, 43, 55, 63, 64 and 65 came to rest at a slight angle or parallel to the direction of movement. Figure B-6a shows a portion of the pile-up where the derailed tank cars were partially buried and crushed against each other. In the main pile-up, the derailed tank cars were stacked up to 3 deep (Figures B-6b, B-6c and B-6d). Figure B-7 shows the relative position of 3 such cars (consist no.38, 39 and 55) after the neighbouring cars were removed during recovery operations. Clearly these cars were extensively crushed against one another. The last jackknifed car (consist no.62) sustained side impacts from cars no. 63 and 64.

2.5 Shell Damage

2.5.1 Table 4 summarizes the shell conditions observed on the derailed tank cars. Twenty-one (21) cars had no breach in the shell. Of these 21 cars, 4 cars (consist no.6, 11, 64 and 65) had no dent whereas 17 cars (consist no.5, 7, 8, 9, 10, 13, 16, 19, 21, 27, 29, 33, 34, 35, 36, 37 and 61) exhibited deformations ranging from localized dents (Figure A-5e) to large-scale buckling (Figure A-31c). The deformations observed on the tank shells were indicative of impacts with bodies ranging from small, relatively sharp objects (coupler, body bolster) to large, very blunt objects (head of another car).

Table 4: Summary of Shell Damage

Condition	No. of cars affected
No dent	4
Deformed/dented with no breach	17
Breached due to impact damage	37
Breached due to thermal tears	4
Unknown[8]	1

2.5.2 Thirty-seven (37) cars were breached due to impact damage to the shell. Figure 4 shows the location of cars with shell breaches due to impact damage within the derailment zone. Four (4) cars had sustained thermal tears in their shell – these cars are discussed in more detail in section 2.10.

2.5.3 Due to the large number of derailed cars and limited time available for inspection of each car, the dimensions of each shell breach were not measured. Nevertheless, the shell breaches may be grouped according to three qualitative size categories:

- "large" breaches: breaches with dimensions commensurate with the car's diameter. Representative examples of large breaches are shown in Figures A-23f, A-30d, A-48g, A-52c and A-57c (consist no. 25, 32, 50, 54 and 59, respectively).

[7] Piled up with an alternating-direction pattern

[8] Car PROX 44150 (consist no.60) was disposed without having been inspected by the TSB investigation team or the RSI-AAR Safety Project. Based on the information available from in-situ and aerial photos, the shell of this car was extensively deformed but it could not be confirmed if it was breached.

- "medium" breaches: breaches with dimensions commensurate with the manway nozzle diameter (about 20 inches). Representative examples of medium breaches are shown in Figures A-1a, A-29d, A-39d and A-56d (consist no.3, 31, 41 and 58, respectively).
- "small" breaches: breaches with dimensions on the order of a few inches. Representative examples of small breaches are shown in Figures A-43b and A-54d (consist no.45 and 56, respectively).

Table 5 summarizes the largest size breach observed for each car and the number of cars affected. The location of cars with different breach size is indicated in Figure 5. The majority of cars with shell breaches (33 out of 37) had medium to large breaches.

Table 5: Size of Shell Breaches[9]

Size of breach	No. of cars affected	Consist no.
Large	20	12, 14, 17, 20, 22, 23, 25, 28, 32, 43, 48, 49, 50, 51, 52, 53, 54, 57, 59, 62
Medium	13	3, 24, 30, 31, 38, 39, 40, 41, 42, 44, 46, 47, 58
Small	4	15, 45, 55, 56

2.5.4 Visual examination of the shell breaches in the field revealed features such as inclined fracture surfaces, a rough appearance, and localized plastic deformation indicative of a ductile overstress mode of failure. No sign of fatigue failure was observed. Occasionally the breach was associated with one of the welds joining the shell rings (see cars ACFX 76605, Table A-23 and TILX 316622, Table A-52 for representative examples). However, such fracture surfaces were typically situated in extremely deformed portions of the shell and there was no indication that a defective weld was contributory to the fracture.

2.5.5 Tank cars with various degrees of impact damage were selected for measurement using a three-dimensional (3D) laser scanning technique and the results are summarized in Table 6. [10] The shells of these cars exhibited impact damage ranging from a localized buckle (consist no.61) to large scale buckling (consist no.25, 35, 38 and 42). Car TILX 316570 (consist no.12) was also scanned as it was representative of a large rupture caused by an axial (head) impact. This large shell rupture was measured to be 3.9 m in length, with a surface area of about 1.1 m^2.

2.5.6 The 3D laser scan analysis revealed that the subject tanks had sustained significant reductions in volume, close to 40% for the most deformed car. The cross-sectional changes in the most deformed portion of the tank shells exhibited reductions of up to 75%. Relatively modest reductions in tank length were measured, ranging from about 0.5 to 2.7%. These results are not unexpected as the tanks are known to be more compliant under side impacts than in the axial direction. [11] The radius of curvature measured at a sharp buckle in the shell of car

[9] Does not include thermal tears
[10] TSB Engineering Report LP165/2013 Tank Car Volume Measurements
[11] S. W. Kirkpatrick, *Detailed Puncture Analyses Tank Cars: Analysis of Different Impactor Threats and Impact Conditions*, (Final Report to the Federal Railroad Administration Office of Research and Development, U.S. Department of Transportation, Washington, D.C.) March 2013

WFIX 130545 was on the order of 0.1 m, as compared to the undamaged shell radius of 1.524 m.

Table 6: Summary of 3D Laser Scan Results

Parameter	Percent change relative to an undamaged car (a negative value indicates a reduction)					
	Car no.12 TILX 316570	Car no.25 ACFX 76605	Car no.35 WFIX 130545	Car no.38 ACFX 71505	Car no.42 CTCX 735572	Car no.61 TILX 316533
Tank volume	-5.52	-39.7	-26.8	-22.8	-11.2	-2.7
Tank length	-0.77	-2.76	-1.58	-2.42	-0.60	-0.51
Tank cross-sectional area	-17 [A]	-73.6 [B]	-52.8 [B]	-53.3 [B]	-17.7 [B]	-11.5 [C]

[A] measured adjacent to the rupture
[B] measured in the most deformed region
[C] measured at the transverse buckle

2.6 Head Damage

2.6.1 Table 7 summarizes the head conditions observed on the derailed tank cars. Thirty-two (32) cars had no breach in the head. Of these 32 cars, 4 cars had no dent whereas 28 cars exhibited deformations ranging from localized dents (consist 16, Figure A-14b) to deep dents covering most of the head area (consist 20, Figure A-18g). The deformations observed on the tank heads were indicative of impacts with bodies ranging from small, relatively sharp objects (coupler, body bolster) to large, very blunt objects (head of another car). Many of the dents were associated with gouges or scrape marks.

Table 7: Summary of Head Damage

Condition	No. of cars affected	Consist no.
No dent or breach	4	4, 11, 13, 65
Dented with no breach	28	5, 10, 12, 14, 16, 20, 21, 22, 23, 24, 26, 30, 31, 32, 35, 37, 39, 40, 43, 47, 48, 49, 50, 51, 57, 59, 61, 64
Breach in bottom portion of head	10	15, 19, 28, 33, 42, 45, 52, 54, 60, 63
Breach in top portion of head	21	3, 6, 7, 8, 9, 17, 18, 25, 27, 29, 34, 36, 38, 41, 44, 46, 53, 55, 56, 58, 62

2.6.2 Thirty-one (31) cars contained at least one head breach. Figure 6 shows the location of the cars with head breaches within the derailment zone. Ten (10) cars were breached in the bottom portion of the head (below mid-height). Twenty-one cars (21) had at least one breach in the top portion of the head (at or above mid-height). Several cars were breached on the side of a head or near the head-to-shell weld; these were counted as head breaches. Most head breaches ranged in size from a few inches to less than a foot. These included rail punctures (consist no. 3 and 6, Figures A-1a and A-4d), rail burns [12] (consist no. 8 and 9, Figures A-6d and A-7d) and punctures from impacts with larger objects such as couplers, trucks

[12] A rail burn is damage to the tank resulting from contact with rail

or bolsters (consist no.19 and 27, Figures A-17d and A-25a). Three (3) cars exhibited large head breaches – consist no.25 (Figures A-23a and A-23c), consist no.36 (Figure A-34b) and consist no.58 (Figures A-56a). These large head breaches were associated with extensive deformations and crushing of the head and adjacent shell.

2.6.3 All of the cars (except for the 4 undamaged cars listed in Table 7) exhibited some form of impact damage (denting or breach) in the top portion of at least one head. This is not unexpected as the majority of these cars came to rest on their side or upside down, thereby bringing the top portion of the heads closer to the ground and increasing the possibility of impacts with objects such as rail, couplers, and body bolsters. It should be noted that the heads of some cars were extensively deformed, yet had no puncture (for example consist no.48 and 51, Figures A-46b and A-49a). This was typically associated with extensive crushing of the shell in the vicinity of the head, consistent with a side impact (consist no.43, Figure A-41a). In some cases the extensive head and shell deformations caused the head to separate from the shell (consist 52, Figure A-50d). This type of breach was considered a large shell breach and is accounted for in the damage summary presented in Table 5.

2.6.4 Visual examination of the head punctures in the field revealed features such as inclined fracture surfaces, a rough appearance, and localized plastic deformation indicative of a ductile overstress mode of failure. No sign of fatigue failure was observed.

2.7 Top Fittings Damage

2.7.1 The information pertinent to the top fittings installed on the derailed tank cars is summarized in Table 8. All of the subject cars were equipped with a top unloading nozzle and flange to which several fittings were attached. On the 32 cars built to COC L116012A, the top fitting housing was a protective structure designed in accordance with the AAR's top fittings protection requirements for non-pressure cars. [13] The top discontinuity protection structures "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", where W is defined as the designed gross rail load of the car, less trucks. [14] The 31 other cars were equipped with hinged protective housings fabricated of material with a minimum thickness of 0.119 inch, as specified by 49 CFR 179.200-16(g).

[13] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 2, paragraph 2.6
[14] Ibid, Appendix E Part 10.2

Table 8: Top Fitting Information

Builder	No. of cars	COC	Top unloading arrangement	Protection type
Trinity	32	L116012A	20-inch diameter multi-housing nozzle with bolted cover plate, 3-inch and 2-inch ball valves, vacuum relief valve and pressure relief valve	¾-inch wall carbon steel housing with a hinged ¼-inch flat cover meeting AAR requirements for top discontinuity protection
	2	L066085	15-inch diameter multi-housing nozzle with bolted cover plate, 2-inch and 1-inch ball valves and vacuum relief valve	0.1198-inch thick hinged flat-top protective housing
Gunderson	9	L114001	15-inch diameter top unloading nozzle and flange with 3-inch and 2-inch ball valves	hinged flat-top protective housing
ARI	9	F111018	15-inch diameter top unloading nozzle and flange with 3-inch ball valve, air inlet and vacuum relief valve	hinged flat-top protective housing
	1	F071004C		
ACF	1	A801029A	15 3/8-inch diameter top unloading nozzle and flange with 2-inch and 1-inch ball valves and vacuum relief valve	0.1198-inch thick hinged dome-shaped protective housing
	2	A811019A		
	1	A861020		
	1	A911018B		
	1	A841016	19 ¾-inch diameter top unloading nozzle and flange with 3-inch ball valve, air inlet and vacuum relief valve	0.1198-inch thick hinged flat-top protective housing
	1	A851028		
Union Tank Car	2	F067034B	top unloading nozzle and flange with siphon and air inlet fittings	hinged flat-top protective housing
	1	F067036B		
	1	F067040A		

2.7.2 A representative example of an undamaged top discontinuity protection-type housing is shown in Figure A-28e (consist no.30). Figures A-56e and A-61f (consist no.58 and 63, respectively) are representative examples of the protective housings.

2.7.3 Table 9 summarizes the top fitting damage observed on the 32 cars with top discontinuity protection-type housings. Twenty-seven (27) cars had sustained some form of impact damage to the housing. The top fittings of 4 cars with impact-damaged housings were sheared off or otherwise compromised. On 3 cars with breached top fittings (consist no. 31, 32 and 54), the housing wall and cover had separated from the top unloading nozzle cover plate (Figures A-29e, A-30e and A-52e). On the fourth car (consist no. 52), the housing wall was deformed and the cover had separated due to impact damage (Figure A-50g).

2.7.4 Table 10 summarizes the top fitting damage observed on the 31 cars with protective housings. The top fitting housings of 26 cars were impact-damaged or missing. The top fittings of 16 cars were breached as a result of this impact

damage. Cars CTCX 735629 (consist no.24, Figure A-22e) and NATX 303128 (consist no. 41, Figure A-39f) are representative examples of impact-damaged protective housings. The location of cars with breached top fittings in the derailment zone is shown in Figure 7.

Table 9: Top Fitting Damage on Cars with Top Discontinuity Protection Housing

Condition	No. of cars affected	Consist no.
No visible impact damage to housing	5	10, 11, 30, 35, 64
Housing impact damaged with cover still attached	20	3, 4, 5, 6, 12, 14, 16, 18, 19, 22, 34, 44, 45, 46, 47, 48, 49, 50, 55, 61
Housing impact damaged with cover missing	4	23, 29, 43, 52
Housing missing	3	31, 32, 54
Top fittings breached	4	31, 32, 52, 54

Table 10: Top Fitting Damage on Cars with Protective Housing

Condition	No. of cars affected	Consist no.
No visible impact damage to housing	4	56, 60, 63, 65
Housing impact damaged	12	8, 9, 20, 24, 26, 28, 33, 39, 42, 51, 53, 58
Housing missing	14	7, 13, 15, 17, 21, 25, 27, 36, 37, 38, 40, 41, 57, 62
Top fittings breached	16	7, 13, 15, 17, 21, 25, 26, 33, 36, 37, 38, 39, 40, 41, 57, 62
Unknown[15]	1	59

2.8 PRD Damage

2.8.1 Pressure relief devices are designed to prevent the rise of internal pressure in excess of a specified value resulting from exposure to abnormal conditions. Federal regulations require that the start-to-discharge (STD) pressure of a PRD may not be lower than 75 psig[16] or exceed 33 percent of the minimum tank burst pressure. [17] Since DOT 111A100W1 tank cars have a minimum tank burst pressure of 500 psig [18], their maximum STD pressure is 165 psig. In the present case, 48 cars had PRDs with a STD pressure of 75 psig, and 15 cars had PRDs with a STD pressure of 165 psig (Table 11). The 7 cars built by ACF had 2 PRDs located on either side of the top fittings housing and manway. The other cars had 1 PRD. The PRD of the 32 cars built to COC L116012A was fastened to the top unloading nozzle assembly, within the top discontinuity protection housing. On

[15] Not visible for inspection
[16] Pounds per square inch gauge, a unit of pressure relative to the surrounding atmosphere
[17] 49 CFR 179.15(b)(2)(i)
[18] 49 CFR 179.201-1

the 31 other cars the PRDs were fastened to a safety valve nozzle attached to the top of the tank.

2.8.2 In addition to different STD pressures, PRDs are also designed with different flow capacities. A PRD that can discharge product at greater than 27000 scfm[19] is considered to have high flow capacity. In the present case, 22 cars were equipped with PRDs providing an actual flow capacity greater than 27000 cfm, including the 15 cars with STD pressure of 165 psig. The STD pressure and the flow capacity together determine how efficiently the PRD can relieve pressure in a tank car.

2.8.3 During a derailment, PRDs can end up in the liquid space of a tank car due to the orientation of the car after the derailment. It should be noted that pressure relief valves designed for compressible (vapour) service may not provide the same operational characteristics when operated in liquid, since liquids do not provide the expansive forces that vapours do. [20] This must be taken into account when calculating a PRD's capacity to release pressure when the tank is over-turned. The AAR requires that the coefficient of discharge [21] shall be 0.8 for vapours and 0.6 for liquids. Other coefficients of discharge may be used if justified by actual flow test data. [22]

Table 11: PRD Information

Builder	No. of cars	COC	No. of PRDs	Start-to-discharge pressure (psig)	Flow capacity, actual (cfm)
Trinity	32	L116012A	1	75	20,464
	2	L066085	1	165	35,608
Gunderson	9	L114001	1	165	38,902
ARI	8	F111018	1	75	20,605
	1	F071004C	1	75	20,605
ACF	1	A801029A	2	75	35,660
	2	A811019A	2	75	35,660
	1	A841016	2	75	35,660
	1	A851028	2	75	35,660
	1	A861020	2	75	35,660
	1	A911018B	2	75	33,808
Union Tank Car	2	F067034B	1	165	38,902
	1	F067036B	1	165	38,902
	1	F067040A	1	165	38,902

[19] Standard cubic feet per minute
[20] API Recommended Practice 520, Seventh Edition, January 2000, 2.2 Pressure Relief Valves
[21] The coefficient of discharge is the ratio of the actual flow to the flow of an ideal conduit with the same orifice area.
[22] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 2, paragraph 2.2.15

2.8.4 The PRDs of 12 derailed cars exhibited breaches due to impact damage. Of the 32 cars with a PRD located within the top discontinuity protection-type housing, only 3 cars had breached PRDs (consist no.31, 32 and 54 – see Figures A-29e, A-30e and A-52e). On the other hand, 9 of the 31 cars with unprotected PRDs had breached PRDs (consist no.21, 24, 25, 33, 37, 38, 56, 57, and 62 – see Figures A-19e, A-22e, A-23h, A-31f, A-35g, A-36h, A-54f, A-55e and A-60f). The location of the cars with breached PRDs within the derailment zone is indicated on Figure 8.

2.9 BOV Damage

2.9.1 The derailed tank cars had different types of BOV and bottom protection. Six (6) cars (consist no.17, 25, 36, 38, 39 and 58) were equipped with an internal self-closing plug-style BOV with a tapered mounting flange that met the AAR Level A protection requirements. [23] All of the other tanks cars (57) were equipped with a 4-inch external ball valve and with a cast or fabricated skid, per AAR requirements. [24]

2.9.2 Table 12 summarizes the bottom outlet damage observed on the derailed cars. The skids of 26 cars had experienced some form of impact damage; mostly deformation and/or cracking caused by side impacts (see Figure A-40f for a representative example). Four (4) cars (consist no.45, 51, 52 and 57) exhibited extensive impact damage such as a broken skid and/or separated skid-to-shell welds. It should be noted that the shell of these cars was severely deformed in the vicinity of the skid, indicating that the tank had been subjected to high impact forces (see Figure A-49g for a representative example). Visual examination of the skid fractures in the field revealed features consistent with an overstress mode of failure.

Table 12: Summary of Bottom Outlet Damage

Skid		Handle assembly		BOV adaptor	
Condition	**No. of cars affected**	**Condition**	**No. of cars affected**	**Condition**	**No. of cars affected**
No impact damage	29	No impact damage	18	No impact damage	25
Impact damaged	26	Deformed or impact damaged	21	Sheared off exposing BOV ball[25]	33
Car has no skid	6	Missing	22	Sheared off exposing BOV plug	3
Unknown[26]	2	Unknown	2	Unknown	2

[23] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Appendix E Paragraph 10.1.5.1
[24] Ibid, Paragraph 10.1.2
[25] Includes consist no.23 (TILX 316556) on which the cap and plug assembly sheared off, exposing the BOV ball
[26] Not visible for inspection

2.9.3 The AAR requires that "Bottom outlet valve handles, unless stowed separately, must be designed to either bend or break free on impact, or the handle in the closed position must be located above the bottom surface of the skid". [27] In the present case, the BOV handle assemblies of 43 cars were deformed, impact damaged or missing (Table 12).

2.9.4 The BOV adaptor was sheared off at the mounting flange (the intended breaking point) of 36 cars, exposing the BOV ball (33 cars) or plug (3 cars). The exposed plugs were closed with no sign of leakage (consist no.36, 39 and 58, Figures A-34f, A- 37g and A-56g). However, on 7 of the 33 cars with exposed BOV balls (consist no.23, 34, 35, 45, 46, 61 and 64), the BOV ball was open, partially open or visibly leaking product (see Figures A-21h, A-32f, A-33h, A-43f, A-44d, A-59h and A-62g). It was noted that these 7 cars also had damaged or missing handle assemblies. Figure 9 shows the location of the 7 cars with breached BOVs within the derailment zone. These tank cars came to rest on their right side (consist no.23 and 34) or upright (consist no.35, 45, 46, 61 and 64). Consequently the gap created by the open/partially BOV ball would have permitted the release of product.

2.9.5 Product residue was observed on the exterior of the BOV adaptor of some cars (consist no. 15 and 37 - see Figures A-13h and A-35f) and on the exposed BOV ball (consist no. 8, 16, 49 and 55 - see Figures A-6h, A-14f, A-47d and A-53h) suggesting that some product had seeped out of these BOVs.

2.9.6 Elastomeric gaskets are typically used in BOV arrangements. Excessive heat will gradually degrade elastomeric materials as well as deteriorate their performance. Gaskets exposed to high temperature or prolonged heat exposure can exhibit premature failure leading to leakage. A temperature above 350°F (177°C) is considered high temperature for this type of material. [28] Temperatures within pool fires on the order of 900 to 1100°C have been reported in the available literature. [29] Thus, it is likely that the seepage observed on the subject BOVs was caused by high temperature damage to the BOV gaskets sustained during the post-derailment fire.

2.10 Thermal Tears

2.10.1 A thermal tear occurs when a tank car is exposed to elevated temperatures such as those resulting from a post-derailment fire. As the temperature inside the tank rises, the product vapourizes, causing an increase in both its internal pressure and the stresses in the tank wall. As temperatures rise, the strength of metal alloys decreases while ductility increases, although various embrittlement phenomena may be encountered. [30] Eventually, if the internal pressure is not relieved by the PRD or if it builds up so quickly that the PRD cannot relieve it, the tank ruptures when the stresses in the tank wall exceed the tank material's stress-rupture

[27] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Appendix E, Paragraph 10.1.2.8
[28] http://www.stockwell.com/high-temp-gaskets.php, website consulted on 16 February 2014.
[29] SPFE Handbook of Fire Protection Engineering, 4th Edition (National Fire Protection Association, 2008), page 3-295
[30] Metals Handbook 9th Ed. Vol.12 Fractography (ASM International, 1987), page 121-122

strength. Such ruptures are quite energetic due to the sudden release of the built-up pressure, resulting in large fire balls.

2.10.2 Thermal protection systems for tank cars consist of various insulating materials and/or coatings that may be covered by a steel jacket. When installed on a tank car, the thermal protection system must prevent release of any of the tank car's content (except through the PRD) when subjected to a pool fire for 100 minutes and a torch fire for 30 minutes. [31] In the present case, none of the derailed tank cars had thermal protection nor was this a requirement at the time of construction.

2.10.3 Four (4) derailed cars contained longitudinal shell ruptures that were identified as thermal tears (see Table 4). Detailed observations for these cars are presented in Tables A-2, A-16, A-24 and A-61 and the salient points are summarized in Table 13. Comparing the location of each thermal tear to the car's orientation after coming to rest, it was determined that all of the thermal tears were situated in the vapour space.

2.10.4 Figure 10 shows the location of the cars with thermal tears within the derailment zone. Car WFIX 130608 (consist no.4) was exposed to the burning product released from punctures in the adjacent car TILX 316547 (consist no.3). The 3 other cars came to rest within the main pile-up and were exposed to the large post-derailment pool fire. Consist no.4 had no other breaches that might have contributed to the release of internal pressure (Table 13). The 3 other cars contained small breaches that might have released some of the built-up pressure.

Table 13: Cars with Thermal Tears

Consist no.	Reporting mark	Orientation of derailed car	Location of thermal tear	Other breach in tank?
4	WFIX 130608	left side	right side	no
18	TILX 316333	right side	left side	small puncture in B end head
26	PROX 44293	upside down	top-left side	bent top fitting
63	NATX 310515	upright & tilted to right	top-left side	small puncture in A end head

2.10.5 Table 14 summarizes the information relative to the PRDs installed on the cars with thermal tears. Two cars had PRDs with a start-to-discharge pressure of 75 psig while the 2 other cars had 165 psig PRDs. Comparing the location of the PRD to the car's orientation after coming to rest, it was determined that the PRDs of these 4 cars were in the liquid space.

[31] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 2, paragraph 2.2.15

Table 14: PRDs on Cars with Thermal Tears

Consist no.	Reporting mark	No. of PRDs	Start-to-discharge pressure (psig)	Flow capacity, actual (cfm)
4	WFIX 130608	1	75	20,464
18	TILX 316333	1	75	20,464
26	PROX 44293	1	165	38,902
63	NATX 310515	1	165	38,902

2.10.6 Analysis of 3D laser scan data[32] collected for car WFIX 130608 indicates that the thermal tear was 4.4 m in length, with a surface area of about 2.5 m^2. The length of this car was reduced by about 0.29% as compared to an undamaged car. The portion of the tank located away from the thermal tear exhibited a small volume increase of about 1.5% relative to an undamaged car. The length of the thermal tears in the 3 other cars was estimated in the field at about 1.6 m for car NATX 310515 and 2.4 m for cars PROX 44293 and TILX 316333.

2.10.7 Tensile ruptures caused by the rapid overheating of a vessel under pressure typically exhibit swelling of the wall in the regions adjacent to the rupture and an obvious reduction of the wall thickness (thin-lip rupture). Prolonged overheating and exposure to oxidizing or other embrittling conditions can result in ruptures with thick-edged fracture lips and little swelling (thick-lip rupture). [33] In the present case, the thermal tears in consist no.4 and 26 displayed features consistent with a thin-lip rupture (see Figures A-2c and A-24e) whereas those in consist no.18 and 63 were more representative of thick-lip ruptures (see Figures A-16f and A-61e). Since these 4 cars were located in different parts of the post-derailment fire, they likely experienced different exposure conditions. In addition, consist no.18, 26 and 63 contained small breaches that may have permitted the release of some of the built-up pressure, whereas consist no.4 had no such breach. This might explain why consist no.18, 26 and 63 had smaller thermal tears than consist no.4.

2.11 Manway Damage

2.11.1 The derailed cars were equipped with hinged and bolted manway covers. On 13 cars, the manway cover was open when the TSB investigation team inspected the staged car. Aerial and in-situ photos indicate that these manway covers were closed when the cars came to rest and subsequently opened during recovery operations.

2.11.2 Table 15 summarizes the condition of the manways. The manway cover of 2 cars had separated as a result of impact damage (consist no.16 and 21, Figures A-14g and A-19f). Car TILX 316379 (consist no.16) came to rest on its left side while car NATX 310477 (consist no.21) came to rest upside down. Consequently, both cars would have released product from the open manway. One manway cover was partially consumed by the post-derailment fire (consist no.38, Figure A-36h).

[32] TSB Engineering Report LP165/2013 Tank Car Volume Measurements
[33] Metals Handbook 9th Ed. Vol.11 Failure Analysis and Prevention (ASM International, 1986) page 605-606

Table 15: Summary of Manway Damage

Condition	No. of cars affected
Cover missing	2
No visible impact damage	34
Hinge, bolts or lugs deformed or broken	22
Unknown[34]	5

2.11.3 The manway cover hinges, bolts and/or lugs of 22 cars exhibited impact damage that likely could have compromised the seal. In addition to this impact damage, it is considered most probable that the manway gaskets of most cars were damaged by exposure to the post-derailment fire. Indeed, some cars exhibited a visible gap and/or product residue between the manway nozzle and cover, suggesting that product was released from the manway (see Figure A-59f for a representative example).

2.12 Burn-throughs

2.12.1 Thirteen (13) cars exhibited extreme fire damage in the form of burn-throughs. [35] The location of these cars within the derailment zone is indicated in Figure 11. Representative examples of burn-throughs are presented in Figures A-33e, A-36h, A-46c and A-59e (consist no.35, 38, 48 and 61). The burn-throughs had jagged edges and the regions around the perforations had visibly reduced wall thickness. In some cases the tank material around the perforation contained brittle cracks and could be easily broken off by hand.

2.12.2 The metallurgical examination of a representative coupon containing a burn-through revealed that the tank material was carburized and oxidized consistent with exposure to crude oil and air at high temperature during the post-derailment fire. It was concluded that these reactions were likely responsible for the loss of material causing the burn-through. [36]

2.13 Stub Sill and Coupler Damage

2.13.1 The AAR Manual of Standards and Recommended Practices specifies the requirements for stub sill, reinforcement pad and shell attachments. The stub sills must be attached to reinforcing plates that are attached to the tank such that "The welds securing the sill to the reinforcing plate must have a total throat area not exceeding 85% of the total throat area for the reinforcing plate-to-shell welds. These areas may be modified to use equivalent area values if the welding procedure differs for each weld area under consideration and also may be modified for parent metal strength considerations". [37] Requirements are also provided for the extension of the reinforcing plate on either side of the sill attachment and at the head brace attachment. [38] These requirements are intended

[34] Not visible for inspection
[35] A burn-through is a perforation caused by fire damage.
[36] TSB Engineering Laboratory Report LP168/2013 Metallurgical Analysis of Tank Car Coupons
[37] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 6, paragraph 6.1.2.5
[38] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 6 paragraphs 6.1.2.5.2 and 6.1.2.5.3 and Appendix E Part 13.0

to ensure that if a stub sill is overloaded, the separation occurs between the sill and the pad rather than at the tank.

2.13.2 Table 16 summarizes the stub sill information provided on the derailed cars' COC. All of the subject stub sill designs incorporated a head brace except for the ACF type stub sills. The AAR Manual of Standards and Recommended Practices requires that all tank cars carrying regulated commodities be equipped with top-and-bottom shelf couplers. [39] All of the subject tank cars were equipped with top-and-bottom shelf couplers.

Table 16: Stub Sill Information

Builder	No. of cars	COC	Stub sill type
Trinity	32	L116012A	TRN 023
	2	L066085	TRN 023
Gunderson	9	L114001	GUN-001
ARI	8	F111018	ARI 300
	1	F071004C	ARI 300
ACF	1	A801029A	ACF
	2	A811019A	ACF
	1	A841016	ACF
	1	A851028	ACF
	1	A861020	ACF
	1	A911018B	ACF
Union Tank Car	2	F067034B	UTL ZBG
	1	F067036B	UTL ZBG
	1	F067040A	UTL ZBG

2.13.3 Table 17 summarizes the impact damage observed on the stub sills and couplers of the derailed tank cars. Only 5 cars had no impact damage to either stub sill or coupler. All of the other cars (58) exhibited at least one damaged stub sill and/or coupler. Most cars (46) were damaged on both ends. Eleven (11) cars exhibited damage to their stub sill(s) but no coupler damage. Forty-seven (47) cars had both stub sill and coupler damage. Representative examples of this damage include deformed stub sill (Figure A-11a, consist no.13), a separated knuckle (Figure A-17d, consist no.19) and a broken stub sill and coupler (Figure A-51f, consist no.53). It was noted that even the last 2 derailed cars (consist no.64 and 65) exhibited significant impact damage to their stub sills and couplers (see Tables A-62 and A-63).

[39] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 6 paragraph 6.1.6.2.1

Table 17: Summary of Stub Sill and Coupler Damage

Condition	No. of cars affected	No. of cars with stub sill damage only	No. of cars with stub sill and coupler damage
No impact damage	5	not applicable	not applicable
Impact damage at one end	12	4	8
Impact damage at both ends	46	7	39

2.13.4 Nine (9) derailed tank cars exhibited separations at the stub sill attachments. The A end stub sill of car ACFX 76605 (consist no.25) had separated from the front sill pad (Figure A-23c). Cars TILX 316319, CTCX 735617 and TILX 316533 (consist no.50, 51 and 61) exhibited separations at the attachments between the head brace and front sill pad or between the stub sill and head brace (Figures A-48b, A-49b and A-59b). On PROX 44293, TILX 316523, TILX 316613 and TILX 316622 (consist no.26, 46, 47 and 54), the front sill pad had separated from the tank at the fillet weld (Figures A-24b, A-44a, A-45b and A-52b).

2.13.5 The A end of car WFIX 130664 (consist no.44) also contained a separation at the fillet weld between the front sill pad and the tank. This crack had propagated to the body bolster pad fillet weld and into the head-to-shell weld, breaching the tank at 2 locations (Figures A-42b and A-42c). The analysis of 3D laser scan data for car WFIX 130664 indicates that the lower tank breach was 0.50 m long and 0.11 m wide. [40] The upper tank breach was 0.25 m long and 0.03 m wide. The gap between the separated front sill pad and head surface was about 5.3 cm. There was a large dent in the left hand portion of the A end head adjacent to the front sill pad separation. The area covered by this dent was about 2.8 m^2 and the dent had a volume of about 0.64 m^3.

3.0 DISCUSSION

3.1 Summary of Tank Car Breaches

3.1.1 Table 18 summarizes the various types of breach observed on each derailed car. Four (4) cars exhibited no visible breach (consist no.5, 10, 11 and 65). Of the 59 breached cars, 33 (56%) had more than 1 type of breach.

[40] TSB Engineering Report LP165/2013 Tank Car Volume Measurements

Table 18: Types of Breach Observed on each Tank Car[41]

Position in consist	Car initial	Car number	Type of breach						
			Head	Shell	Top fittings	PRD	Manway	BOV	Thermal tear
3	TILX	316547	■	■					
4	WFIX	130608							■
5	TILX	316359							
6	TILX	316338	■						
7	NATX	310428	■		■				
8	CTCX	735541	■						
9	DBUX	303879	■						
10	WFIX	130682							
11	TILX	316641							
12	TILX	316570		■					
13	NATX	310457			■				
14	WFIX	130638		■					
15	NATX	310473	■	■	■				
16	TILX	316379					■		
17	ACFX	79709	■	■	■				
18	TILX	316333	■						■
19	TILX	316549	■						
20	CTCX	735527		■					
21	NATX	310477			■	■	■		
22	WFIX	130603		■					
23	TILX	316556		■				■	
24	CTCX	735629		■	■	■			
25	ACFX	76605	■	■	■	■			
26	PROX	44293			■				■
27	NATX	310581	■						
28	PROX	44202	■	■					
29	TILX	316234	■						
30	TILX	316584		■					
31	WFIX	130571		■	■	■			
32	TILX	316330		■	■	■			
33	NATX	310412	■		■	■			
34	TILX	316317	■					■	
35	WFIX	130545						■	
36	ACFX	79698	■		■				
37	NATX	302784			■	■			
38	ACFX	71505	■	■	■	■			
39	ACFX	71121		■					
40	CTCX	735537		■	■				
41	NATX	303128	■	■	■				
42	CTCX	735572	■	■					
43	WFIX	130616		■					
44	WFIX	130664	■	■					
45	WFIX	130630	■	■				■	
46	TILX	316523	■	■				■	
47	TILX	316613		■					

[41] Cells highlighted in orange indicate one or more breach

Position in consist	Car initial	Car number	Type of breach						
			Head	Shell	Top fittings	PRD	Manway	BOV	Thermal tear
48	TILX	316616							
49	TILX	316206							
50	TILX	316319							
51	CTCX	735617							
52	TILX	316572							
53	CTCX	735526							
54	TILX	316622							
55	WFIX	130585							
56	NATX	310508							
57	CTCX	735525							
58	ACFX	79383							
59	PROX	44428							
60	PROX	44150							
61	TILX	316533							
62	ACFX	94578							
63	NATX	310515							
64	TILX	316528							
65	NATX	310470							

3.1.2 Table 19 summarizes the total number of cars exhibiting each type of breach. Shell breaches (37 cars) were the most frequently observed cause of product release, followed by head breaches (31 cars), and breached top fittings and PRDs (20 and 12 cars, respectively). BOV (7 cars), thermal tear (4 cars) and manway (2 cars) breaches were the less frequent causes of product release.

Table 19: Tank Car Damage Summary

Type of breach	No. of cars affected
Shell	37
Head	31
Top fittings	20
PRD	12
BOV	7
Thermal tear	4
Manway	2

3.2 Release from Breached Tank Car Shells and Heads

3.2.1 Shell breaches were the most frequent type of damage observed in this derailment. The shell breaches ranged in size from small punctures (a few inches in diameter) to large ruptures (commensurate with the tank's diameter). The majority of the shell breaches (20 out of 37, 54%) were of a size commensurate with the car's diameter. Thus, shell breaches were the most important contributors to the release of product in terms of their size (cross-sectional area) as well as the number of cars affected. It is considered that cars with large shell breaches would have released their lading almost instantaneously. Consequently, the high number of large shell breaches was a contributing factor to the large fire ball and pool fire in this derailment. Release from small shell breaches, while not instantaneous,

contributed to feed the pool fire and to spillage of product after the fire was extinguished.

3.2.2 Head breaches were the second most frequent type of damage with 31 cars affected (Table 19). The head breaches were generally smaller than the shell breaches, ranging from a few inches to about 1 foot in diameter. These head breaches would also have contributed to feed the pool fire and to product spillage.

3.2.3 The heads and shells of the derailed tank cars were constructed of 7/16 to 15/32-inch thick steel, which is thinner than specified for some other classes of tank cars. The heads were made of normalized (19 cars) or non-normalized steel (44 cars). There was no sign that non-normalized heads were less puncture resistant than normalized heads - 50% of the cars with non-normalized steel heads exhibited head breaches whereas 59% of cars with normalized heads contained head breaches. The shells were also made of normalized (11 cars) or non-normalized steel (52 cars). Only 3 of the cars with shell breaches were made of normalized steel; the others were made of non-normalized steel. It should be noted that most cars with normalized steel shells were in the portions of the derailment zone where the derailment forces were less severe (see paragraph 3.2.8). The tank fracture surfaces exhibited the typical features of ductile overstress failures (fracture surfaces inclined at 45 degrees, plastic deformation, and rough appearance). No sign of brittle failure (lack of plastic deformation, chevrons, granular appearance) was noted during the investigation. Furthermore, representative coupons taken from derailed car tanks made of normalized and non-normalized steel gave similar tensile test results. [42] In conclusion, there is no indication that the non-normalized steels used for some of the tanks were a contributing factor to the product release in this derailment.

3.2.4 The investigation showed that 18 cars exhibited both shell and head breaches (Table 18). Thirteen (13) cars had only shell breaches and 7 cars had only head breaches, with no other type of breach. It is considered most probable that some of the product release by these cars could have been reduced had their shells and heads been more impact-resistant. Specifically, cars built with thicker steel, head shields and/or tank jackets are known to be better protected. It should be noted that all of the cars (except for the 4 undamaged cars) exhibited some form of impact damage (denting or breach) in the top portion of at least one head. This suggests that full-head shields would be more beneficial than half-head shields (which only protect the bottom portion of the head) in this type of derailment.

3.2.5 Parameters such as the number of cars in the train, car weight, initial train speed, and on-track (rail) and off-track (ground) coefficients of friction are known to affect the severity of derailments. [43] In addition, the magnitude of impact forces was found to be related to the cars' relative velocity at the moment of contact (impact speed) and impact location. Tank car puncture modelling indicates that when an object contacts the tank, the forces resisting the impact loads are the pressure on the inside surface of the contact patch and the shear stress around the

[42] TSB Engineering Report LP168/2013 Metallurgical Analysis of Tank Car Coupons

[43] D. Y. Jeong et al., *Engineering Studies on Structural Integrity of Railroad Tank Cars under Accident Loading Conditions*, Volpe National Transportation Systems Center, U.S. Department of Transportation, Final Report DOT/FRA/ORD-09/18, October 2009

perimeter of the contact patch. [44] Thus the car's outage and the impactor size also influence the car's behaviour when subjected to an impact.

3.2.6 Derailments are complex and chaotic events that can involve a wide range of collisions between the various cars in the train. It was beyond the scope of the present report to analyze the circumstances of every dent and breach observed on the derailed tank cars' shell and heads. However, a qualitative analysis of the tank damage suggests that the derailed tank cars were subjected to a range of impact speeds and forces, depending on their position in the train.

3.2.7 It was noted that the cars at the front of the train (consist no.3 through 11) travelled on relatively straight trajectories. These cars also sustained relatively minor impact damage - mostly small head punctures from rail contact, with the exception of the first car (consist no.3) that impacted a box car parked on yard track 2 (Figure B-3b). These observations suggest that although these cars may have been travelling at higher speed, they were subjected to less severe impact forces than the cars located in the main pile-up.

3.2.8 The cars located immediately to the rear of consist no.12 that was anchored by the rails in its AR bolster (see paragraph 2.4.3) came to rest in alternating directions, collapsed on each other. In general these cars sustained multiple dents and punctures, with many cars exhibiting damage to both shell and heads. This suggests that these cars were exposed to more severe impact conditions than those located at the front of the train. Although cars with large shell ruptures (indicated in red on Figure 5) were scattered throughout the pile-up, about half of these cars were clustered towards the end of the train. It is considered that these cars would have encountered more severe derailment conditions than those experienced by cars located towards the front of the train. By the time these cars came to rest, there was already a large pile-up, with some cars dug into the ground and others stacked up to 3 deep. This pile-up likely acted like a wall for the derailing cars. It was noted that most of the cars at the rear of the train came to rest approximately upright (Figure B-2b), suggesting that as soon as each car derailed and came off the track, it was jackknifed and crushed against the pile-up by the cars at its rear. These highly constrained derailment conditions caused large-scale buckling and extreme tank deformations (so-called plastic collapse) and resulted in the large shell ruptures.

3.2.9 In 2011 the AAR tank car standards were amended to incorporate a number of enhancements to all Class 111 tank cars built for the transportation of Packing Group I or II materials with the proper shipping names "Petroleum Crude Oil", "Alcohols, n.o.s." and "Ethanol and Gasoline mixture". [45] For tanks constructed of normalized TC128 Grade B steel, non-jacketed tanks must be at least ½-inch thick and jacketed tanks at least 7/16-inch thick. For tanks constructed of normalized ASTM A516 Grade 70 steel, non-jacketed tanks must be at least 9/16-inch thick and jacketed tanks at least 1/2-inch thick. Cars must also be equipped with at least ½-inch half-head shields. Such enhancements have been found to

[44] S. W. Kirkpatrick, *Detailed Puncture Analyses Tank Cars: Analysis of Different Impactor Threats and Impact Conditions*, Applied Research Associates, Inc., Final Report DOT/FRA/ORD-13/17, March 2013
[45] AAR Manual of Standards and Recommended Practices, Specifications for Tank Cars C-III [M-1002], Chapter 2, paragraph 2.7

decrease the probability of product loss from tank punctures. However, it is not clear whether these enhancements would provide sufficient protection under severe impact conditions resulting in plastic collapse of the tanks, such as those prevailing during the present derailment.

3.3 Release from Breached Top Fittings and PRDs

3.3.1 The investigation showed that 4 out of 27 (15%) cars with impact-damaged top discontinuity protection housings had top fitting breaches. The top fittings of 16 out of 26 (62%) cars with impact-damaged protective housings were breached.

3.3.2 The 32 cars with a PRD located within the top discontinuity protection-type housing had significantly fewer product releases from impact-damaged PRDs – only 3 out of 32 (9%) of these protected PRDs were breached. On the other hand, 9 of the 31 (29%) cars with unprotected PRDs exhibited product release from a breached PRD.

3.3.3 Of the 20 cars with breached top fittings, more than half (11 cars, 55%) also had breached PRDs. This is not unexpected as the top fittings and PRDs are located adjacent to each other on the top of the car. Consequently, there is a fairly high probability that an impact that affects the one would also affect the other.

3.3.4 These observations indicate that top discontinuity protection is an effective means to reduce the release of product from impact-damaged top fittings and PRDs.

3.3.5 The cars with breached top fittings and/or PRDs were principally in the main pile-up (Figures 8 and 9). Most of these cars came to rest on their side or upside down, so that product would have flowed from the damaged top fitting and/or PRD to feed the pool fire. Most of the cars with breached top fittings and/or PRD had some form of head and/or shell damage in addition to the top fittings and/or PRD damage. However, 2 cars (consist no. 13 and 21) exhibited product release only from impact-damaged top fittings and/or PRD. Had these 2 cars been equipped with top discontinuity protection, they might not have had any product loss due to impact damage.

3.4 Release from Breached BOVs

3.4.1 The BOV adaptor was sheared off at the mounting flange (the intended breaking point) of more than half of the derailed cars (36 out of 63 - 57%), exposing the BOV ball (33 cars) or plug (3 cars). On 7 cars with exposed BOV balls, the ball valve was open, partially open or visibly leaking product. These 7 cars also had impact-deformed or missing handle assemblies. The breached BOV was the only type of breach observed on 3 of these 7 cars. Furthermore, these 3 cars had come to rest in the upright position such that product would have flowed from their breached BOVs. These observations suggest that these 3 cars might not have experienced any product loss if they had been equipped with a handle assembly configured to prevent actuation of the ball valve when the handle is deformed or broken off.

3.4.2 It was noted that whereas some of the cars with an internal self-closing plug-style BOV experienced damage to their bottom fittings, the exposed plug remained

closed and there was no loss of product. This suggests that the self-closing plug-style valves are inherently better protected against product loss than the external ball valves.

3.4.3 The investigation into a 2013 derailment involving Class 111 tank cars in Ontario (TSB occurrence R13T0060) has previously identified this issue and TSB Rail Safety Advisory 15/13 was issued to Transport Canada to communicate the risk of product loss through BOV handles that are damaged during derailments. The investigation results from this occurrence further reinforce the need for design improvements to reduce the risk of product loss from impact-damaged bottom fittings.

3.5 Release from Thermal Tears

3.5.1 Of the 63 derailed cars, 4 cars exhibited thermal tears. Thermal tears occur when a tank car is exposed to fire and the PRD and any other breaches in the tank are unable to vent the rising internal pressure, causing an energetic rupture of the tank. The sudden release of the pent-up pressure results in loss of the tank lading as a large fire ball. No fragments of tank material were separated as a result of the thermal tears in the present derailment. This indicates that the catastrophic releases associated with these thermal tears were less energetic than those caused by a BLEVE. [46]

3.5.2 Two of the cars with thermal tears had PRDs with a start-to-discharge pressure of 75 psig whereas the 2 other cars had 165 psig PRDs. It has been suggested that PRDs with higher start-to-discharge pressure might pose a risk of building up excessive internal pressure during a fire, thus resulting in more energetic thermal tears. In the present case, the car with the largest thermal tear (4.4 m, consist no.4) was equipped with a 75 psig PRD, whereas the car with the smallest thermal tear (1.6 m, consist no.63) had a 165 psig PRD. Thus, there was no sign that the type of PRD was contributory to the limited number of thermal tears in the present derailment.

3.5.3 The investigation revealed that at least 2 of the thermal tears occurred within 20 minutes of the accident whereas the 2 other thermal tears occurred during the extended pool fire. The AAR requirements for thermal protection systems are intended to ensure that the combination of tank car, PRD, thermal protection system and lading material must be capable of withstanding a full-immersion pool fire for 100 minutes with no product loss except through the PRD. In the present case, none of the cars were equipped with a thermal protection system nor were any required.

3.5.4 It was noted that one of the cars with thermal tears (consist no.4) came to rest adjacent to another car that was exposed to similar derailment conditions but did not sustain a thermal tear (consist no.5). This car had no visible breach (Table A-3). Its tank was slightly bulged on the side located closest to the breached cars

[46] A BLEVE (boiling liquid expanding vapour explosion) is “an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure” (SPFE Handbook of Fire Protection Engineering, 4th Edition (National Fire Protection Association, 2008), page 2-213)

(consist no.3 and no.4) that would have fed the pool fire. It is considered likely that consist no.5 had experienced a build-up of internal pressure but that the combination of temperature and internal pressure did not quite reach the levels required to cause a thermal tear. These observations suggest that relatively modest improvements in fire survivability might have been sufficient to prevent consist no.4 from sustaining a thermal tear. Simulations for tank car survivability conducted by the AAR indicate that thermal protection, thicker steel and jacketed cars can significantly extend the time a tank car can survive in a pool fire.

3.6 Release from Burn-throughs

3.6.1 All of the cars with burn-throughs contained at least one other type of breach due to impact damage. The impact-related breaches would have resulted in an immediate release of product. On the other hand, it is considered that the tank material was exposed to the post-derailment fire for some time before the cars were breached by burn-throughs. Therefore the product released from the burn-throughs contributed to feed the pool fire and the spill, after the fire was extinguished.

3.6.2 Car WFIX 130585 (consist no.55) came to rest on top of the main pile-up. It had sustained extensive fire damage with a burn-through on the top of the tank. Minor impact damage was noted. The tank was slightly bulged near the B end and contained small ruptures with a red discoloration indicative of fire damage and product residue. Neither the BOV nor the top fittings were visibly breached, although product residue was present suggesting some leakage occurred. These observations indicate that this tank car experienced a rise in internal pressure while it sat in the pool fire. The burn-through likely contributed to release some of this internal pressure so that when the tank finally failed, the result was a few small ruptures instead of a large thermal tear.

3.7 Release due to Stub Sill Failure

3.7.1 The examination showed that the vast majority of the derailed tank cars (58 of 63 – 92%) had at least one damaged stub sill and/or coupler. Most cars (46) were damaged on both ends. It was noted that even the last 2 derailed cars (consist no.64 and 65) exhibited significant impact damage to their stub sills and couplers. This is consistent with the predominantly severe impact conditions observed in this derailment.

3.7.2 Nine (9) derailed tank cars exhibited separations at the stub sill attachments. On 5 cars, these separations were located at the fillet weld between the front sill pad and the tank. On 1 car (WFIX 130664), this crack had propagated into the tank, resulting in 2 breaches, one with a length of 0.50 m and the other 0.25 m.

3.7.3 National Transportation Safety Board (NTSB) Safety recommendation R-12-09 was issued in connection with the NTSB investigation of the 19 June 2009 derailment of Canadian National freight train U7069l-l8 in Cherry Valley, Illinois. The NTSB investigation of the Cherry Valley, IL accident determined that as a result of downward loading on the draft sill of a tank car, a pad fractured from the tank wall. After the pad separation, the tank wall experienced a circumferential fracture. It was determined that the draft sill and pad attachments were configured

in a way that made this tank design susceptible to tank wall fracture resulting from a downward loading of the draft sill.

3.7.4 It was determined that car WFIX 130664 had a similar design of stub sill and exhibited a similar type of stub sill failure as that in the Cherry Valley, IL accident.

3.7.5 The NTSB recommendation asked AAR to revise the design requirements for stub sill attachments as needed to ensure that appropriate distances between welds are maintained in all directions, to prevent a crack from travelling from one attachment weld to the other and into the tank wall. It was reported that the AAR Tank Car Committee has discussed this recommendation and decided on a minimum distance between welds of 3 times the thickness of the plate being attached to the tank. The next step would be for the Committee to incorporate this change into a revised issue of the Manual of Standards and Recommended Practices C-III.

4.0 CONCLUSION

4.1 The majority (94%) of the derailed cars exhibited some type of breach resulting in loss of product. Of the breached cars, 56% had more than 1 type of breach.

4.2 Shell breaches (37 cars) were the most frequently observed cause of product release, followed by head breaches (31 cars), and breached top fittings (20 cars) and PRDs (12 cars). BOV (7 cars), thermal tear (4 cars) and manway (2 cars) breaches were less frequent causes of product release.

4.3 Most (54%) of the shell ruptures were of a size commensurate with the car diameter, and would have caused the almost instantaneous release of the car's lading. Consequently, the high number of large shell breaches was a contributing factor to the large fire ball and pool fire in this derailment.

4.4 The head breaches were generally smaller than the shell breaches, ranging from a few inches to about 1 foot in diameter. These head breaches would have contributed to feed the pool fire and to product spillage.

4.5 There was no indication that the use of non-normalized steels for some of the tanks was a contributing factor to the product release in this derailment.

4.6 Thirteen (13) cars had only shell breaches and 7 cars had only head breaches, with no other type of breach. It is likely that some of the product loss by these cars could have been reduced had they been built with thicker steel, head shields and/or tank jackets.

4.7 Most cars (except for the 4 undamaged cars) exhibited some form of impact damage (denting or breach) in the top portion of at least one head. This suggests that full-head shields would be more beneficial than half-head shields (which only protect the bottom portion of the head) in this type of derailment.

4.8 A qualitative analysis of the tank damage suggests that the derailed tank cars at the front of the train (consist no.3 through 11) experienced less severe impact forces than those located in the main pile-up.

4.9 About half of the cars with large shell ruptures were clustered towards the end of the train. These cars would have encountered more severe derailment conditions than those experienced by cars located towards the front of the train. The large pile-up likely acted like a wall for the derailing cars, resulting in highly constrained derailment conditions. This caused large-scale buckling, extreme tank deformations (so-called plastic collapse) and resulted in the large shell ruptures.

4.10 The investigation showed that 15% of cars with impact-damaged top discontinuity protection housings had breached top fitting whereas 62% of those with impact-damaged protective housings were breached. Likewise, only 9% of protected PRDs were breached whereas 29% of cars with unprotected PRDs exhibited product loss from a damaged PRD. This indicates that top discontinuity protection is an effective means to reduce the release of product from impact-damaged top fittings and PRDs.

4.11 More than half of the derailed cars exhibited impact damage to the BOV that exposed the BOV ball (33 cars) or plug (3 cars). Seven cars with exposed BOV balls exhibited an open, partially open or visibly leaking BOV ball, all with impact-deformed or missing handle assemblies. The breached BOV was the only type of breach observed on 3 of these cars. This suggests that these 3 cars might not have experienced any product loss had they been equipped with a handle assembly configured to prevent actuation of the ball valve when the handle is deformed or broken off.

4.12 On cars equipped with an internal self-closing plug-style BOV, the exposed plug remained closed and there was no loss of product. This suggests that the self-closing plug-style valves are inherently better protected against product loss than the external ball valves.

4.13 Four of the derailed tank cars exhibited thermal tears. The sudden release of the pent-up pressure in the tanks resulted in loss of the tank lading as a large fire ball. No fragments of tank material were separated as a result of the thermal tears.

4.14 The car with the largest thermal tear (4.4 m, consist no.4) was equipped with a PRD with a STD pressure of 75 psig, whereas the car with the smallest thermal tear (1.6 m, consist no.63) had a 165 psig PRD. There was no indication to suggest that the type of PRD was contributory to the limited number of thermal tears in the present derailment.

4.15 One of the cars with thermal tears came to rest adjacent to another car that was exposed to similar conditions but did not sustain a thermal tear. This suggests that relatively modest improvements in fire survivability might have prevented the thermal tear. Thermal protection, thicker steel and jacketed cars can significantly extend the time a tank car can survive in a pool fire.

4.16 All of the cars with burn-throughs contained at least one other type of breach due to impact damage. The product released from the burn-throughs would have contributed to feed the pool fire and the spill, after the fire was extinguished.

4.17 Almost every derailed tank car (92%) exhibited at least one damaged stub sill and/or coupler. Most were damaged on both ends. The last 2 derailed cars had significant impact damage to their stub sills and couplers. This is consistent with the severe impact conditions observed in this derailment.

4.18 Nine (9) derailed tank cars exhibited separations at the stub sill attachments. One car contained a separation at the fillet weld between the front sill pad and the tank that had propagated into the tank and breached the shell at 2 locations. This was a similar type of stub sill failure as that observed during the NTSB's investigation of the Cherry Valley, IL accident.

4.19 Identification of some derailed tank cars in the field was hindered by the lack of legible stenciling or stamped markings. Some identification plates had been affixed with low melting point fasteners and separated from the tank during the post-derailment fire.

Figure 1: Aerial photograph of the derailment zone

Derailed tank cars are identified according to their position in the consist

(a) Stamped marking on stub sill of field car no. 33 identifying it as tank car WFIX 130603 (consist no. 22)

(b) Stamped marking on the top fitting pressure plate of field car no. 35 identifying it as tank car NATX 310412 (consist no. 33)

Figure 2: Representative examples of stamped markings on the derailed tank cars

(c) Stamped marking “R50175-182” (circled) on the head of field car no. 21 identifying it as tank car NATX 310581 (consist no.27)

Figure 2: Representative examples of stamped markings on the derailed tank cars

(a) Tank identification plate on the inboard side of the BL bolster on car WFIX 130682

(b) Tank identification plate welded onto the bolster of car CTCX 735617

Figure 3: Representative examples of tank car identification plates

(c) Separated tank identification plate found adjacent to car TILX316622

(d) Tank identification plate with missing text attached to car PROX 44428

Figure 3: Representative examples of tank car identification plates.

Figure 4: Aerial photograph showing cars with breaches from impact-damaged shells indicated in red

Figure 5: Aerial photograph showing cars with small (green), medium (yellow) and large (red) shell breaches

Figure 6: Aerial photograph showing cars with breaches from impact-damaged heads indicated in red

Figure 7: Aerial photograph showing cars with breaches from impact-damaged top fittings indicated in red

Figure 8: Aerial photograph showing cars with breaches from impact-damaged PRDs indicated in red

Figure 9: Aerial photograph showing cars with breaches from impact-damaged BOVs indicated in red

Figure 10: Aerial photograph showing cars with breaches from thermal tears indicated in red

Figure 11: Aerial photograph showing cars with burn-throughs indicated in red

Appendix A: Tank Car Inspection Results

Tables A-1 through A-63 summarize the results of the field inspection of the derailed tank cars. Representative photographs of each tank car are presented in Figures A-1 through A-63.

Key to abbreviations used in this Appendix

AL: A end, left side
AR: A end, right side
BL: B end, left side,
BR: B end, right side
BOV: bottom outlet valve
PRD: pressure relief device

All orientation observations are indicated from the perspective of facing the B end of the tank car.

In some tank cars, a “liquid-vapour line” was noted. This liquid-vapour line corresponds to a difference in the extent of fire damage sustained by the top and bottom portions of the tank as it came to rest. The top portion would have been in the vapour space during the post-derailment fire and thus more oxidized. The bottom portion was in the liquid space and had less fire damage due to the cooling effect of the liquid.

Table A-1: Tank Car TILX 316547

Consist position	3
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side next to the box car, perpendicular to yard track 2.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized and had a rusty colour above an inclined liquid/vapour line going from about 1/4 of the height on the B end to 1/3 of height on the A end.
Shell	The top-left side of the shell adjacent to the B end exhibited a large dent with a rectangular depressed area and an approximately 2-foot long puncture in the middle.
Heads	The A end head had no impact damage. The top-left quadrant of the B end head contained a puncture with a piece of rail embedded in it. There was a second puncture of similar size adjacent to this puncture and a linear depression above it. Another piece of rail was stuck in a puncture in the BR bolster.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed position but not locked as the securement mechanism was damaged.
Top fittings	The housing cover was warped but still secured. There was no impact damage to the housing wall. The fittings inside the housing were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was closed with all 6 bolts intact.
Stub sills and couplers	No visible impact damage.

(a) B end head

b) Rail piece through BR bolster

(c) A end head

(d) Shell

(e) Top fittings and manway

(f) BOV

Figure A-1: Photographs showing the condition of tank car TILX 316547

Table A-2: Tank Car WFIX 130608

Consist position	4
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side next to car TILX 316547, approximately parallel to yard track 2.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized above a liquid/vapour line located approximately mid-height.
Shell	The shell contained an approximately 15-foot long longitudinal thermal tear on the right side between the middle and the A end.
Heads	No impact damage on either head.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	The wall of the housing was deformed. The housing cover was torn due to impact damage but it was still closed and secured. There was no visible damage to the fittings inside the housing.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was closed with all 6 bolts intact.
Stub sills and couplers	No visible impact damage.

(a) B end head

b) A end head

(c) Shell

(d) Close-up of thermal tear in shell

(e) Top fittings and manway

(f) BOV

Figure A-2: Photographs showing the condition of tank car WFIX 130608

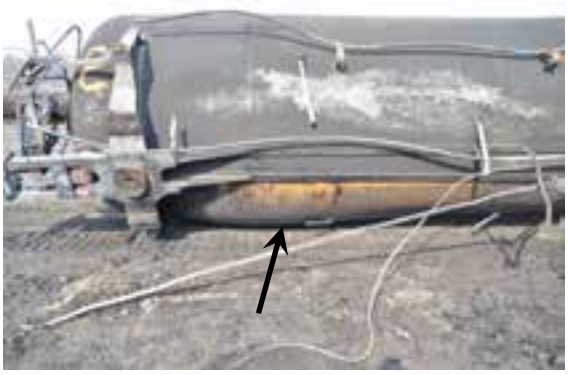
Table A-3: Tank Car TILX 316359

Consist position	5
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest nearly upside down with its B end still coupled to the B end of car WFIX 130608, approximately parallel to yard track 2.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized above an inclined liquid/vapour line going from about ¾ of the height on the B end to nearly the top of the A end.
Shell	The top of the shell contained some shallow dents near the A end. The shell near the AL bolster was visibly bulged. The bulged region was located above the liquid/vapour line.
Heads	There was no impact damage on the A end head. The B end head was slightly dented around its top edge.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	The cover of the housing was deformed inwards but still attached. The fittings inside the housing were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was open with all 6 bolts intact. It was likely opened for product recovery.
Stub sills and couplers	Both stub sills were slightly deformed.

(a) In-situ photo showing car WFIX 130608 (left) coupled to car TILX 316359 (right) (RSI-AAR Safety Project photo)

(b) B end head

(c) A end head



d) Arrow points to bulged shell between the A end and the middle (RSI-AAR Safety Project photo)

(e) View of bulged shell taken before car was staged (RSI-AAR Safety Project photo)

(f) Shell

(g) Top fittings and manway

(h) BOV

Figure A-3: Photographs showing the condition of tank car TILX 316359

Table A-4: Tank Car TILX 316338

Consist position	6
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side approximately parallel to yard track 2.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. There was no difference in extent of oxidation indicative of a liquid/vapour line.
Shell	No impact damage was noted.
Heads	The A end head had a piece of rail embedded on the left side at about mid-height. The B end head had no impact damage.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	The cover of the housing was askew and deformed. It was found in the closed position with the pin unsecured. There was extensive fire damage on the cover and housing.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was open with all 6 bolts intact. It was likely opened for product recovery.
Stub sills and couplers	No significant impact damage on either end. A separated coupler from car NATX 310428 was still attached to the B end coupler of car TILX 316338.

(a) B end head

b) Separated coupler attached to B end coupler

(c) A end head with embedded piece of rail (circled)

(d) Embedded piece of rail photographed before the car was staged (RSI-AAR Safety Project photo)

(e) Shell

(f) Top fittings and manway

(g) BOV

Figure A-4: Photographs showing the condition of tank car TILX 316338

Table A-5: Tank Car NATX 310428

Consist position	7
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its bottom-left side angled relative to car TILX 316338 and yard track 2.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized above a liquid/vapour line located at about 2/3 of the head height.
Shell	The shell contained an angled dent on the right side between the middle and the A end.
Heads	The A end head has a gouge and small puncture on its right edge at about mid-height. The B end head has a small dent on its right edge at about mid-height.
Bottom outlet valve	The fabricated skid was unremarkable. The BOV nozzle and chain were still attached but covered with product residue. The BOV handle was deformed and had pulled out of its connection with the valve just inside the skid.
Top fittings	The housing had separated at the hinge and was missing. The top fitting nozzles were sheared off.
Pressure relief device	The PRD was plugged with debris but externally appeared undamaged.
Manway	The manway cover was open and all 8 bolts were released with 1 bolt slightly bent. The manway cover was closed on aerial photographs confirming it was opened during recovery operations.
Stub sills and couplers	Both stub sills were slightly deformed. The B end coupler was missing and was found still attached to car TILX 316338.

(a) B end head

b) A end head

(c) Close-up of gouge and puncture in A end head (RSI-AAR Safety Project photo)

(d) Shell

(e) Top fittings and manway. The arrow points to an angled dent in the shell

(f) BOV

Figure A-5: Photographs showing the condition of tank car NATX 310428

Table A-6: Tank Car CTCX 735541

Consist position	8
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side approximately parallel to yard track 3. The A end of the car was still coupled to the B end of car DBUX 303879.
Extent of fire damage	The exterior finish of the car was blackened throughout with a rusty patch covering a large portion of the B end.
Shell	The shell contained a dent on the top-right near the A end.
Heads	The A end head has a puncture on its right edge at about mid-height. The B end head has a dent on its bottom-right quadrant.
Bottom outlet valve	The cast skid was unremarkable. The BOV adaptor had sheared off at the flange, exposing a closed ball valve. The handle was secured in the closed position. Signs of light seepage were noted on the ball valve.
Top fittings	The housing was deformed due to impact and was displaced laterally. It was found in the closed position but unsecured. One of the fittings inside the housing was impact damaged (bent) the others were not visible for inspection.
Pressure relief device	No visible impact damage.
Manway	The manway cover was open. 2 of the 6 bolts were missing and 1 bolt was bent. The cover was closed on aerial photographs of the derailment site indicating that it was opened during recovery operations.
Stub sills and couplers	No visible impact damage.

(a) B end head

b) A end head

(c) Photo showing aligned head punctures on cars CTCX 735541 (left) and DBUX 303879 (right) (RSI-AAR Safety Project photo)

(d) Close-up of gouge and puncture circled in (b) (RSI-AAR Safety Project photo)

(e) Shell

(f) Top fittings and manway

(g) BOV

(h) Close up showing light seepage from BOV

Figure A-6: Photographs showing the condition of tank car CTCX 735541

Table A-7: Tank Car DBUX 303879

Consist position	9
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side approximately parallel to yard track 3. The B end of the car was still coupled to the A end of car CTCX 735541.
Extent of fire damage	The exterior finish of the car was extensively burned throughout with white/red surface oxides.
Shell	The shell contained a deep angular dent on the top-left near the B end. There was a shallow dent on the top-left near the head-to-shell junction at the A end.
Heads	The A end head had a large dent in the top-right quadrant. It also had a gouge and small puncture at its left edge, aligned with a similar gouge and puncture on the B end of car CTCX 735541 (see Figure A-6c). The B end head is unremarkable.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	The housing was deformed, torn and hanging from one side of the hinge. The fittings had no visible impact. A 2-inch ball valve had been removed after the derailment and was hanging from its chain.
Pressure relief device	No visible impact damage.
Manway	The manway cover was open with 1 of the 6 bolts missing. The gasket was burnt. The cover was closed on aerial photographs of the derailment site indicating that it was opened during recovery operations.
Stub sills and couplers	No visible impact damage.

(a) B end head

b) A end head

(c) In-situ photo showing small puncture at the left edge of the A end (RSI-AAR Safety Project photo)

(d) Close-up of the gouge and puncture shown in (c) (RSI-AAR Safety Project photo)

(e) Shell

(f) BOV

(g) Top fittings and manway

(h) PRD

Figure A-7: Photographs showing the condition of tank car DBUX 303879

Table A-8: Tank Car WFIX 130682

Consist position	10
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side between the west leg of the wye and yard track 3, angled with respect to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was undamaged by the fire, with all stencils and decals intact.
Shell	The shell contained a shallow transverse dent along the left side in the middle. There was longitudinal scraping along the right side of the car with a shallow dent at the A end.
Heads	The A end contained a small dent in the upper-right quadrant surrounded by fresh gouges and scrape marks. The B end head contained a dent at its right edge at approximately mid-height.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	The housing cover was open when examined by TSB but photographs taken by the RSI-AAR Safety Project team indicate it was closed and secured when the car came to rest. The fittings inside had no visible impact damage. It was noted that the housing was partly filled with product after the derailment, suggesting some fittings may have released product.
Pressure relief device	No visible impact damage.
Manway	The manway cover was open with all 6 bolts intact. It was opened during recovery operations as it had been found closed after the derailment.
Stub sills and couplers	Both stub sills were slightly deformed.

(a) B end head

b) A end head

(c) Shell

(d) BOV

(e) Top fittings and manway (RSI-AAR Safety Project photo)

(f) Product in housing (RSI-AAR Safety Project photo)

Figure A-8: Photographs showing the condition of tank car WFIX 130682

Table A-9: Tank Car TILX 316641

Consist position	11
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side forward of the main pileup and parallel to the west leg of the wye. The B end of the car was still coupled to the B end of car TILX 316570.
Extent of fire damage	The exterior finish of the car was blackened due to fire damage. Some markings were still partly visible.
Shell	Some longitudinal scrape marks on the bottom but no dents or other impact damage.
Heads	No impact damage.
Bottom outlet valve	The skid, BOV nozzle and handle assembly had no impact damage. The BOV handle was in the closed and secured position.
Top fittings	No impact damage to housing wall and cover; the cover was closed and secured. The fittings inside the housing were not visible for inspection.
Pressure relief device	The PRD was inside the closed housing and not visible for inspection.
Manway	The manway cover was open with all 6 bolts intact. It was opened during recovery operations as it had been found closed after the derailment.
Stub sills and couplers	The A end stub sill was slightly bent to the left. The B end stub sill was unremarkable.

(a) B end head

b) A end head

(c) Shell

(d) BOV

(e) Top fittings and manway

(f) In-situ photo showing car TILX 316570 (left) still coupled to car TILX 316641 (right) (RSI-AAR Safety Project photo)

Figure A-9: Photographs showing the condition of tank car TILX 316641

Table A-10: Tank Car TILX 316570

Consist position	12
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side just forward of the main pileup and parallel to the west leg of the wye. The B end of the car was still coupled to the B end of car TILX 316641.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized above a liquid/vapour line located approximately mid-height.
Shell	The shell was significantly buckled between the A end and the middle with a large rupture on its left side in the buckled zone.
Heads	The A end head had a large dent near the top with a smaller dent below. The B end head was unremarkable.
Bottom outlet valve	The fabricated skid had no impact damage. The BOV nozzle was intact but the handle assembly had separated at the connection with the valve, inside the skid.
Top fittings	The cover of the housing was deformed, damaged at the hinge and had pulled out of its locking mechanism. The cover fell off when the car was staged. The housing was partially filled with dirt but visible fittings had no visible impact damage.
Pressure relief device	No visible impact damage.
Manway	The manway cover was closed with 1 bolt loose and the other 5 bolts intact.
Stub sills and couplers	Two rails were embedded in the AR bolster. The A end stub sill was slightly bent to the right. The B end stub sill was unremarkable.

(a) B end head

b) A end head

(c) Shell

(d) In-situ photo showing buckling of the shell at the A end and piled-up ballast at the B end (RSI-AAR Safety Project photo)

(e) In-situ photo showing rails embedded through the car's AR bolster (Transport Canada photo)

(f) Close-up of the 2 rails in the AR bolster (Transport Canada photo)

(g) Top fittings and manway

(h) BOV

Figure A-10: Photographs showing the condition of tank car TILX 316570

Table A-11: Tank Car NATX 310457

Consist position	13
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down at the forward end of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The car exhibited extensive fire damage with a rusty colour in the less damaged ends and blistering and metal loss near the top fittings.
Shell	The shell contained a large dent on the AR side corresponding to the location where the car impacted the A end of car TILX 316570. There was a matching dent on the AL side where the car was squeezed between car WFIX 130638 and car TILX 316570 (see Figure A10e). There was a dent on the left side near the B end.
Heads	No impact damage.
Bottom outlet valve	The fabricated skid and BOV nozzle did not exhibit any impact damage. The handle was in the closed position and the extension and elbow were intact; however, the handle itself and the locking pin assembly were impact damaged.
Top fittings	The housing was missing and the fittings had sheared off and the eduction pipe was partly pulled out of the tank.
Pressure relief device	The PRD was plugged with dirt but there was no visible impact damage.
Manway	The manway cover was closed with 1 bolt loose and the other 7 bolts intact.
Stub sills and couplers	The A end stub sill was slightly bent to the left. The B end stub sill was extensively deformed to the left.

(a) B end head

b) A end head and bottom of shell

(c) A end head and right side of shell (RSI-AAR Safety Project photo)

(d) Close-up showing dent on AR side of tank (RSI-AAR Safety Project photo)

(e) BOV

(f) PRD, top fittings and manway

Figure A-11: Photographs showing the condition of tank car NATX 310457

Table A-12: Tank Car WFIX 130638

Consist position	14
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest nearly upside down in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The car exhibited extensive fire damage with a more reddish discolouration near the transverse rupture in the shell.
Shell	The top of the shell contained a deep dent with a large transverse rupture in the first ring from the B end. This rupture was not associated with a weld. The shell also exhibited a longitudinal buckle along most of its length. The AR side of the shell and the AR bolster were impact damaged.
Heads	The A end head had a large dent near the top. The B end head was unremarkable.
Bottom outlet valve	The fabricated skid exhibited impact damage and scoring on its right side. The BOV adaptor had sheared-off at the flange, exposing a closed and oxidized (fire damaged) BOV ball. The BOV handle had separated at its connection with the valve and was missing.
Top fittings	The housing cover was slightly deformed and askew but still secured. Some debris was observed inside the housing but the condition of the fittings could not be determined as they were not visible.
Pressure relief device	The PRD was not visible for inspection.
Manway	The manway cover was closed with 1 bolt loose and the other 5 bolts intact.
Stub sills and couplers	The A end stub sill was slightly bent to the left. The B end stub sill was bent to the left. Both stub sills had some impact damage.

(a) B end head

b) A end head

(c) Shell

(d) View showing longitudinal buckle along entire tank (RSI-AAR Rail Safety photo)

(e) Dent and damaged bolster on AR side of shell (RSI-AAR Rail Safety photo)

(f) Top fittings and manway

(g) BOV

(h) Close-up of BOV ball

Figure A-12: Photographs showing the condition of tank car WFIX 130638

Table A-13: Tank Car NATX 310473

Consist position	15
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized above a liquid/vapour line inclined from about mid-height on the B end to below mid-mid-height on the A end.
Shell	The shell was buckled/dented on its top-left side near the A end and on its top-left side near the B end. There was a narrow angled dent with a small puncture on the BL side near the B end.
Heads	The A end head had 3 small shallow dents near the edge of the top-left quadrant. The B end head had a large dent near the top and a smaller dent on its right side. It also contained a dent and a puncture near the edge of the lower-left quadrant (at about 8 o'clock).
Bottom outlet valve	The fabricated skid and BOV nozzle did not exhibit any impact damage. The handle was in the closed position and secured. However, the extension and support brackets were impact damaged and some product seepage was noted inside the skid.
Top fittings	The housing was missing and both nozzles were sheared; 1 nozzle was hanging from its end cap chain.
Pressure relief device	The PRD was plugged with dirt but had no visible impact damage.
Manway	The manway cover was open with 1 of the 8 bolts and lugs broken. The cover was closed when the car came to rest and had been opened during recovery operations.
Stub sills and couplers	The A end stub sill was bent to the right. The B end stub sill was bent slightly upwards.

(a) B end head

b) Close-up showing puncture in B end head

c) A end head

(d) Shell

(e) Dent and small puncture (arrow) on BL side of tank (RSI-AAR Rail Safety photo)

(f) Top fittings and manway

(g) BOV

(h) Close-up showing seepage from BOV

Figure A-13: Photographs showing the condition of tank car NATX 310473

Table A-14: Tank Car TILX 316379

Consist position	16
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car exhibited fire damage throughout. The tank surface was more oxidized with a rusty colour above a liquid/vapour line inclined from about ¾ height on the B end to the top of the A end.
Shell	The top half of the shell contained several bulges/buckles.
Heads	The A end head had a large shallow dent on the right edge (where it joins the shell) and a small dent in the lower right quadrant. The B end head was unremarkable.
Bottom outlet valve	The fabricated skid exhibited impact damage and scoring on its right side. The BOV adaptor had sheared-off at the flange, exposing a BOV ball that was partly covered by a product residue. After wiping the BOV ball to remove some of this residue, it was observed to be closed and possibly seeping. The BOV handle had separated at its connection with the valve and was missing.
Top fittings	The housing cover was deformed and askew with the locking pin unsecured. There was no visible impact damage to the fittings inside; however, the fittings and housing a reddish colour indicative of extensive fire damage.
Pressure relief device	No visible impact damage.
Manway	The manway cover was found beside the staged car. The hinge and 2 of the 6 bolts were broken.
Stub sills and couplers	The A end stub sill was unremarkable. The B end coupler had separated and the stub sill was deformed (impact damaged).

(a) B end head.

b) A end head. Arrow points to separated manway cover

c) Shell

(d) Angled view showing bulges on the right side of the tank (AAR-RSI Safety Project photo)

(e) BOV

(f) Photo taken after wiping product residue to show closed BOV ball

(g) Top fittings and manway

Figure A-14: Photographs showing the condition of tank car TILX 316379

Table A-15: Tank Car ACFX 79709

Consist position	17
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was fire damaged though some paint was still visible on the left side.
Shell	The top and sides of the shell were deformed inwards. There was a long transverse rupture in the top of the 4th shell section from the B end. The AR side near the A end contained a longitudinal dent with a small puncture just above it. This dent extended to the edge of the A end head.
Heads	The A end head was unremarkable. The B end head had multiple dents with a small puncture in the top-right dent near the edge.
Bottom outlet valve	The BOV was intact with its handle closed and secured.
Top fittings	The housing was missing and both nozzles were sheared. The housing hinge was sheared off and the cover was missing.
Pressure relief device	One of the 2 PRDs exhibited minor impact damage (broken bolt). The other PRD was unremarkable.
Manway	The manway cover was closed.7 of the 8 bolts had released; the 8th bolt was intact.
Stub sills and couplers	The top shelf of the B end double-shelf coupler was broken. The B end stub sill was unremarkable. The A end coupler had separated and the stub sill was deformed and bent to the right.

(a) B end head

b) Close-up of small puncture in B end head - see arrow in (a)

(c) A end head

(d) Shell

(e) Close-up of area arrowed in (d) showing longitudinal dent and small shell puncture (AAR-RSI Safety Project photo)

(f) Top fittings and manway

(g) BOV

Figure A-15: Photographs showing the condition of tank car ACFX 79709

Table A-16: Tank Car TILX 316333

Consist position	18
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) above an inclined liquid-vapour line going from about 2/3 of the height on the A end to more than 3/4 of the height on B end.
Shell	The shell contained an 8 to 9-foot long longitudinal thermal tear in the top-left portion of the first ring from the B end. There was a large dent on the top of this first ring, just above the thermal tear. The shell also contained a deep dent on the left side adjacent to the A end.
Heads	The A end head has a shallow dent in its middle. The B end head has a dent approximately mid-height on the left side, with a small (about 3-inch long) gouge and puncture at its deepest point.
Bottom outlet valve	The fabricated skid exhibited slight impact damage and scoring on its right side. The BOV adaptor had sheared-off at the flange, exposing a closed BOV ball. The BOV handle had separated at its connection with the valve and was missing.
Top fittings	The housing cover was slightly warped but closed and secured. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	Manway cover was closed but 4 of the 6 bolts had released.
Stub sills and couplers	The A end stub sill was unremarkable. The B end stub sill was impact damaged and bent to the left.

(a) B end head

b) Close-up of small puncture in B end head

(c) B end stub sill

(d) A end head

(e) Shell

(f) Thermal tear in shell

(g) Top fittings and manway

(h) BOV

Figure A-16: Photographs showing the condition of tank car TILX 316333

Table A-17: Tank Car TILX 316549

Consist position	19
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest leaning on its left side and almost upside down, in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) above a liquid-vapour line located at approximately 2/3 height.
Shell	The shell contained several angled dents on both sides near the A end and B end. It was crushed inwards on the top-right in the middle and bulged out on the bottom.
Heads	The A end head had several small dents and a larger, deep dent with an approximately rectangular puncture located in the lower-right quadrant. The B end head contained several shallow dents in its top half.
Bottom outlet valve	The BOV was intact with its handle closed and secured.
Top fittings	The housing cover was slightly warped but closed and secured. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was open with all 6 bolts intact. The cover exhibited round patterns at the bolt locations with less fire damage than the surrounding surface. This suggests the bolts had been secured when the car was exposed to the post-derailment fire and that the cover was subsequently opened during recovery operations.
Stub sills and couplers	The A end stub sill was slightly bent to the left and the knuckle was missing from the coupler. The B end stub sill was extensively damaged and bent to the left. The coupler had been pulled out of the stub sill and was partially separated from it.

(a) B end head

b) Shell

(c) Shell

(d) A end head

(e) Top fittings and manway

(f) BOV

Figure A-17: Photographs showing the condition of tank car TILX 316549

Table A-18: Tank Car CTCX 735527

Consist position	20
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side underneath car WFIX 130603 (consist 22) in the forward part of the pile-up, oriented perpendicularly to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) with a red discolouration around a large puncture in the shell. The liquid-vapour line was inclined from about ¼ height on the B end to ½ height on the A end.
Shell	The shell contained large dents on the BL side and on the bottom between the B end and the middle. There was a large puncture with edges curled inward in the top portion of the first ring from the B end. The shell was also buckled longitudinally at the top between the middle and A end.
Heads	The A end head has a deep dent covering most of its area, resulting in a concave instead of convex profile. The B end head has a shallow dent near the right edge.
Bottom outlet valve	The cast skid was impact damaged on its right side. The BOV adaptor had sheared-off at the flange, exposing a closed and oxidized (fire damaged) BOV ball. The BOV handle had separated at its intended break-off point and was missing.
Top fittings	The housing was deformed and askew. It was closed but unsecured. The fittings inside were not visible for inspection.
Pressure relief device	No visible impact damage to PRD.
Manway	The manway cover was closed with all 6 bolts intact.
Stub sills and couplers	The A end stub sill was impact damaged and bent to the left. The B end stub sill was broken, bent to the left and the coupler assembly was missing.

(a) B end head

b) BL shell

(c) B end head and shell

(d) Puncture in shell

(e) PRD, top fittings and manway

(f) BOV

(g) A end head

(h) Buckle in shell near A end (RSI-AAR Safety Project photo)

Figure A-18: Photographs showing the condition of tank car CTCX 735527

Table A-19: Tank Car NATX 310477

Consist position	21
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down under car TILX 316556 (consist 23) on the south side of the main pile-up. The car was oriented approximately parallel to the west leg of the wye.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) with a red discolouration and metal loss in some areas.
Shell	The center portion of the shell was crushed. In the most deformed areas the radius of curvature was less than 1 foot. This deformation was consistent with general buckling due to impacts at both ends. In addition, the bottom of the car was crushed where car 23 came to rest on top of it. No shell ruptures were noted.
Heads	The A end and B end heads contained multiple dents covering a large part of their surface. Impact marks and gouges were noted in several of these dents but no punctures.
Bottom outlet valve	The fabricated skid and BOV assembly had no significant impact damage. The handle was in the closed position and secured. However, the handle extension and the support brackets were deformed due to impact damage.
Top fittings	The housing had separated and the top fittings were sheared off.
Pressure relief device	The PRD nozzle was sheared off just above the reinforcement pad on the shell.
Manway	The manway cover and several of the bolts were missing.
Stub sills and couplers	The A end stub sill was bent to the top-right and its left side was broken. The B end stub sill was bent in the top-right direction.

(a) B end head

b) A end head

(c) Shell

(d) BOV

(e) PRD, manway and top fittings

(f) Manway and top fittings

Figure A-19: Photographs showing the condition of tank car NATX 310477

Table A-20: Tank Car WFIX 130603

Consist position	22
Orientation in the consist	A end leading
Position and orientation of derailed car	The car came to rest under cars ACFX 76605 (consist 24) and TILX 316556 (consist 23). Part of the B end of this car was visible between the 2 other cars, suggesting it was approximately upright.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) with a red discolouration.
Shell	The shell exhibited sideways crushing consistent with side impacts. It was bent in opposite directions at each end, resulting in an overall “s” shape. There was a large transverse rupture in the first ring near the B end, with a size commensurate with the car diameter.
Heads	The A end head was slightly deformed. The left side of the B end head was extensively crushed, consistent with the adjacent shell deformation and rupture.
Bottom outlet valve	The fabricated skid and BOV assembly had no significant impact damage. The handle was in the closed position and secured. However, the extension and support brackets were deformed due to impact damage.
Top fittings	The housing cover was deformed and hanging from the hinge but the wall was intact. The fittings inside the housing had no visible impact damage.
Pressure relief device	The PRD inside the housing had no impact damage.
Manway	The manway cover was closed with all 6 bolts intact.
Stub sills and couplers	The A end stub sill was broken and bent to the right. Its coupler had been torn out. The B end stub sill was bent to the right and the left side was broken.

(a) B end head

b) A end head

(c) Shell

(d) Detail of shell rupture

(e) Manway and top fittings

(f) BOV

Figure A-20: Photographs showing the condition of tank car WFIX 130603

Table A-21: Tank Car TILX 316556

Consist position	23
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest in the main pile-up on its right side, on top of cars CTCX 735527 (consist 20), NATX 310477 (consist 21 and WFIX 130603 (consist 22). It was angled about 45 degrees to the left relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) all over, with a red discolouration around the BOV and the top-left portion of the shell.
Shell	The shell exhibited extensive sideways crushing consistent with side impacts. The top-right portion of the shell (1st ring from the B end) was deeply crushed and had a large puncture.
Heads	The A end head was unremarkable. The B end head has a deep dent near the top edge and the right side was crushed, consistent with the adjacent shell deformation.
Bottom outlet valve	The fabricated skid was unremarkable. The cap and plug assembly sheared off the BOV adaptor, exposing an almost fully open and extensively oxidized (red discolouration) BOV ball. The handle assembly and securement mechanism were impact damaged and the handle was in the open position.
Top fittings	The cover of the housing assembly was missing and the wall was extensively deformed, having started to separate from the flange. The interior of the housing was partly filled with debris, preventing inspection of 1 fitting (vacuum relief valve). The remaining top fittings did not exhibit any visible impact damage.
Pressure relief device	The PRD inside the housing had no visible impact damage.
Manway	The manway cover was closed with 2 bolts missing and 4 bolts intact.
Stub sills and couplers	The A end stub sill was bent to the right. The knuckle was broken off the coupler. The B end stub sill was unremarkable.

(a) B end head

b) A end head

(c) Shell

(d) Detail of shell rupture (RSI-AAR Safety Project photo)

(e) Manway and top fittings

(f) Detail showing damaged housing wall (arrow)

(g) BOV

(h) Open BOV ball

Figure A-21: Photographs showing the condition of tank car TILX 316556

Table A-22: Tank Car CTCX 735629

Consist position	24
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side between car TILX 316556 (consist 23) and ACFX 76605 (consist 25) in the main pile-up. It was angled about 45 degrees to the left relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized (fire damaged) all over, with a red discolouration on the bottom-right near the A end. There was a steeply inclined liquid-vapour line going from about 3/4 of the height on the B end and disappearing between the middle and the A end, consistent with the inclined position of the car in the pile-up.
Shell	The bottom of the shell exhibited shallow denting. It was crushed from both sides with a deeper dent and puncture on the bottom-right side near the A end.
Heads	The A end head had a deep dent covering most of its area. The B end head had a small dent on the right side.
Bottom outlet valve	The cast skid had no significant impact damage. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle was secured in the closed position.
Top fittings	The housing was flattened and askew. Burnt product residue and product seepage from the damaged housing suggested that there was release from the top fittings inside.
Pressure relief device	The top portion of the PRD was impact damaged and missing.
Manway	The manway cover was closed. 5 out of 6 bolts were broken or released and there was burnt product residue between the cover and manway nozzle.
Stub sills and couplers	Both the A end and B end stub sill were extensively deformed and bent upwards. Both couplers were missing. The B end stub sill was very fire damaged (red colour) likely due to the car coming to rest with this stub sill in close proximity to the puncture in the top of car CTCX 735527 (Figure A-18d).

(a) B end head

b) A end head

(c) Shell looking towards A end (RSI-AAR Safety Project photo)

(d) Detail of shell puncture (RSI-AAR Safety Project photo)

(e) PRD, manway and top fittings

(f) BOV

Figure A-22: Photographs showing the condition of tank car CTCX 735629

Table A-23: Tank Car ACFX 76605

Consist position	25
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down in the forward portion of the pile-up and at an angle relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized all over, with blistering, metal loss and red discolouration around punctures.
Shell	The shell had extensive deformation and crushing from both sides. There was a puncture (with a size similar to a coupler) on the top-right in the first ring from the B end. A small rupture (less than a foot in length) was located at the top-right in the weld between the first and second rings from the B end. A large transverse rupture was located at the top, in the weld between the first and second rings from the A end. This large rupture was associated with an area of extensive deformation in the shell. There were also 2 smaller ruptures in the shell at the AL and AR ends of the A end bolster.
Heads	The A end head was very deformed with a large puncture the left side at the junction with the shell. The B end head was also very deformed and had large puncture on the left side.
Bottom outlet valve	The BOV had no impact damage and the handle was in the closed position and secured.
Top fittings	The housing had separated and the top fittings were sheared off.
Pressure relief device	The B end PRD had no visible impact damage. The nozzle of the A end PRD was sheared off just above the reinforcement pad on the shell.
Manway	The manway cover was closed with 1 of the 8 bolts released.
Stub sills and couplers	The A end stub sill had separated from the front sill pad at the fillet weld and the coupler was missing. None of the weld failures had propagated to the tank. The B end stub sill was extensively damaged and twisted to the left and upwards. The coupler was missing.

(a) B end head and shell

b) Detail of puncture near B end head and small tear at weld (circled) (RSI-AAR Safety Project photo)

(c) A end head

(d) Ruptures at the AL and AR ends of the A end bolster (RSI-AAR Safety Project photo)

(e) Shell

(f) Detail of large shell rupture and smaller puncture (arrow) (RSI-AAR Safety Project photo)

(g) BOV

(h) PRDs, manway and top fittings

Figure A-23: Photographs showing the condition of tank car ACFX 76605

Table A-24: Tank Car PROX 44293

Consist position	26
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down in the forward portion of the pile-up and at an angle relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with rusty areas above an inclined liquid/vapour line going from about 3/4 of the height on the A end to 1/4 of the height on the B end. Thermal tear is about at liquid/vapour line.
Shell	The shell contained a large longitudinal thermal tear on the right side in the second and third rings from the B end. The thermal tear was about 8 feet long. The shell was visibly bulged in the vicinity of the thermal tear.
Heads	The B end head had a dent at its right-top edge. The A end head was dented at the bottom-left.
Bottom outlet valve	The cast skid had no significant impact damage. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle had separated at the edge of the skid with the remaining portion secured in the closed position with the locking pin in place.
Top fittings	The housing was deformed at the hinge and unsecured, partially exposing the fittings inside. One of the fittings was impact damaged (bent at its flange).
Pressure relief device	There was no visible impact damage to the PRD.
Manway	The manway cover was closed with no impact damage.
Stub sills and couplers	The B end stub sill was broken and the coupler was missing. The front sill pad had separated from the tank at the fillet weld. None of the weld failures had propagated to the tank. The A end stub sill had no significant impact damage.

(a) B end head

b) Close-up showing broken B end stub sill

(c) A end head

(d) Top of shell as viewed from the B end

(e) Shell

(f) Manway, top fittings and PRD

(g) BOV

Figure A-24: Photographs showing the condition of tank car PROX 44293

Table A-25: Tank Car NATX 310581

Consist position	27
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upside down in the forward portion of the pile-up and at an angle relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized throughout with red discolouration around the punctures in the A end head.
Shell	The upper-left portion shell contained a large deep buckling deformation between the B end and the middle, consistent with axial compressive impact loading.
Heads	The B end head contained multiple deep dents and 2 punctures (one in the center and one in the bottom-right). The A end head was unremarkable.
Bottom outlet valve	The fabricated skid and BOV assembly had no significant impact damage. The handle was in the closed position and secured. However, the extension and support brackets were deformed due to impact damage.
Top fittings	The housing had separated at the hinge and was missing. The exposed top fittings had no visible impact damage.
Pressure relief device	The PRD was plugged with debris but had no visible impact damage.
Manway	The manway cover was closed. 1 of the 8 bolts and its lug were broken off.
Stub sills and couplers	The B end stub sill was broken bent up and to the left. The B end coupler was impact damaged (the knuckle and bottom shelf were broken off). The A end stub sill was bent to the right and its coupler was missing.

(a) B end head

b) A end head

(c) Shell

(d) Shell

(e) BOV

(f) PRD, manway and top fittings

Figure A-25: Photographs showing the condition of tank car NATX 310581

Table A-26: Tank Car PROX 44202

Consist position	28
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side in the forward portion of the pile-up and at an angle relative to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized throughout with red discolouration around the large puncture, the bottom and the A end.
Shell	The shell was dented on both sides. The first ring from the A end contained a deep dent with a large puncture on its left-bottom side.
Heads	The B end head had 2 deep dents covering most of the right side and the bottom-right quadrant, and a small puncture at the bottom-right edge. The A end head had a large dent covering most of its area.
Bottom outlet valve	The cast skid was impact damaged on its right side. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle had separated at the locking pin remaining in the closed position.
Top fittings	The housing was slightly askew but otherwise undamaged. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was plugged with debris but had no visible impact damage.
Manway	The manway cover was closed with no impact damage.
Stub sills and couplers	The A end stub sill was bent to the right. The B end stub sill was bent to the left and the coupler was missing.

(a) B end head

b) Close-up showing small puncture at edge of B end head (RSI-AAR Safety Project photo)

(c) A end head

(d) Shell

(e) Close-up of large puncture in the shell

(f) BOV

(g) PRD, top fittings and manway

Figure A-26: Photographs showing the condition of tank car PROX 44202

Table A-27: Tank Car TILX 316234

Consist position	29
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with the bottom surface with extensive fire damage (blistering, red discolouration).
Shell	The middle portion of the shell was deeply bent and crushed on the right side. The shell was extensively deformed all around the housing and manway reinforcement pad. However, this reinforcement pad was not visibly deformed.
Heads	The A end head had a deep dent in the top-left quadrant with a tear at the edge of the head (most deformed area) and a smaller dent in the bottom-left quadrant. The B end head had a large shallow dent with an impact mark in the bottom, located in the top-left quadrant.
Bottom outlet valve	The fabricated skid and BOV assembly had no significant impact damage. The handle was in the closed position and secured. However, the handle extension and the support brackets were slightly bent as a result of tank deformation in this area.
Top fittings	The housing cover was missing and the wall is deformed as a result of impact damage. The housing was partially filled with debris. The 3-inch valve handle was not in the horizontal position, suggesting it might have been displaced. However, there was no visible damage to the caps assemblies.
Pressure relief device	The PRD had no visible impact damage.
Manway	The manway cover was closed with 1 of the 6 bolts bent.
Stub sills and couplers	The A end stub sill was bent to the right and its coupler was impact damaged (missing knuckle and broken yoke). The B end stub sill was twisted to the left and broken. The knuckle was missing.

(a) B end head

b) A end head

(c) Shell viewed from the A end

(d) Shell viewed from the B end (RSI-AAR Safety Project photo)

(e) Manway and top fittings (RSI-AAR Safety Project photo)

(f) BOV

Figure A-27: Photographs showing the condition of tank car TILX 316234

Table A-28: Tank Car TILX 316584

Consist position	30
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized above an inclined liquid/vapour line going from about 1/4 of the height on the B end to 1/2 of the height on the A end.
Shell	The shell had several transverse buckles on the top and a deeper dent near the B end. It was dented along most of its left side with a puncture with jagged, curled-out edges in the area of the weld between the first and the second rings from the A end. In-situ photographs of this car indicate that the location of this puncture was consistent with an impact from the BL bolster of car TILX 316234 (consist 29).
Heads	The A end head was unremarkable. The B end head had a shallow dent extending over most of its surface.
Bottom outlet valve	There was an impact mark on the A end portion of the fabricated skid. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle assembly was missing and the securement mechanism was impact damaged.
Top fittings	The housing assembly had no impact damage. The fittings inside were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover was closed with 1 of the 6 bolts broken.
Stub sills and couplers	The A end stub sill was broken and twisted upwards, nearly touching the head. The knuckle was missing. The B end stub sill was bent to the right. The coupler was impact damaged and a piece of knuckle was missing.

(a) B end head

b) A end head

(c) Shell viewed from the A end

(d) Shell puncture

(e) Manway and top fittings

(f) BOV

Figure A-28: Photographs showing the condition of tank car TILX 316584

Table A-29: Tank Car WFIX 130571

Consist position	31
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was oxidized with a red discolouration at the B end. The left side was extensively fire-damaged with blistering and a burn-through near the A end.
Shell	The left side of the shell contained several large dents. The top was crushed inwards along most of the car's length. In the portion between the top fittings and B end, there was an about 10-foot long gouge ending in a 2-foot long puncture.
Heads	The A end head had two dents located at the edge in the middle-left and upper-left positions. B end head has a larger but relatively shallow dent in its bottom-left quadrant.
Bottom outlet valve	The fabricated skid and BOV assembly had no impact damage.
Top fittings	The housing had separated at the flange and was observed resting near the B end. All of the bolts securing the housing to the flange were sheared and there was an impact mark on the wall of the separated housing. Three of the bolts clamping the flange to the top fitting nozzle were also sheared off. The location of these damaged bolts was in line with the gouge and puncture on the top of the tank, suggesting the damage was caused by the same impact. All of the fittings inside had sheared off.
Pressure relief device	The top portion of the PRD was sheared off.
Manway	The car had come to rest with its manway cover closed. 2 of the 6 bolts were broken. The manway cover was subsequently opened during recovery operations.
Stub sills and couplers	The A end stub sill had no impact damage. The B end stub sill was bent to the left. The coupler was impact damaged and the bottom shelf was missing.

(a) B end head

b) A end head

(c) Car viewed in-situ from the B end. The arrow points to an impact mark on the side of the separated housing (RSI-AAR Safety Project photo)

(d) Shell puncture

(e) Top fittings and manway

(f) BOV

Figure A-29: Photographs showing the condition of tank car WFIX 130571

Table A-30: Tank Car TILX 316330

Consist position	32
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was oxidized with a red discolouration at the A end.
Shell	The shell contained a deep dent on its left side with a puncture and a large transverse rupture. Part of this rupture was associated with the between the 1st and 2nd rings from the A end. The right side of the shell was also dented along most of the car's length. Dents were also noted on the top between the manway and B end.
Heads	The A end head had a shallow dent covering the bottom-right quadrant with a smaller dent above it. The B end head was slightly dented on the left side.
Bottom outlet valve	The fabricated skid was impact damaged and deformed on its right side. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle assembly and securement mechanism were missing.
Top fittings	The housing had separated at the flange. All of the fittings inside were impact damaged or sheared off. The area around the damaged fittings was partially covered with product residue.
Pressure relief device	The top portion of the PRD was sheared off.
Manway	The manway cover was closed with 1 of the 6 bolts broken.
Stub sills and couplers	The A end stub sill was broken and bent to the right. Its knuckle was missing. The B end stub sill had no visible damage but its knuckle was impact damaged.

(a) B end head

b) A end head

(c) Shell

(d) Shell puncture and rupture

(e) Manway and top fittings

(f) BOV

Figure A-30: Photographs showing the condition of tank car TILX 316330

Table A-31: Tank Car NATX 310412

Consist position	33
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with blistering, metal loss and red discolouration. The B end head and stub sill were extremely fire damaged.
Shell	The top half of the shell contained several longitudinal buckles. It was also deformed with a deep transverse buckle along the bottom, on the A end side of the skid.
Heads	The A end head contained a shallow dent and puncture in the bottom-left quadrant The B end head contained a dent covering most of the left-bottom quadrant and was crushed on its top-right edge.
Bottom outlet valve	The fabricated skid was impact damaged on its left side. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle assembly and securement mechanism were missing.
Top fittings	The housing was impact damaged and broken. The 3-inch valve was sheared off and the 2-inchvalve was impact damaged.
Pressure relief device	The PRD was deformed due to impact damage. It was also fire-damaged.
Manway	The manway cover was closed. The cover and bolts were extensively fire-damaged.
Stub sills and couplers	The A end stub sill was bent to the left. The B end stub sill was bent to the right and its knuckle was missing. The BL bolster had separated and was missing.

(a) B end head

b) A end head

(c) Shell (RSI-AAR Safety Project photo)

(d) Close-up showing blistering and metal loss on shell

(e) Top fittings

(f) PRD

(g) BOV

Figure A-31: Photographs showing the condition of tank car NATX 310412

Table A-32: Tank Car TILX 316317

Consist position	34
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its right side in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with blistering and metal loss. The areas around the puncture in the B end and on the top between the top fittings and the B end had a red colour, with a small burn-through.
Shell	The shell was crushed on the top-right near the B end. The left side was dented inwards along the entire length.
Heads	The A end head had a large dent covering the bottom-right quadrant and extending into the upper-right quadrant. The shell was ruptured at its bottom-right edge and had a small puncture at the bottom of a gouge almost at mid-height near the right edge. The top portion of the B end head was dented and crushed, with a puncture approximately in the middle.
Bottom outlet valve	The fabricated skid was impact damaged on its right side. The BOV adaptor had sheared off at the flange, exposing a partially open BOV ball (opened approximately 1/16 to 1/8 inch). The handle assembly and securement mechanism were missing.
Top fittings	The housing cover was deformed and askew. The wall of the assembly was deformed due to impact damage on the right side. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was closed with no visible impact damage.
Stub sills and couplers	The A end stub sill was broken and bent upwards and to the right. The BR bolster and right side of the B end stub sill were impact damaged. The coupler was missing.

(a) B end head

b) A end head

(c) Shell (RSI-AAR Safety Project photo)

(d) Manway and top fittings

(e) BOV

(f) Close-up showing partially open BOV ball

Figure A-32: Photographs showing the condition of tank car TILX 316317

Table A-33: Tank Car WFIX 130545

Consist position	35
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with blistering and metal loss. The top was extensively burned with a burn-through on the upper left near the A end.
Shell	The shell exhibited extensive crushing and reduction of volume in the center portion. A small puncture located near the burn-through on the left side near the A end was associated with bright (non-oxidized) gouges, indicating it likely occurred during recovery.
Heads	The A end head had deep dents on the top and left edges but no puncture. The B end head had no impact damage.
Bottom outlet valve	The fabricated skid was impact damaged with a torn inside corner and bent side plate on the left side. The valve body also had an impact mark on its left side. The BOV adaptor had sheared off at the flange, exposing a partially (about 2/3) open and extensively oxidized BOV ball. The handle assembly and securement mechanism were missing.
Top fittings	The housing cover was closed but extensively fire-damaged. The portion adjacent to the locking mechanism and the locking pin were burned away. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was inside the housing and not visible for inspection.
Manway	The manway cover was closed. The cover and bolts were extensively fire-damaged.
Stub sills and couplers	The A end stub sill and coupler were impact damaged. The bottom shelf was broken. The B end stub sill was bent downwards and twisted to the right. The knuckle was missing and the bottom shelf was broken.

(a) B end head

b) Shell viewed from B end head

(c) A end head

(d) Shell viewed from A end head

(e) Close up of shell puncture and burn-through

(f) Manway and top fittings

(g) BOV

(h) Close-up showing partially open BOV ball

Figure A-33: Photographs showing the condition of tank car WFIX 130545

Table A-34: Tank Car ACFX 79698

Consist position	36
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its right side, crushed under car NATX 302784 (consist 37), in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with blistering, metal loss and red discolouration.
Shell	The right side of the shell was crushed by car WFIX 130545 (consist 35) and the left side by car NATX 302784 (consist 37). This resulted in extensive deformation with reduction of volume along most of the length of car. At the crease between the two crushed areas at the top of the tank, the local radius was only a few inches and the shell material had begun to separate from the top fitting reinforcement pads.
Heads	The A end head contained 4 dents. The largest of these dents was approximately in the middle and contained a large rupture extending from the top to the bottom. There was a smaller puncture at the bottom-right where the damaged stub sill had been forced back against the head. The B end contained a large dent over most of its left side. This dent was further deformed by crushing in a direction consistent with car NATX 302784 (consist 37) coming to rest on top of this car. The combined deformation resulted in a large rupture approximately in the middle of the head.
Bottom outlet valve	This car did not have a skid; impact protection was provided by the BOV saddle which exhibited small impact marks around its periphery. The base, handle and cap assembly had sheared off at the saddle as designed, exposing a closed plug.
Top fittings	The housing cover had separated at the hinge and was missing. The liquid valve bolts were broken and the valve was pulled out several inches.
Pressure relief device	Both PRDs were impact damaged and dented and exhibited extensive fire damage.
Manway	The manway cover was in the closed position but 3 of the 8 bolts had sheared off and 1 bolt was bent. There was a visible gap between the manway nozzle and cover.
Stub sills and couplers	The A end stub sill was broken and bent up and to the right. The B end stub sill was broken and the knuckle was missing.

(a) B end head

b) A end head

(c) Bottom of shell viewed from A end

(d) Top of shell viewed from A end

(e) Bottom of shell viewed from B end

(f) BOV

(g) Manway and top fittings (RSI-AAR Safety Project photo)

Figure A-34: Photographs showing the condition of tank car ACFX 79698

Table A-35: Tank Car NATX 302784

Consist position	37
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its right side in the main pile-up, on top of car 36 (ACFX 79698) and perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of the car was extensively oxidized with red discolouration. There was a burn-through in the shell on the left side between the middle and B end. The edges of this burn-through were curled in the outward direction suggesting internal pressure was present when the perforation occurred.
Shell	The bottom of the shell was dented along the car length and contained a deeper transverse dent between the middle and A end. Multiple dents were observed on the top of the tank.
Heads	The A end head contained a shallow dent in the bottom-right quadrant and an impact mark with a deep gouge at the top-left edge. The B end head had no visible impact damage.
Bottom outlet valve	The fabricated skid and BOV assembly had no significant impact damage. The handle was in the closed position and secured. However, the handle extension and the support brackets were deformed due to impact damage. Product residue was observed on the BOV assembly.
Top fittings	The housing cover had separated at the hinge and was missing. The fittings were sheared off. The area surrounding the top fittings was extensively oxidized with a red discolouration.
Pressure relief device	The top portion of the PRD was sheared off and the PRD was filled with product residue.
Manway	The manway cover was in the closed position but 2 of the 6 bolts had released.
Stub sills and couplers	The A end stub sill was slightly bent to the right and the knuckle was missing. The B end stub sill had no significant impact damage.

(a) B end head

b) A end head

(c) Shell (RSI-AAR Safety Project photo)

(d) Burn-through in shell (RSI-AAR Safety Project photo)

(e) BOV

(f) Close-up showing product residue on BOV

(g) Manway, top fittings and PRD

Figure A-35: Photographs showing the condition of tank car NATX 302784

Table A-36: Tank Car ACFX 71505

Consist position	38
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The top portion of the tank was extremely fire damaged with burn-throughs along the bent edge of the shell. The top fittings were partly consumed (metal loss). The bottom of the tank was less fire damaged (lightly oxidized).
Shell	The left side of the shell was crushed up against cars ACFX 71121 (consist 39) and NATX 302784 (consist 37). This resulted in extensive deformation with reduction of volume along most of the length of the car. In the most deformed areas at the top of the tank, the local radius was only a few inches. This whole area was also extensively burned and exhibited cracks with bright, non-oxidized fracture surfaces. It is considered most probable that the shell was weakened by fire damage and cracked during tank car recovery and staging. The shell also contained an approximately 1-foot long rupture associated with the weld between the 1st and 2nd rings from the B end. This rupture had oxidized fracture surfaces indicating it occurred during the derailment.
Heads	The A end head had a shallow dent in the bottom-left quadrant. The left side of the B end head contained several dents and impact marks with a small puncture approximately in the middle.
Bottom outlet valve	This car did not have a skid; impact protection was provided by the BOV saddle. The BOV assembly had no impact damage. The handle was displaced towards the open position. The locking pin was hanging from its chain.
Top fittings	The housing cover had separated at the hinge and was missing. The fittings were sheared off. The top fitting nozzle was partly consumed by the fire.
Pressure relief device	The top portion of the A end PRD was impact damaged. The B end PRD had some impact damage. Both PRDs had sustained extensive fire damage.
Manway	The manway cover was in the closed position and partly consumed by the fire.
Stub sills and couplers	The A end stub sill was impact damaged and bent to the right. The knuckle was missing. The B end stub sill had no significant damage but the knuckle and bottom shelf were broken off.

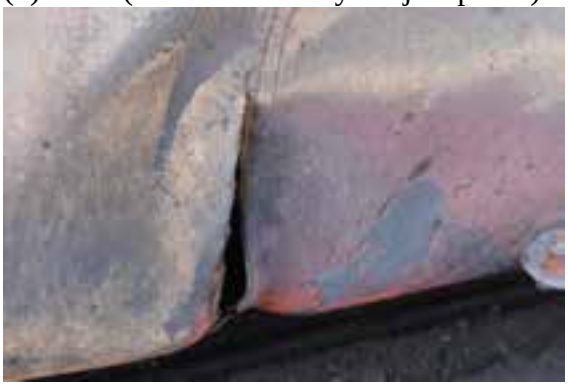
(a) B end head

b) Close-up of small puncture in B end head

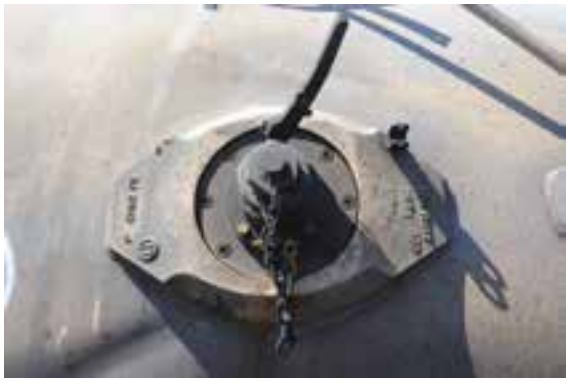
(c) A end head

(d) Shell (RSI-AAR Safety Project photo)

(e) Rupture in shell (arrow)



(f) Close-up of rupture arrowed in (e)



(g) BOV

(h) Top fittings, manway and PRDs

Figure A-36: Photographs showing the condition of tank car ACFX 71505

Table A-37: Tank Car ACFX 71121

Consist position	39
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side under cars ACFX 71505, WFIX 130616 and WFIX 130585 (consist no. 38, 43 and 55 respectively), in the main pile-up perpendicular to the direction of movement.
Extent of fire damage	The tank was extremely fire damaged with several areas of burn-through near the BOV.
Shell	The top of the shell contained a deep dent with a puncture at the junction with the A end head. It also was deformed with 2 deep folds at the junction with the B end head. The tank was flattened and dented along the bottom and right side. There were several burn-throughs on the bottom, one of which was associated with a puncture.
Heads	The edges of both heads were deformed adjacent to dents in the shell.
Bottom outlet valve	This car did not have a skid; impact protection was provided by the BOV saddle. The base, handle and cap assembly had sheared off at the saddle as designed, exposing a closed plug and a portion of the cam mechanism.
Top fittings	The housing was crushed and askew, exposing an impact damaged (bent) liquid valve.
Pressure relief device	The two PRDs had no visible impact damage.
Manway	The manway cover was in closed with 2 of the 8 bolts released.
Stub sills and couplers	The A end stub sill separated at the inboard draft gear lug location. The coupler was missing. The B end stub sill is impact damaged and the knuckle was missing.

(a) B end head (RSI-AAR Safety Project photo)

b) Deformation near B end head (RSI-AAR Safety Project photo)

(c) A end head (RSI-AAR Safety Project photo)

(d) Puncture at the bottom of a deep dent (RSI-AAR Safety Project photo)

(e) Shell (RSI-AAR Safety Project photo)

(f) Burn-throughs and puncture (arrow) on shell (RSI-AAR Safety Project photo)

(g) BOV (RSI-AAR Safety Project photo)

(h) Top fittings, manway and PRDs (RSI-AAR Safety Project photo)

Figure A-37: Photographs showing the condition of tank car ACFX 71121

Table A-38: Tank Car CTCX 735537

Consist position	40
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest close to upright, squeezed between cars ACFX 71505 and NATX 303128 (consist no. 38 and 41), in the main pile-up and perpendicular to the direction of movement. The B end of the car was also crushed underneath car WFIX 130585 (consist 55).
Extent of fire damage	The tank was extensively fire-damaged, with several burn-throughs associated with the more deformed areas along the top-right. The bottom was less fire-damaged.
Shell	The top of the shell contained a large crushed area between the B end and the top fittings, with extremely deformed (bent) material and a rupture between the manway and PRD. A long dent on the top-right near the A end had a torn and jagged edge, likely due to fire damage. There was another large dent on the left side near the B end. The bottom of the shell had several smaller dents.
Heads	The A end head had a deep dent in the bottom-right quadrant and a shallower dent on the bottom-left. The top-right edge of the B end head was severely crushed and contained a large rectangular impact mark.
Bottom outlet valve	The cast skid was impact damaged on its right side. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle was in the closed position. The securement mechanism was impact damaged.
Top fittings	The housing was missing and the top fittings were sheared off.
Pressure relief device	The PRD was extensively fire damaged.
Manway	The manway cover was closed. All of the bolts were damaged and/or covered with debris.
Stub sills and couplers	Both stub sills were broken with the remaining portion bent upwards. Both couplers were missing.

(a) B end head

b) A end head

(c) Shell viewed from the B end (RSI-AAR Safety Project photo)

(d) Shell viewed from the A end (RSI-AAR Safety Project photo)

(e) BOV

(f) Top fittings, manway and PRD

Figure A-38: Photographs showing the condition of tank car CTCX 735537

Table A-39: Tank Car NATX 303128

Consist position	41
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side, crushed between cars CTCX 735537 and CTCX 735572 (consist no. 40 and 42) and underneath car WFIX 130585 (consist 55), in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively oxidized with blistering and red discolouration above an inclined liquid/vapour line going about 1/3 of the height on the A end to 0 near the middle.
Shell	The shell was crushed all along the top-right, with a deep dent and a rectangular puncture near the A end. The shell contained 2 ruptures (one partly along the weld) at the top of the head-to-shell junction on the B end. These ruptures were located at the edge of a deep dent in the head. There was a deep dent with a buckled edge on the bottom-left near the B end.
Heads	The A end head was crushed on the top and contained a dent in the bottom-left quadrant. The B end head had a large dent covering most of its right side, with rupture at the head-to-shell weld at the top-right (see shell)
Bottom outlet valve	The fabricated skid was impact damaged on both sides. The BOV assembly was intact but the handle extension and securement mechanism were missing.
Top fittings	The housing was missing and the 2 valves were impact damaged (one was bent and the other sheared off).
Pressure relief device	The PRD had minor impact damage to one bolt on the top portion.
Manway	The manway cover was closed with 2 of the 6 bolts broken.
Stub sills and couplers	Both stub sills were impact damaged and twisted to the right. The B end coupler was still connected to the separated B end coupler from car CTCX 735537 (consist 40). The A end coupler was missing.

(a) B end head

b) Close-up showing the ruptures indicated by the arrow in (a)

(c) A end head

(d) Shell

(e) Shell

(f) Manway, top fittings and PRD

(g) BOV

Figure A-39: Photographs showing the condition of tank car NATX 303128

Table A-40: Tank Car CTCX 735572

Consist position	42
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright, pressed against cars NATX 303128 (consist no. 41) and underneath car WFIX 130585 (consist 55), in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively oxidized with flaking (metal loss) and red discolouration.
Shell	The shell was flattened along both sides resulting in a sharp crease near the bottom. There was a puncture on the bottom-left near the B end. The top was crushed between the top fittings and the A end.
Heads	The A end had a deep dent on its right side, with a puncture at the bottom-right edge. There was a shallow dent close to the middle. The B end had a puncture at the bottom-left edge and 2 deep parallel dents in its right half.
Bottom outlet valve	The cast skid was impact damaged on its left side. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle was closed and secured.
Top fittings	The housing was open and deformed. In-situ photos show that it was open and had some damage when the car came to rest. It was further deformed during staging. There was no visible impact damage to the top fittings.
Pressure relief device	The PRD had no visible impact damage.
Manway	The manway cover was closed with no impact damage.
Stub sills and couplers	The A end stub sill was impact damaged and the separated A end coupler from car WFIX 130616 was still attached to its coupler. The B end stub sill was broken and bent to the left. Its coupler was missing.

(a) B end head

b) Close-up showing the puncture indicated by the arrow in (a) (RSI-AAR Safety Project photo)

(c) Close-up showing a rupture in the area circled on (a) (RSI-AAR Safety Project photo)

(d) A end (RSI-AAR Safety Project photo)

(e) Top fittings, manway and PRD

(f) BOV

Figure A-40: Photographs showing the condition of tank car CTCX 735572

Table A-41: Tank Car WFIX 130616

Consist position	43
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upside down, on top of cars ACFX 71121 and CTCX 735537 (consist 39 and 40) in the main pile-up and angled with respect to the direction of movement.
Extent of fire damage	The tank was extensively oxidized with flaking (metal loss) and red discolouration.
Shell	The portion of the shell between the middle of the tank and the B end was crushed inward from the top and bottom directions. This resulted in extreme deformation near the B end where both sides were less than a foot apart, causing the shell and B end head to separate almost completely. Part of the rupture was associated with the head-to-shell weld. The left side of the shell had a puncture in a sharp dent near the middle of the tank.
Heads	The A end head was dented in the top-left quadrant and had a smaller dent on the bottom-left quadrant. The B end head was extremely deformed and almost completely separated from the shell (see above).
Bottom outlet valve	The fabricated skid and BOV assembly were unremarkable. The handle was secured in the closed position.
Top fittings	The housing cover had separated and there was an impact mark on the wall of the housing. The housing was partially filled with debris. The top fittings inside had no visible impact damage.
Pressure relief device	The PRD had no visible impact damage.
Manway	The manway cover was closed with 1 of the 6 bolts broken, 2 bolts released and impact damage to the hinge.
Stub sills and couplers	The A end stub sill had no significant impact damage but its coupler was broken. The B end stub sill was bent to the left. Its coupler was broken.

(a) B end head viewed from different orientations

(b) A end head

(c) Close-up showing puncture in shell in the area indicated by the arrow on (b)

(d) Shell viewed from the A end

(f) Top fittings and manway

Figure A-41: Photographs showing the condition of tank car WFIX 130616

Table A-42: Tank Car WFIX 130664

Consist position	44
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest in the upright position under car WFIX 130585 (consist 55) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was blackened and oxidized with red discolouration near the A end.
Shell	The left side of the shell was crushed and its top was flattened between the middle and A end. The left side also had a deeper transverse dent near the middle. Two ruptures were observed adjacent to the deep dent in the A end head: one rupture was associated with the body bolster pad fillet weld and the other with the head-to-shell weld.
Heads	The A end head contained a deep dent covering most of its left side. The B end head had multiple dents. A deeper dent near the top contained a gouge and small puncture.
Bottom outlet valve	The left and A end sides of the fabricated skid were impact damaged. The BOV adaptor had sheared off at the flange, exposing the BOV ball. The ball appeared to be closed although this could not be confirmed as it was partially obscured by dirt. The handle assembly and securement mechanism were deformed as a result of impact but the handle was still secured.
Top fittings	The housing assembly was extensively impact damaged – the cover and wall were deformed and the wall was partially separated from the nozzle. Some of the fittings were hidden from view – the others had no visible damage.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover was closed when the car came to rest. It was opened during recovery operations. One manway cover bolt was missing and 1 bolt was bent.
Stub sills and couplers	The A end stub sill was broken, bent to the left and its coupler knuckle was missing. This stub sill had separated at the fillet weld between the front sill pad and the head. This crack had propagated to the body bolster pad fillet weld and into the head-to-shell weld. The B end stub sill was partially obscured by dirt. The portions visible were unremarkable.

(a) B end head

(b) A end head

(c) Close-up showing front sill pad separation - see lower arrow in (b)

(d) Close-up showing separations at body bolster pad and head-to-shell welds – see upper arrow in (b) (RSI-AAR Safety Project photo)

(e) Shell viewed from the A end

(f) Top fittings and manway

(g) BOV

Figure A-42: Photographs showing the condition of tank car WFIX 130664

Table A-43: Tank Car WFIX 130630

Consist position	45
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest in the upright position between cars WFIX 130664 and TILX 316523 (consist 44 and 46) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was oxidized all over with extensive fire damage (red discolouration) around the B end.
Shell	The right side of the shell between the middle and the B end was extensively dented with two small punctures. The bottom of the shell between the BOV and the A end was crushed with a large transverse buckle.
Heads	The A end head had no significant impact damage. The B end head contained a deep puncture just above the stub sill and a large dent with a rupture at the junction with the shell on the right side.
Bottom outlet valve	The fabricated skid was extensively impact damaged. The tapered plate had separated at both welds on the side pointing to the B end. The BOV adaptor had sheared off at the flange, exposing a partially open (about ½) BOV ball. The handle assembly and securement mechanism were missing.
Top fittings	The housing cover was slightly askew but still secured. The fittings inside were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover was closed with no visible impact damage.
Stub sills and couplers	The A end stub sill was partially obscured by dirt. The portions visible were unremarkable. The B end stub sill was broken and bent to the right.

(a) B end head

(b) Small punctures in shell near B end head (RSI-AAR Safety Project photo)

(c) Shell viewed from the A end

(d) A end head and view of bottom of shell

(e) BOV

(f) Close-up showing partly open BOV ball

(g) Top fittings and manway

Figure A-43: Photographs showing the condition of tank car WFIX 130630

Table A-44: Tank Car TILX 316523

Consist position	46
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest nearly upright position between cars WFIX 130630 and TILX 316613 (consist 45 and 47) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was oxidized all over with extensive fire damage (red discolouration).
Shell	The bottom half of the shell was crushed on both sides near the middle. The shell was flattened all along its top-left side with a large puncture with outward curled edges on the top between the A end and top fittings.
Heads	The A end head contained a small puncture at the bottom of a deep dent on its left edge. The B end head contained 2 dents in the top-left quadrant - one had an impact mark and small puncture in it.
Bottom outlet valve	The left side of the fabricated skid was impact damaged. The BOV adaptor had sheared off at the flange, exposing a BOV ball that was visibly leaking product. The handle assembly and securement mechanism were missing.
Top fittings	The housing cover and wall were deformed due to impact. The fittings were partially visible – no impact damage was noted.
Pressure relief device	The PRD inside the housing had no visible damage.
Manway	The manway cover was closed with no visible impact damage.
Stub sills and couplers	The A end stub sill was broken and bent to the right. The coupler was broken. The B end stub sill was not deformed but the fillet weld between the front sill pad and the head had separated. The coupler knuckle was missing.

(a) B end head (RSI-AAR Safety Project photo)

(b) A end head (RSI-AAR Safety Project photo)

(c) Shell bottom viewed from the B end (RSI-AAR Safety Project photo)

(d) BOV (RSI-AAR Safety Project photo)

(e) Shell top viewed from B end

(f) Top fittings and manway

(g) Close-up of puncture side of A end shell (RSI-AAR Safety Project photo)

(h) Close-up of puncture in shell (RSI-AAR Safety Project photo)

Figure A-44: Photographs showing the condition of tank car TILX 316523

Table A-45: Tank Car TILX 316613

Consist position	47
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side squeezed between cars TILX 316523 and TILX 316616 (consist 46 & 48) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was oxidized all over with extensive fire damage (red discolouration) primarily on the A end.
Shell	The shell was crushed inward from the top and bottom directions. This resulted in extreme deformation near the middle with opposite sides coming close together. The shell bottom contained a large puncture with inward-curled edges near the B end and the top had a smaller puncture adjacent to the manway.
Heads	The upper half of the A end head had shallow denting. The bottom-right and top-left sides of the B end head were crushed (consistent with the shell crushing).
Bottom outlet valve	The fabricated skid had no impact damage. The BOV adaptor had sheared off at the flange, exposing an oxidized BOV ball. A small gap was visible between the ball and valve housing but there was no sign of product leakage. The handle extension and securement mechanism were deformed due impact damage.
Top fittings	The housing assembly and its cover were present but only partially visible due to the orientation of the car after it was staged. The fittings inside were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway was not visible for inspection due to the orientation of the car after it was staged.
Stub sills and couplers	The A end stub sill front sill pad had separated from the head at the fillet weld. The crack extended back to the body bolster pad weld. The B end stub sill was broken and its coupler was missing.

(a) B end head

(b) A end head

(c) Shell viewed from the A end

(d) Puncture in shell bottom

(e) Shell bottom viewed from B end

(f) Puncture in top of shell, manway and top fittings (RSI-AAR Safety Project photo)

Figure A-45: Photographs showing the condition of tank car TILX 316613

Table A-46: Tank Car TILX 316616

Consist position	48
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its right side underneath car TILX 316206 (consist 49) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was oxidized all over with more intense fire damage (red discolouration, metal loss, rusty areas, and burn-throughs) on the top portion.
Shell	The shell was crushed inward from both sides, with a more extensive deformation on the right side between the B end and the middle, resulting in a sharp crease near the top fittings. It contained a long rupture on a slant plane in the crushed area on the right side. The region with extreme deformation near the top fittings had extensive fire damage and several transverse cracks.
Heads	The bottom-right quadrant of the A end head was extensively dented. The top portion has several shallow dents. The B end head was flattened from both sides consistent with the crushing deformation of the shell and had a very deep dent with extensive deformation on the bottom left side.
Bottom outlet valve	The fabricated skid was impact damaged on both sides. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle extension and securement mechanism were missing.
Top fittings	The housing assembly and its cover were present but only partially visible due to the orientation of the car after it was staged. The fittings inside were not visible for inspection. The housing cover was partially torn off. The wall was deformed inward due to impact damage and was partially separated from the nozzle as several bolts had sheared off. The top fittings inside were extensively fire-damaged, with red discolouration and metal loss.
Pressure relief device	The PRD inside the housing was extensively fire-damaged.
Manway	The manway was closed and extensively fire-damaged.
Stub sills and couplers	The A end stub sill was slightly bent to the left. The B end stub sill was broken and twisted to the right.

(a) A end head

(b) B end head

(c) Shell damage in the area indicated by the arrow on (b)

(d) Bottom of the shell viewed from the B end

(e) Shell rupture in the area indicated by the arrow on (d)

(f) Manway and top fittings

(g) BOV

Figure A-46: Photographs showing the condition of tank car TILX 316616

Table A-47: Tank Car TILX 316206

Consist position	49
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side on top of car TILX 316616 (consist 48) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged all over (red discolouration, blistering and metal loss). The shell had a large burn-through on the bottom near the B end.
Shell	The shell was compressed inward from both sides. It was extensively buckled in the transverse direction at both ends (towards the right at the B end and the left at the A end), resulting in an overall “s” shape. There was a large transverse rupture in the buckled area near the weld between the shell and B end head.
Heads	The left side of the A end head had shallow denting. The B end head had a very large dent on the right side and was flattened from both sides consistent with the shell deformation.
Bottom outlet valve	The fabricated skid was slightly impact damaged on the left side. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. Rusty deposits around the ball and inside the skid suggest there was product seepage from the BOV. The handle extension was deformed and separated from the valve assembly.
Top fittings	The housing cover was closed and slightly deformed. The top fittings inside were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway is not visible on any photograph.
Stub sills and couplers	The A end stub sill was broken and twisted to the left. The B end stub sill was broken, bent to the right. Both couplers were broken.

(a) A end head (RSI-AAR Safety Project photo)

(b) Shell (RSI-AAR Safety Project photo)

(c) Shell (RSI-AAR Safety Project photo)

(d) BOV (RSI-AAR Safety Project photo)

(e) B end head (RSI-AAR Safety Project photo)

(f) Rupture at B end head-to-shell joint (RSI-AAR Safety Project photo)

(g) Top fittings (RSI-AAR Safety Project photo)

(h) Shell (RSI-AAR Safety Project photo)

Figure A-47: Photographs showing the condition of tank car TILX 316206

Table A-48: Tank Car TILX 316319

Consist position	50
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright, compressed between cars TILX 316206 and CTCX 735617 (consist 49 and 51) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged with flaking and red discolouration on the left side with a large burn-through near the B end
Shell	The shell was extremely crushed from both sides – the diameter in the middle was nearly reduced to the width of the BOV skid (Figure A-48d). The buckled regions on the top between the manway and the B end contained long transverse ruptures with torn edges. The reinforcing bars on the tank bottom were broken at the buckle between the BOV and B end. A small rupture had extended into the shell from a fracture in the right reinforcing bar.
Heads	The right edge of the A end head was dented. The B end head had no significant impact damage.
Bottom outlet valve	The fabricated skid and BOV assembly were unremarkable. The handle extension was separated from the BOV inside the skid. The handled extension and securement mechanism were extensively deformed due to impact damage.
Top fittings	The housing cover was slightly deformed and askew but still secured. The top fittings inside were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover was closed with 2 of the 6 bolts broken above the nut and 1 bolt bent and knocked out of its lug.
Stub sills and couplers	The A end stub sill was bent to the left. The coupler was partially obscured by dirt - the knuckle was missing. The B end stub sill was broken and had separated at the head brace to front sill pad fillet weld, exposing the draft gear inboard lugs. The coupler was missing.

(a) A end head

(b) B end head

(c) Shell

(d) BOV

(e) Close-up showing small rupture (arrow) in the area circled on (c) (RSI-AAR Safety Project photo)

(f) Shell viewed from the B end

(g) Large ruptures in the shell

(h) Manway and top fittings

Figure A-48: Photographs showing the condition of tank car TILX 316319

Table A-49: Tank Car CTCX 735617

Consist position	51
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright, its A end compressed between cars TILX 316206 and CTCX 735526 (consist 49 and 53) and its B end compressed between cars TILX 316319 and TILX 316572 (consist 50 and 52) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged with flaking and red discolouration.
Shell	The shell exhibited crushing and twisting deformation with extreme loss of volume in the middle portion. The welds joining the skid to the shell had separated, with tears extending into the shell on both sides. There was a large transverse rupture associated with a weld in the extremely deformed area on the bottom, between the BOV and B end. There was a small puncture on the bottom-right of the second ring from the A end.
Heads	The right edge of the A end head had a shallow dent. The B end head was very deformed (crushed from both sides) and contained a large deep dent in the upper-right quadrant, extending into the shell. It also had a smaller dent on the bottom-right.
Bottom outlet valve	The cast skid was extensively impact damaged and had partially separated from the shell. The BOV adaptor had sheared off at the flange, exposing the BOV ball. Most of the visible ball surface was oxidized but there was a bright, non-oxidized crescent at the A end side suggesting the ball was displaced after the occurrence. The handle was deformed and not secured. The securement mechanism was impact damaged.
Top fittings	The housing was crushed and askew. The top fittings inside were not visible for inspection.
Pressure relief device	The top portion of the PRD exhibited minor impact damage (broken bolt).
Manway	The manway cover was closed with 1 of the 6 bolts broken above the nut.
Stub sills and couplers	The A end stub sill was broken and the coupler was missing. The B end stub sill was broken. It had separated at the fillet weld between the head brace and the stub sill. This crack propagated across the front sill pad, into the front sill pad to shell fillet weld and stopped at the body bolster pad.

(a) B end head

(b) Close-up showing failed B end stub sill welds

(c) Shell viewed from the B end

(d) Top fittings, manway and PRD

(e) Shell viewed from the A end

(f) Close-up of small puncture in shell

(g) BOV

(h) Rupture in shell between BOV and B end

Figure A-49: Photographs showing the condition of tank car CTCX 735617

Table A-50: Tank Car TILX 316572

Consist position	52
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright, compressed between cars TILX 316319, CTCX 735617, CTCX 735526 and TILX 316622 (consist 50, 51, 53 and 54) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged with flaking and red discolouration.
Shell	The car exhibited crushing deformation with extreme loss of volume over most of its length. The top of the shell contained a large rupture adjacent to the manway. A transverse rupture nearly separated the B end head from the shell. The shell was extremely crushed around the BOV and contained 2 aligned punctures through both sides.
Heads	The A end contained multiple impact marks and 2 punctures just below the middle. The top-right edge was crushed. The B end head was extremely deformed and partially separated from the BR bolster and shell.
Bottom outlet valve	The fabricated skid was extensively impact damaged and had partially separated from the shell. The BOV adaptor had sheared off at the flange, exposing a closed BOV ball. The handle extension and securement mechanism were missing.
Top fittings	The housing cover had separated and was missing. The wall of the housing was slightly deformed. The housing was partially filled with dirt. The liquid valve nozzle had sheared off. The other fitting that was visible had no impact damage.
Pressure relief device	The PRD inside the housing was partially covered by dirt; the visible portion was not damaged.
Manway	The manway cover was closed with fire damage but no visible impact damage.
Stub sills and couplers	The A end stub sill was bent to the left. The B end stub sill was impact damaged and its coupler was broken.

(a) A end head and bottom of shell

(b) BOV

(c) Shell at BOV

(d) B end head

(e) Shell viewed from the B end

(f) Shell rupture adjacent to manway

(g) Top fittings and manway

Figure A-50: Photographs showing the condition of tank car TILX 316572

Table A-51: Tank Car CTCX 735526

Consist position	53
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged with red discolouration.
Shell	The car exhibited crushing deformation with extreme loss of volume in the middle. The shell had a large rupture on the right side at the A end head-to-shell weld. It was punctured on the right side at the B end head-to-shell and bolster pad welds.
Heads	The A end was extensively deformed with deep horizontal buckles in the middle. The right hand portion of the B end head had a large dent with a buckled edge on the right side. At the bottom-right, this dent was coincident with the puncture at the head-to-shell weld. There was also a small rupture at the top-right edge of the dent.
Bottom outlet valve	The cast skid was impact damaged on the left side. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle was in the closed position and secured.
Top fittings	The housing was impact damaged and askew. It was only partially visible due to the position of the car after staging. The fittings inside were not visible for inspection.
Pressure relief device	The PRD was only partially visible due to the position of the car after staging. No impact damage was observed.
Manway	The manway was only partially visible due to the position of the car after staging. It was closed with a gap between the cover and nozzle. Three bolts were visible: 1 was broken and another was released.
Stub sills and couplers	The A end stub sill was bent and partially broken behind the striker plate. The coupler was missing. The B end stub sill was bent to the right and broken. Its coupler was broken.

(a) B end head

(b) Shell viewed from B end

(c) Close-up showing rupture at shell-to-head weld at B end

(d) Top fittings, manway and PRD

(e) Shell (RSI-AAR Safety Project photo)

(f) Shell viewed from the A end

(g) BOV

Figure A-51: Photographs showing the condition of tank car CTCX 735526

Table A-52: Tank Car TILX 316622

Consist position	54
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its top-left (almost upside down) between cars TILX 316572, CTCX 735526 and NATX 310508 (consist no. 52, 53 and 56) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The tank was extensively fire-damaged with red discolouration and blistering (metal loss).
Shell	The shell was extensively crushed from about midway between the A end and the middle of the B end, with large ruptures in the most deformed areas. Some of these ruptures were associated with shell welds. There was a puncture on the top near the A end.
Heads	The A end head had a dent at the top edge. The B end head was extensively deformed and had a large dent on the top-right. The head was separated from the shell at the bottom, with a circumferential rupture extending from the left side of the stub sill, through the front sill pad location, and up to the dent on the top-right. Some of this rupture was associated with the BR body bolster pad fillet weld.
Bottom outlet valve	The shell was extensively deformed and had ruptured in the area of the fabricated skid. The skid itself was not present on the visible portions of shell. The BOV adaptor had sheared off at the flange. Due to the orientation of the tank car after staging, the condition of the BOV ball could not be determined. The handle extension had separated from the BOV. The handle assembly and securement mechanism were extensively deformed but remained attached to a separated portion of shell.
Top fittings	The housing had separated at the flange. All of the bolts securing the housing to the flange were sheared. Nine of the 20 bolts clamping the flange to the top fitting nozzle were also sheared off. These bolts were located on the left side and the bolt fracture surfaces were stretched towards the right, indicating the housing was impacted from the left to the right. All of the fittings inside had sheared off or were impact damaged.
Pressure relief device	The top portion of the PRD was sheared off.
Manway	The manway cover is closed with 3 of the 6 bolts released, 1 bolt was broken above the nut.
Stub sills and couplers	The A end stub sill was impact damaged and slightly bent downward. The coupler was broken. The B end stub sill was broken apart. The front sill pad had separated from the tank at the fillet weld. The BR body bolster had partially separated from its pad and the pad had also partially separated from the tank at the fillet weld. The coupler was missing.

(a) B end head

(b) Close-up showing separations at B end stub sill and BR body bolster

(c) Shell

(d) Shell viewed from A end

(e) Top fittings and manway

(f) BOV

Figure A-52: Photographs showing the condition of tank car TILX 316622

Table A-53: Tank Car WFIX 130585

Consist position	55
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its right side, on top of the 7 cars ranging from car ACFX 71121 (consist no. 39) to TILX 316523 (consist no. 46) in the main pile-up and parallel to the direction of movement.
Extent of fire damage	The top portion of the shell between the top fittings and the B end and the B end head exhibited extensive fire damage with flaking and red discolouration. There was a burn-through on the top of first ring from the B end.
Shell	The shell was dented on the bottom-left between the A end and BOV. It had a shallow buckle on the top-right near the B end, with a burn-through. The region near the B end was slightly bulged. A small (less than 1-foot long) longitudinal rupture with red discolouration and product residue was located on the left side near the shell-to-B end head junction. This rupture was not associated with any visible deformation. It was likely due to internal pressurization of the tank during the post-derailment fire (see main text).
Heads	The A end head had no significant impact damage. The B end head had a shallow dent in the bottom-right quadrant near the stub sill. It had 3 small ruptures on the left side near the edge of the head. These ruptures had a red discolouration and product residue. There was no dent in this region. It is likely that these ruptures were also due to tank pressurization during the post-derailment fire (see shell and main text).
Bottom outlet valve	The fabricated skid was impact damaged on the right side. The shell adjacent to the damaged portion of the skid had an impact mark. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle assembly and securement mechanism were missing. The two securement mechanism pads were in the dented portion of the shell. A rusty residue was noted on the BOV ball suggesting there was product seepage.
Top fittings	The housing cover was slightly deformed but closed and secured. Product residue was noted in the gap between the cover and housing suggesting some of the fittings may have released product. The fittings inside the housing were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover is closed with no visible impact damage.
Stub sills and couplers	The A end stub sill was broken and bent to the right. The B end stub sill was broken and bent downward. Both couplers were missing.

(a) B end head

(b) Close-up showing small ruptures at B end

(c) Shell viewed from the B end

(d) Manway and top fittings

(e) Product residue in gap between housing and cover

(f) Shell viewed from the A end

(g) BOV

(h) Close-up showing closed BOV ball

Figure A-53: Photographs showing the condition of tank car WFIX 130585

Table A-54: Tank Car NATX 310508

Consist position	56
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright and slightly tilted to the right side between cars TILX 316622 and CTCX 735525 (consist no. 54 and 57) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The car was extensively oxidized with red discolouration, blistering and flaking around the punctures in the A end head and the rupture between the BOV and A end.
Shell	The shell was compressed on the top-left near the B end and on the bottom-right near the A end. It had deep angled buckles extending from the BOV towards the A end. There was a short longitudinal rupture in the large dent on the bottom between the BOV and the A end.
Heads	The A end head exhibited numerous shallow dents. It had a rectangular puncture near the top and a second puncture on the bottom-right edge. The B end head had no significant impact damage.
Bottom outlet valve	The fabricated skid was unremarkable. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle assembly and securement mechanism were not visible for inspection due to the orientation of the car after staging.
Top fittings	The housing had no visible impact damage. The fittings inside were not visible for inspection.
Pressure relief device	The top portion of the PRD was impact damaged.
Manway	Part of the manway was visible indicating the cover was closed. The condition of the bolts was not determined.
Stub sills and couplers	The A end stub sill was broken and bent to the right. The bottom shelf was broken. The B end stub sill was bent to the right.

(a) B end head (RSI-AAR Safety Project photo)

(b) A end head (RSI-AAR Safety Project photo)

(c) Shell (RSI-AAR Safety Project photo)

(d) Close-up showing small rupture in the shell bottom (arrow) (RSI-AAR Safety Project photo)

(e) Top fittings (RSI-AAR Safety Project photo)

(f) PRD (RSI-AAR Safety Project photo)

(g) BOV (RSI-AAR Safety Project photo)

(h) Shell (RSI-AAR Safety Project photo)

Figure A-54: Photographs showing the condition of tank car NATX 310508

Table A-55: Tank Car CTCX 735525

Consist position	57
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest on its left side, crushed between cars NATX 310508 and ACFX 79383 (consist no. 56 and 58) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The B end and the portion of the shell around the large rupture showed extensive fire damage (red discolouration). The rest of the tank was oxidized.
Shell	The top and bottom of the shell were extremely compressed by adjacent cars. This extreme deformation resulted in large transverse ruptures located between the B end and top fittings that nearly separated the shell into two portions. There was also a transverse buckle on the bottom near the A end and a deep dent on the top-left near the B end.
Heads	The left side of the A end head contained several dents. The B end head had a small dent with an impact mark near the top.
Bottom outlet valve	The cast skid was broken at the side pointing towards the B end. The crack extended to the skid-to-shell weld and into the rupture in the shell. The BOV adaptor had sheared off at the flange, exposing a closed and oxidized BOV ball. The handle was closed and secured.
Top fittings	The housing was missing and the top fittings were sheared off.
Pressure relief device	The PRD nozzle was sheared off at the reinforcement pad.
Manway	The manway cover was closed with all 6 bolts damaged or released.
Stub sills and couplers	The A end stub sill had minor impact damage. The B end stub sill was broken and distorted to the right. The coupler was missing.

(a) B end head

(b) Shell viewed from the B end

(c) Shell viewed from the A end

(d) BOV

(e) Top fittings, manway and PRD

Figure A-55: Photographs showing the condition of tank car CTCX 735525

Table A-56: Tank Car ACFX 79383

Consist position	58
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright, pushed up against car CTCX 735525 (consist 57) in the main pile-up and angled relative to the direction of movement.
Extent of fire damage	The car was oxidized with red discolouration around the punctures.
Shell	The sides of the shell were deformed inward with a larger dent on the left side in the middle with a puncture in it. The body-mounted brake cylinder was torn off at the weld to the shell, with the crack breaching the tank.
Heads	The A end head was slightly dented on the right side and at the bottom. The B end head had an impact mark with a small puncture at the bottom-right. It had several larger dents in the top-right quadrant with 3 punctures with jagged edges.
Bottom outlet valve	This car did not have a skid; impact protection was provided by the BOV saddle. The base, handle and cap assembly had sheared off at the saddle as designed, exposing a closed plug.
Top fittings	The housing was closed, slight askew and not secured. The top fittings inside had no visible impact damage.
Pressure relief device	The top of the B end PRD was dented. The A end PRD had no visible impact damage.
Manway	The manway cover was closed with 4 of the 8 bolts broken or loose.
Stub sills and couplers	Both stub sills were bent to the left and broken, exposing the draft gear inboard lugs. Both couplers were missing.

(a) B end head

(b) Shell bottom viewed from the A end

(c) Shell top viewed from the A end (RSI-AAR Safety Project photo)

(d) Close-up showing a puncture in the left side near the middle - refer to arrow in (c)

(e) PRDs, manway and top fittings

(f) Top fittings

(g) BOV

(h) Body-mounted brake cylinder separated from tank

Figure A-56: Photographs showing the condition of tank car ACFX 79383

Table A-57: Tank Car PROX 44428

Consist position	59
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upside down, pushed under car CTCX 735525 (consist 57) in the main pile-up and slightly angled relative to the direction of movement.
Extent of fire damage	The area around the rupture and the bottom portion of the shell had extensive fire damage (red discolouration, flaking and metal loss). The rest was oxidized.
Shell	The top and bottom of the shell were extremely compressed and were less than 1 foot apart in the middle of the car. This extreme deformation resulted in large transverse ruptures in the vicinity of the BOV and top fittings. The car was nearly separated into 2 portions.
Heads	The A end head was slightly dented on the bottom-left edge The B end head was completely dented inward.
Bottom outlet valve	The BOV area was not visible for inspection.
Top fittings	The top fittings were not visible for inspection.
Pressure relief device	The PRD was not visible for inspection.
Manway	The manway was not visible for inspection.
Stub sills and couplers	The A end stub sill was broken and the coupler was missing. The B end stub sill was bent to the left and partially separated at the draft gear. The coupler was still connected to the separated A end coupler from car ACFX 79383 (consist 58).

(a) B end head

(b) Shell bottom viewed from the B end

(c) Ruptures in middle of the shell's right side

(d) A end head and shell

(e) Ruptures in middle of the shell's left side

Figure A-57: Photographs showing the condition of tank car PROX 44428

Table A-58: Tank Car PROX 44150

Consist position	60
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright, squeezed between cars PROX 44428 and TILX 316533 (consist no. 59 and 61) in the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The car was oxidized with red discolouration in the area around the puncture in the B end.
Shell	The aerial views and in-situ photos available show the shell was compressed inward on both sides between the top fittings and the A end with a longitudinal buckle on the top. It was also compressed inward on the right side between the top fittings and B end.
Heads	The B end head had a shallow dent on its right side and a deep dent with a puncture at the left-bottom edge. The A end head was not inspected.
Bottom outlet valve	The BOV area was not visible for inspection.
Top fittings	The housing was closed. Based on aerial and in-situ photographs, it appeared to have no impact damage. The top fittings inside the housing were not visible for inspection.
Pressure relief device	Based on aerial and in-situ photographs, the PRD was undamaged.
Manway	The manway was closed. Based on aerial and in-situ photographs, it had no damage.
Stub sills and couplers	The A end stub sill was not visible for inspection. The B end stub sill was broken, bent upwards and to the right. The coupler was missing.

(a) Aerial view showing car PROX 44150 (arrow) in- upright, squeezed between cars PROX 44428 and TILX 316533 (consist no. 59 and 61)

(b) Aerial view showing the car (arrow) from a different angle

(c) Left side of shell viewed from the B end (RSI-AAR Safety Project photo)

(d) Right side of shell viewed from the B end (RSI-AAR Safety Project photo)

Figure A-58: Photographs showing the condition of tank car PROX 44150

Table A-59: Tank Car TILX 316533

Consist position	61
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright and slightly tilted to the right, between cars PROX 44150 and ACFX 94578 (consist 60 and 62) at the aft end of the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of this car was oxidized with a rusty discolouration and extensive fire damage above an inclined liquid/vapour line going from about 1/2 of the height at the A end to 2/3 of the height at the B end. There was a burn-through on the left side between the A end and the top fittings.
Shell	The top and right side of the shell contained a transverse buckle on either side of the top fittings.
Heads	The B end head had a deep dent on the top-right quadrant. The A end head had no impact damage.
Bottom outlet valve	The fabricated skid exhibited some scrape marks. The BOV adaptor had sheared off at the flange exposing a product-covered BOV ball that appeared to be closed. Product was visibly leaking from the BOV. The handle assembly and securement mechanism were extensively deformed and the handle was not secured.
Top fittings	The housing cover was significantly deformed but closed and secured. Product residue was noted in the gap between the cover and housing indicating some of the fittings had released product. The fittings inside the housing were not visible for inspection.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway was closed with no impact damage. A large amount of product residue was noted in the gap between the cover and manway nozzle indicating that the manway had released product.
Stub sills and couplers	The A end stub sill was unremarkable. The B end stub sill was slightly bent to the right. The head brace had separated from the front sill pad at the fillet weld. The coupler was broken.

(a) Shell top viewed from the B end

(b) Close-up showing separation at B end head brace to front sill pad fillet weld - see arrow in (a)

(c) Shell bottom viewed from B end

(d) Shell top viewed from A end

(e) Burn-through on left side of shell – see arrow in (d)

(f) Top fittings and manway

(g) BOV

(h) Close up showing product leaking from BOV

Figure A-59: Photographs showing the condition of tank car TILX 316533

Table A-60: Tank Car ACFX 94528

Consist position	62
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest on its left side and with its bottom crushed by the ends of cars NATX 310515 and TILX 316528 (consist 63 and 64) at the aft end of the main pile-up and perpendicular to the direction of movement.
Extent of fire damage	The exterior finish of this car was extensively oxidized with a rusty discolouration, blistering and metal loss due to flaking.
Shell	The shell was extremely deformed (crushed from the bottom to the top, with both sides almost touching in the middle). It had a transverse rupture in the left side in the middle and a longitudinal rupture on the top between the middle and A end.
Heads	The B end head had a deep dent in the top-left quadrant. It was punctured at the top-left edge near the head-to-shell weld. The A end head had no impact damage.
Bottom outlet valve	The fabricated skid had no impact damage. The BOV adaptor had sheared off at the flange exposing a closed and oxidized BOV ball. The handle and securement mechanism were impact damaged and the handle was not secured.
Top fittings	The housing was missing and the fittings were impact damaged.
Pressure relief device	The A end PRD nozzle had sheared off; the B end PRD was impact damaged.
Manway	The manway was closed.
Stub sills and couplers	The A end stub sill was impact damaged and broken. The coupler was missing. The B end stub sill had no significant impact damage. The coupler knuckle was missing.

(a) Shell viewed from the B end

(b) Close-up showing puncture at the edge of the B end head - see arrow in (a) (RSI-AAR Safety Project photo)

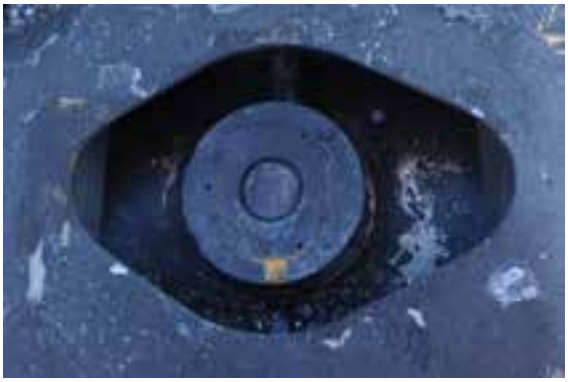
(c) Shell viewed from A end

(d) Close-up showing rupture in shell top – see arrow on (c) (RSI-AAR Safety Project photo)

(e) Rupture in middle of right side – see area circled in (c)

(f) PRDs, top fittings and manway (circled)

(g) BOV



(h) Close up showing BOV ball

Figure A-60: Photographs showing the condition of tank car ACFX 94528

Table A-61: Tank Car NATX 310515

Consist position	63
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright and slightly tilted to the right adjacent to car TILX 316528 (consist 64) at the aft end of the main pile-up and parallel to the direction of movement.
Extent of fire damage	The exterior finish of this car on the B end and bottom was blackened but markings were still visible. The A end and top were extensively oxidized with a rusty colour.
Shell	The shell had no significant impact damage. There was a thermal tear on the top-left side below the PRD. This thermal was 2/3 of a ring in length (about 65 inches) by about 6 inches wide. The shell was somewhat bulged around the thermal tear.
Heads	The A end head was dented all over with deeper denting and scrape marks in the middle. There was a small puncture associated with one of these scrape marks at the bottom-right edge of this dent. The bottom-right quadrant was also deeply dented. The B end head had a dent at the edge of the bottom-left quadrant.
Bottom outlet valve	The fabricated skid exhibited some scrape marks. The BOV adaptor had sheared off at the flange. The BOV ball was partially obscured by dirt and appeared to be closed. The handle extension was separated from the valve. The handle assembly and securement mechanism were extensively deformed.
Top fittings	The housing was closed. The fittings inside were not visible for inspection.
Pressure relief device	The PRD had no visible impact damage.
Manway	The manway cover was closed when the derailed car came to rest. It was subsequently opened during recovery operations. None of the bolts were damaged.
Stub sills and couplers	The A end stub sill was unremarkable. The knuckle was missing. The B end stub sill was broken and bent to the left. The coupler was missing.

(a) Shell viewed from B end

(b) A end head

(c) Close-up of small puncture in circled portion of A end head – see (b) (RSI-AAR Safety Project photo)

(d) Shell

(e) Thermal tear in shell – see arrow on (d)

(f) PRD, manway and top fittings

(g) BOV

Figure A-61: Photographs showing the condition of tank car NATX 310515

Table A-62: Tank Car TILX 316528

Consist position	64
Orientation in the consist	A end leading
Position and orientation of derailed car	This car came to rest upright adjacent to car NATX 310515 (consist 63) at the aft end of the main pile-up and parallel to the direction of movement.
Extent of fire damage	The exterior finish of this car was blackened but markings were still visible in some areas. It was extensively fire-damaged on the top around the top fittings.
Shell	The shell had no significant impact damage.
Heads	The A end head was extensively dented and deformed but had no punctures. The B end head had no impact damage.
Bottom outlet valve	The fabricated skid was dented on the B end side. The BOV adaptor had sheared off at the flange exposing a partially open (about 1/5) product-covered BOV ball. The handle extension was bent. The handle was still secured to the impact damaged and deformed securement mechanism.
Top fittings	The housing assembly and its closed cover were partially consumed by fire damage. There was no visible impact damage. The top fittings were only partially visible for inspection. The one fitting that was visible had no impact damage. The housing was partially filled with product residue, some of which had spilled out onto the shell. This indicates that product was released from inside the housing assembly.
Pressure relief device	The PRD inside the housing was not visible for inspection.
Manway	The manway cover was closed when the derailed car came to rest. It was subsequently opened during recovery operations. None of the bolts were impact damaged.
Stub sills and couplers	Both stub sills were broken and bent to the right. Both couplers were almost completely separated and hanging from the draft key.

(a) Shell top viewed from the B end

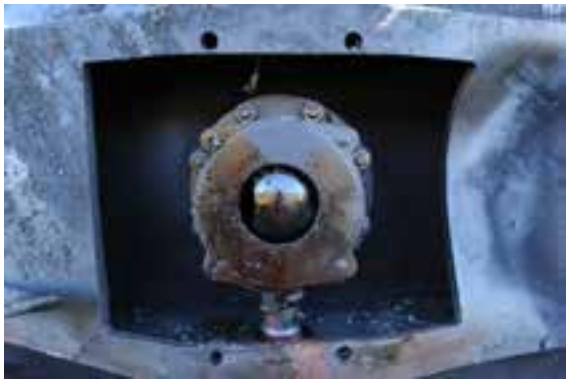
(b) A end head

(c) Shell bottom viewed from A end

(d) Manway and top fittings

(e) Close-up showing product residue in housing (RSI-AAR Safety Project photo)

(f) BOV



(g) Close-up showing partially open BOV ball

Figure A-62: Photographs showing the condition of tank car TILX 316528

Table A-63: Tank Car NATX 310470

Consist position	65
Orientation in the consist	B end leading
Position and orientation of derailed car	This car came to rest upright at the aft end of the main pile-up, with the B end truck derailed. The car was re-railed after the derailment.
Extent of fire damage	The exterior finish of this car had no fire damage.
Shell	The shell had no impact damage.
Heads	Both heads had no impact damage.
Bottom outlet valve	The fabricated skid and BOV were unremarkable. The handle was secured in the closed position.
Top fittings	No visible damage.
Pressure relief device	No visible damage.
Manway	No visible damage.
Stub sills and couplers	The striker face of the B end stub sill was impact damaged on the right side. The coupler shank was broken.

(a) In-situ photo showing the B end viewed from the right side

(b) B end stub sill

(c) Re-railed car

Figure A-63: Photographs showing the condition of tank car NATX 310470

Appendix B: In-situ Photographs of Derailed Tank Cars

Figure B-1: Aerial view of derailment zone showing the position of derailed cars from consist no.2 (box car) through consist no.13 (tank car NATX 310457)

Letters A through F indicate the different tracks:

A - main track
B - yard track 1
C – yard track 2
D – yard track 3
E - west leg of wye
F - east leg of wye

(a) The A end and B end are marked on each derailed tank car. Arrows point in the direction of the end leading in the occurrence train.

(b) Color coding indicates how each car came to rest with yellow (upright), pink (upside down) and violet (on its side)

Figure B-2: Aerial views showing the orientation of the derailed tank cars

(a) Aerial view looking north showing consist no.3 through 10. The broken portions of yard tracks 1 and 2 are circled.

(b) In-situ photo showing location of consist no.3 near a box car parked on yard track 2 (RSI-AAR Safety Project photo)

Figure B-3: Aerial view looking north showing the orientation of consist no.3 through 10

(c) In-situ photo showing a ground mark originating from the top fittings of consist no.5 (RSI-AAR Safety Project photo)

(d) In-situ photo showing a close-up of the area circled in Figure B-3a. The arrow points to a broken rail bent back 180 degrees (RSI-AAR Safety Project photo).

Figure B-3: Aerial view looking north showing the orientation of consist no.3 through 10

(e) In-situ photo showing a ground mark and debris originating from consist no.8 and 9 (RSI-AAR Safety Project photo)

Figure B-3: Aerial view looking north showing the orientation of consist no.3 through 10

(a) View looking south

(b) View looking north

Figure B-4: Aerial views of the derailment zone showing how the jackknifed cars came to rest against car TILX 316570 (consist no.12)

(c) View looking west. Note the rails impaled in the car's body bolster (circled).

Figure B-4: Aerial views of the derailment zone showing how the jackknifed cars came to rest against car TILX 316570 (consist no.12)

(a) View looking south. Cars were piled three deep in the circled zone

(b) View looking south-west. The thermal tear in car NATX 310515 (consist no.63) is circled.

Figure B-5: Aerial view of the derailment zone showing the main pile-up and last derailed cars

(a) View showing derailed tank cars partially embedded in soil and crushed against each other. The ends of consist no. 30, 32, 34, 36 and 38 are visible (field no. 26, 27, 28, 31 and 36, respectively) (RSI-AAR Safety Project photo).

(b) View looking north showing the piled up tank cars circled in Figure B-5a. From left to right, the ends of consist no.45, 44, 42 and 41 are visible. Consist no.55 is resting on top of these cars.

Figure B-6: In-situ photos of main pile-up

(c) View looking south showing the piled up tank cars circled in Figure B-5a. From left to right, consist no.42, 44, 45, 46, 48 (field no. 40, 42, 43, 44, 46) are visible. Consist no.47 (field no.45) is partially visible underneath consist no.48 (arrow). Consist no.49 and 55 are resting on top of these cars (RSI-AAR Safety Project photo).

(d) Close-up showing consist no. 45, 46 and 47 (field no.43, 44 and 45) underneath the pile (RSI-AAR Safety Project photo)

Figure B-6: In-situ photos of main pile-up

Figure B-7: Photo taken after most of the cars were removed for recovery, showing the relative position of consist no.38, 39 and 55

Figure B-8: In-situ photo showing the head of consist no.64 (field no.56) impacted against consist no.62 (field no.55) (RSI-AAR Safety Project photo)