CERTIFICATION TESTING OF UNITED STATES DEPARTMENT OF ENERGY ATLAS AND BUFFER RAILCARS–PHASE 4 REPORT

for the United States Department of Energy

Prepared by Chris Pinney, David Cackovic, and Russell Walker

Certification Report

P-22-012

January 18, 2023

Revised July 21, 2023

MxV Rail
A subsidiary of the Association of American Railroads
Pueblo, Colorado USA
www.mxvrail.com

DISCLAIMER:

Executive Summary

As part of the United States Department of Energy (DOE) Atlas Railcar Project, the Atlas and Buffer railcars were developed to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. MxV Rail (formerly Transportation Technology Center, Inc.), a subsidiary of the Association of American Railroads (AAR), performed single-car certification testing and modeling on these railcars.

Testing and modeling were performed according to the certification requirements in the AAR *Manual of Standards and Recommended Practices* (MSRP), Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material (HLRM)."[1] This report provides a summary of testing and modeling results in accordance with S-2043 requirements for the Single-Car Test (Paragraph 5.0) and Post-Test Analysis (Paragraph 8.0). The work was performed as part of Phase 4 under DOE Contract 89243218CNE000004/P00022.

In summary, Phase 4 covered the following Standard S-2043 test criteria for the Atlas and Buffer Railcars.

Standard S-2043 Test Criteria covered in Phase 4

S-2043 Paragraph		
5.2 Nonstructural Static Tests	5.2.1	Truck Twist Equalization
	5.2.2	Carbody Twist Equalization
	5.2.3	Static Curve Stability
	5.2.4	Horizontal Curve Negotiation
5.4 Structural Tests	5.4.2	Squeeze (Compressive End) Load
	5.4.3	Coupler Vertical Loads
	5.4.4	Jacking
	5.4.5	Twist
	5.4.6	Impact
	5.4.7	Securement System Analysis
5.5 Dynamic Tests	5.5.7	Hunting
	5.5.8	Twist and Roll
	5.5.9	Yaw and Sway
	5.5.10	Dynamic Curving
	5.5.11	Pitch and Bounce (Chapter 11)
	5.5.12	Pitch and Bounce (Special)
	5.5.13	Single Bump Test
	5.5.14	Curve Entry/Exit
	5.5.15	Curving with Single Rail Perturbation
	5.5.16	Standard Chapter 11 Constant Curving
	5.5.17	Special Trackwork
	5.5.18	Ride Quality (N/A for Atlas and Buffer)

Notes:

- Paragraph 5.3, Static Brake Tests, not listed in the table above, were performed at Kasgro Rail prior to shipment to the Transportation Technology Center (TTC).
- Paragraph 5.4.7, Securement System Analysis, was satisfied through analysis rather than test as allowed in the paragraph.

The Atlas railcar met most of the AAR S-2043 criteria. However, when the Atlas railcar test included a minimum test load and the AAR Standard KR wheel profile (i.e., worn) wheelsets and operated at high speed (above 65 mph), it did not meet the single-car dynamic test requirement for hunting (S-2043, Paragraph 5.5.7). All three of these conditions were necessary simultaneously to create poor hunting performance. Based on the test results, it was determined that DOE could adjust any one of three conditions to meet the test requirement for hunting. The adjustment options included:

- For shipments with a very light shipping cask, the DOE could add ballast weight to the load.
- The DOE could replace the wheelsets on a regular schedule before they become significantly worn.
- Operate the train in accordance with the 50-mph speed limit of S-2043, which references AAR Circular No. OT-55 "Recommended Railroad Operating Practices for Transportation of Hazardous Materials." Given the 50-mph speed limit for actual train operations, the train's speed should never approach 65 mph as required during testing.

It should be noted that during Phase 5 testing of the Atlas train, which was underway as this Phase 4 report was being prepared, the Atlas Railcar Project discovered that all the railcars exhibited better curving performance with 2A wheel profiles. In order to achieve acceptable curving performance, the Project, with agreement from the AAR, had to change all the wheels from the 1B profile to the new 2A profile. The 1B wheel profile is being phased out across the freight rail industry. The 2A profile is similar to the KR (i.e., worn) profile and will likely produce hunting performance similar to the KR. Therefore, DOE will not be able to choose the second option above to prevent hunting. Nevertheless, the first and third options above are still operative. The Atlas railcar will have acceptable hunting performance as long as DOE operates the trains with heavy loads and/or in strict accordance with the 50-mph speed limit.

The Atlas railcar testing and modeling results were presented to AAR's Equipment Engineering Committee (EEC) for approval with the exceptions not met under the hunting (S-2043, Paragraph 5.5.7) requirements. Based on the compromise of hunting performance versus curving performance, and because OT-55 restricts loaded Atlas railcar operations to speeds well below the hunting speed of 65 mph, the EEC granted approval for single-car testing of the Atlas railcar under S-2043. The summary results for the Atlas railcar can be referenced in Table 6 of this report.

The Buffer car met all S-2043 single-car structural and dynamic testing requirements of Phase 4. Under specific modeling cases, the S-2043 criteria were not met. The unmet criteria do not affect approval but are included as information regarding the railcar's overall performance. The summary results for the Buffer railcar can be referenced in Table 7 of the report.

The AAR EEC approval letters for the Atlas and Buffer railcars for Phase 4 testing and modeling are included in Appendix A, Appendix B, and Appendix C for reference. With the AAR EEC approval of the single-car tests of Atlas and Buffer railcars in 2021 and 2022, the next testing phase began. This is Phase 5, which is ongoing and includes Multiple-Car Tests (S-2043, Paragraph 6.0). During Phase 5, the Atlas and Buffer railcars, along with the new Rail Escort

Vehicle (REV), are being tested as a complete train on test tracks and on selected revenue services routes.

The first three completed design and fabrication phases of this project, governed by DOE Contract Number DE-NE0008390 (Reference: EIR-3021970 – Design and Prototype Fabrication of Railcars for Transport of High-Level Radioactive Material; Phase 3 – Prototype Fabrication and Delivery), as well as the current completed phase (4) and the next phase (5) of testing and modeling, are summarized below.

1. Phase 1 Mobilization and Conceptual Design (completed) included:
    a. The mobilization and conceptual design of an Atlas railcar and its associated Buffer railcar.
    b. The conceptual design of cask cradles for securement of HLRM casks on the Atlas railcar.
    c. General Loading Procedures for cask-to-cradle-to-railcar.
    d. The railcar's functional, design, operational, and maintenance requirements.
2. Phase 2 Preliminary Design (completed) entailed:
    a. The submission of the preliminary design packages of the Atlas and Buffer railcars designed to meet the AAR Standard S-2043 guidelines.
    b. The delivery of the preliminary design data package and dynamic modeling input and output data files to the DOE.
    c. The subsequent receipt from the AAR EEC of a notice to "proceed with the test phase," which allows the prototype railcars to be built in accordance with Paragraph 3.2.1 of S-2043.
3. Phase 3 Fabrication and Delivery (completed) comprised:
    a. The fabrication and delivery of one Atlas and two Buffer prototype railcars,
    b. The delivery of an as-built design package including drawings, inspection reports, and Bill of Materials (BOM) for both the Atlas and Buffer railcars.
    c. Operation and maintenance manuals, including maintenance intervals for both the Atlas and Buffer railcars.
    d. Final design information necessary for the fabrication of test loads, cradles, and end stops necessary for testing of the Atlas railcar.
4. Phase 4 Single-Car Tests (completed) involved:
    a. Fabrication of test loads, cradles, and end stops necessary for future testing of the Atlas railcar.
    b. S-2043 (Paragraph 5.0) Static, structural, and dynamic testing and modeling.
    c. S-2043 (Paragraph 8.0) Post-Test Analysis modeling.
    d. Approval from the AAR EEC of the single-car tests on the Atlas and Buffer railcars.
5. Phase 5 Multiple-Car Tests (ongoing) will include Atlas and Buffer railcars tested together with an REV under the requirements of S-2043:
    a. Dynamic tests at the controlled test site.
    b. System monitoring tests.
    c. Revenue service tests.

d. Demonstration Test Run.
e. Approval from the AAR EEC of the final tests including the Atlas, Buffer, and REV railcars as a complete train.

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

The Atlas and Buffer railcars were developed and are being tested as part of the U.S. Department of Energy (DOE) Atlas Railcar Project to meet the need for future large-scale rail transport of spent nuclear fuel and high-level radioactive waste. Transportation Technology Center, Inc. (MxV Rail), a subsidiary of the Association of American Railroads (AAR), performed single-car certification testing and modeling on the DOE twelve-axle Atlas cask-carrying railcar and the four-axle Buffer railcar.

The testing and modeling were performed to determine whether the Atlas and Buffer railcars meet the requirements of the AAR *Manual of Standards and Recommended Practices* (MSRP), Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," revised 2017.[1] This report provides a summary of the testing and modeling results for the Single-Car Test (Paragraph 5.0) and Post-Test Analysis (Paragraph 8.0) phase of certification for the Atlas and Buffer railcars.

The Atlas and Buffer railcar testing and analysis was conducted primarily by MxV Rail at the Transportation Technology Center (TTC) in Pueblo, Colorado. The work reported was performed during Phase 4 under DOE Contract 89243218CNE000004/P00022.

2.0 OBJECTIVE

The objective of this report is to provide a summary of testing and modeling results for Single-Car Test (Paragraph 5.0) and Post-Test Analysis (Paragraph 8.0) for Phase 4 certification activities.

3.0 AAR STANDARD S-2043

In North America, freight rail is relied upon for the safe movement of all types of commodities, including hazardous materials. The AAR Safety and Operations (S&O) Department is responsible for the rules and standards for rail vehicles used on North American railroads. These rules and standards are developed and maintained by the voting members of the various S&O technical committees and published by the AAR. Each railroad is required to sign and abide by an interchange agreement before it can interchange rolling stock with other common carrier railroads. The common carrier obligation refers to the statutory duty of railroads to provide transportation or service on reasonable request.

There are more than 600 AAR standards and specifications that cover a wide variety of components and sub-systems used in the North American market. The AAR introduced the term "High-Level Radioactive Material (HLRM)" to include high-level radioactive waste and spent nuclear fuel. The DOE has accepted this term for the purpose of rail transport. To ensure the safety of transport of HLRM, AAR created Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material." It is the most robust of all AAR standards. For example, AAR Specification M-1001, Chapter 11, "Service-Worthiness Tests and Analyses for New Freight Cars," presents guidelines for testing and analysis to ascertain the worthiness of the interchange-service and the safety of new freight car designs. Standard S-2043 applies to all railcars used in trains that transport HLRM, including spent nuclear fuel cask-carrying railcars and non-HLRM equipment, and requires the use of the same vehicle performance regimes for testing and analysis as AAR Specification M-1001, Chapter 11. However, S-2043 requires higher levels of performance than those already considered sufficient to ensure an adequate margin of safety for railcars as indicated in M-1001, Chapter 11.

Atlas railcar dynamic curving test results and simulation predictions are shown in Figure 1 The simulations and tests showed lateral/vertical (L/V) ratios below the Chapter 11 requirement of 1.0 and the more stringent S-2043 requirement of 0.8.

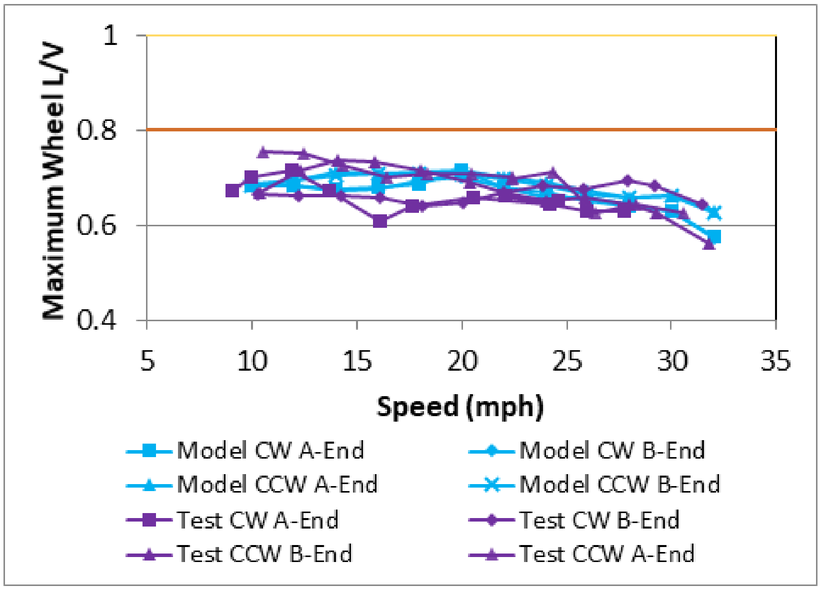

Figure 1. Simulation and test results on L/V ratios

In summary, Phase 4 covered the following test criteria of Standard S-2043 for both the Atlas railcar and the Buffer railcar (see Table 1).

Table 1. Standard S-2043 test criteria

S-2043 Paragraph		
5.2 Nonstructural Static Tests	5.2.1	Truck Twist Equalization
	5.2.2	Carbody Twist Equalization
	5.2.3	Static Curve Stability
	5.2.4	Horizontal Curve Negotiation
5.4 Structural Tests	5.4.2	Squeeze (Compressive End) Load
	5.4.3	Coupler Vertical Loads
	5.4.4	Jacking
	5.4.5	Twist
	5.4.6	Impact
	5.4.7	Securement System Analysis
5.5 Dynamic Tests	5.5.7	Hunting
	5.5.8	Twist and Roll
	5.5.9	Yaw and Sway
	5.5.10	Dynamic Curving
	5.5.11	Pitch and Bounce (Chapter 11)

S-2043 Paragraph		
	5.5.12	Pitch and Bounce (Special)
	5.5.13	Single Bump Test
	5.5.14	Curve Entry/Exit
	5.5.15	Curving with Single Rail Perturbation
	5.5.16	Standard Chapter 11 Constant Curving
	5.5.17	Special Trackwork
	5.5.18	Ride Quality (N/A for Atlas and Buffer railcars)

Notes:

- Paragraph 5.3 Static Brake Tests, not listed in the table above, were performed at Kasgro Rail prior to shipment to the TTC.
- Paragraph 5.4.7 was satisfied through analysis rather than testing as allowed in the paragraph.

4.0 ATLAS AND BUFFER RAILCAR DESCRIPTION

In 2018, Kasgro manufactured the Atlas railcar in addition to two prototype Buffer railcars. The Atlas railcar delivered for testing was numbered IDOX 010001. The Atlas (12-axle) and Buffer (four-axle) cars are designed to be operated as a railcar transport system propelled by a locomotive and accompanied by a Rail Escort Vehicle (REV).

4.1 Atlas Railcar Description

The Atlas railcar is a 12-axle span bolster railcar with fittings to accommodate cradles and end stops designed to allow the railcar to carry various casks used for the transportation of spent nuclear fuel and high-level radioactive waste. The railcar deck is supported on two span bolsters. Each span bolster rests on three two-axle trucks. Figure 2 shows the railcar with a test load installed. Table 2 lists the railcar dimensions.

Figure 2. IDOX 010001 during testing with minimum test load

Table 2. Atlas railcar dimensions

Dimension	Value
Length over pulling faces	78 feet 1 1/4 inches
Length over strikers	73 feet 5 1/4 inches
Span bolster spacing	38 feet 6 inches
Axle spacing on trucks	72 inches
Distance between adjacent trucks	10 feet 6 inches

The railcar uses six Amsted Swing Motion® trucks (Figure 3). Each truck uses two wheelsets with AAR Class K-axles and AAR-1B narrow flange wheels. These wheels are specified for this railcar because the increased gage clearance allows more lateral movement for better performance. The trucks are designed to use a primary suspension polymer pad between the bearing adapter and the side frame. The suspension polymer pad gives the truck an improved passive steering capability. Figure 4 shows the primary suspension polymer pad (also called a bearing adapter pad).

Table 3 shows the truck configuration used for testing. The secondary suspension is made up of springs in a non-AAR-standard configuration.

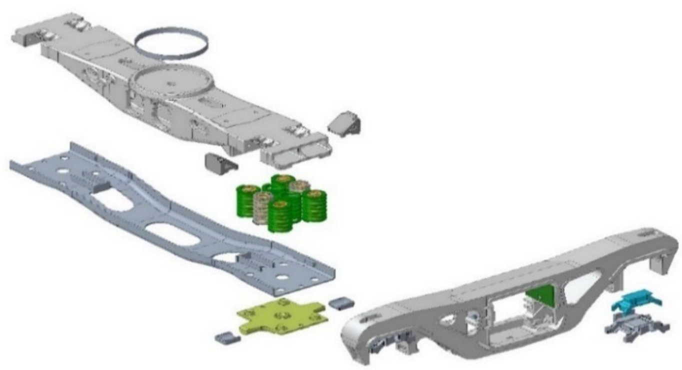

Figure 3. Exploded view of Swing Motion® truck

Figure 4. Primary suspension (or bearing adapter) pad

Table 3. Atlas railcar configuration

Component	Description	
Secondary Suspension Springs at End Trucks (A,B,D,E)	(2) 1-94, (2) 1-95, (2) 1-96, (4) 1-97, (4) 1-92, (4) 1-99	
Secondary Suspension Springs at Middle Trucks (C,F)	(2) 1-88, (2) 1-89, (2) 1-90, (4) 1-91, (4) 1-92, (2) 1-93, (4) 1-99	
Primary suspension	12A Adapter Plus pads, ASF-Keystone part number 10523A	
Side Frames	F9N-10FH-UB	
Bolsters	B9N-71 EJFZ on A, F, and C-trucks B9N-71 HN-FX on B, D, and E-trucks	
Side Bearings	Miner TCC-III 60LT	
Friction Wedge, composition faced (four per truck)	ASF-Keystone Part number 48446	
Bearings and Adapters	AAR Class K 6 1/2 × 9 bearings with 6 1/2 × 9 Special Adapter ASF-Keystone Part number 10523A	
Center Bowl Plate	Metal Horizontal Liner	
	End Truck Average	Middle Truck Average
Minimum Test Load Spring Nest Height	8.97 inches	9.13 inches
Maximum Test Load Spring Nest Height	8.20 inches	8.17 inches
	Actual Weight on Rail Used During Testing	
Scale Weight Empty Test Load	222,050 (lbs.)	
Scale Weight Minimum Test Load	421,050 (lbs.)	
Scale Weight Maximum Test Load	709,050 (lbs.)	

The convention for wheel and truck identification is shown in Figure 5. The B-end of a railroad freight car is normally the end with the handbrake, but because the Atlas railcar has two handbrakes, the railcar manufacturer designated and stenciled the B-end. The right and left sides of the railcar are designated from the perspective of standing at the B-end of the railcar and looking toward the A-end of the car. Axles are numbered starting from the B-end. For axle numbers greater than nine, the locations are stenciled with letters descending from Z.

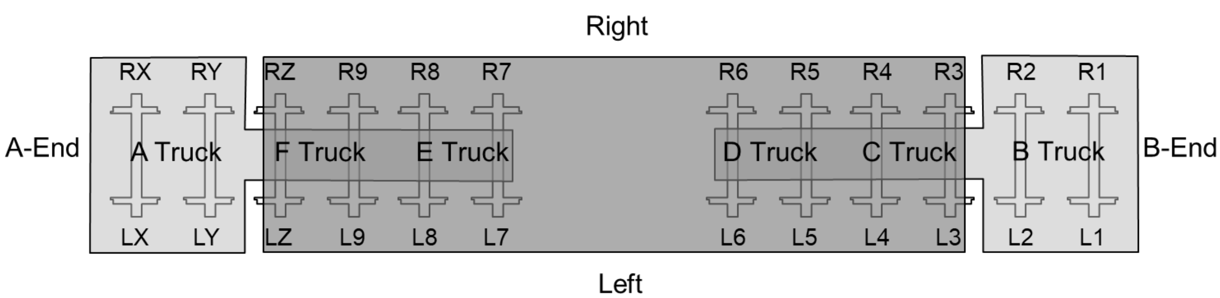

Figure 5. Axle and side naming convention

4.1.1 Variations in Components During Testing

During the initial tests, the Atlas railcar, loaded with the minimum test load, showed some hunting instability at speeds above 65 mph. The Atlas railcar was stable up to 75 mph when loaded with the maximum test load. MxV Rail tested different side bearings, centerplate liners, and primary pads to address the hunting instability with the minimum test load. The stiffer primary pads (prototype chlorosulfonated polyethylene or CSM 70 pads) were the only change that improved the hunting performance. After the change to stiffer pads resulted in improved hunting stability performance, all Standard S-2043 prescribed dynamic test regimes were completed with CSM 70 pads. However, using these stiffer pads, railcar performance did not meet Standard S-2043 criteria in Dynamic Curving or Curve with Single Rail Perturbation regimes, despite the improved hunting stability performance.

On October 15, 2020, MxV Rail reviewed the results with the AAR Equipment Engineering Committee (EEC). The EEC directed MxV Rail to re-test the railcar with softer primary pads with a minimum test load in the Dynamic Curving regime. Because the railcar would be limited to less than 50 mph by OT-55 when in high-level radioactive material (HLRM) service, the EEC noted that curving performance was more important than high speed stability performance.

During the testing program, MxV Rail tested the railcar with a total of four primary suspension pad models. The pads are made from CSM and are categorized by the Shore D durometer hardness value with higher numbers indicating a harder pad. The railcar arrived with CSM 58 production pads. MxV Rail also tested the railcar with prototype pad types CSM 70, CSM 68, and CSM 65.

The hunting regime was tested with CSM 58 pads in both the minimum and maximum test load conditions. The dynamic curving regime was tested with CSM 58 pads in the minimum test load condition. All other dynamic tests were completed with CSM 70 pads. Considering the results of curving and hunting tests, when compared to the tested alternative pad materials, the production CSM 58 pads provided the best performance overall.

Recorded test data regimes using CSM 70 pads were modeled with these pads to demonstrate the model was validated. These regimes were modeled again with CSM 58 pads to show the change in performance with the final pad.

4.2 Buffer Railcar Description

The Buffer railcar is a four-axle flatcar with a permanently attached ballast load (Figure 6). In 2018, Kasgro manufactured IDOX 020001 and IDOX 020002, two prototype Buffer cars that were delivered to the TTC. The tests described in this report were conducted on IDOX 020001. Figure 7 shows the general arrangement drawing of the car. Table 4 shows the railcar dimensions.

Figure 6. Buffer railcar IDOX 020001 during static testing

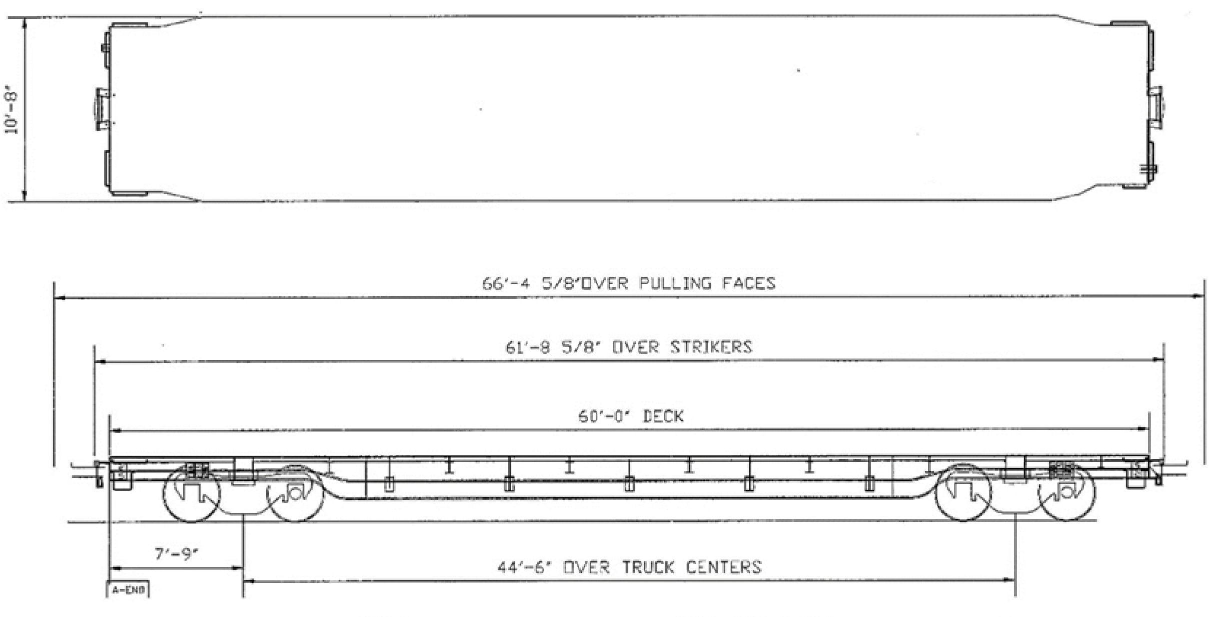

Figure 7. Buffer railcar IDOX 020001 arrangement drawing

Table 4. Buffer railcar dimensions

Dimension	Value
Length over pulling faces	66 feet, 4 5/8 inches
Length over strikers	61 feet, 8 5/8 inches
Truck center spacing	44 feet 6 inches
Axle spacing on trucks	72 inches

The computer vehicle dynamic simulations required for Standard S-2043 showed that an empty Buffer railcar would not meet the requirements in the buff and draft curving regime

(S-2043, Paragraph 4.3.13). A ballast weight of 196,000 pounds—included as permanently installed steel plates—was added to resolve this issue.

The steel plates were welded to the railcar during the manufacturing process, resulting in a railcar with a permanent gross rail load of 263,000 pounds. Because the railcar was not rated to carry any additional load, 263,000 pounds was the only load condition that was tested.

The railcar uses two Swing Motion® trucks supplied by Amsted Rail. Each truck uses two wheelsets with K-axles and AAR-1B[1] narrow flange wheels. These wheels were specified for use with this railcar because the increased gage clearance allowed more lateral movement for better performance. The trucks were specially designed to use a polymer pad between the bearing adapter and side frame to give each truck a passive steering capability. The Buffer railcar bearing adapter pad is the same as the Atlas railcar's pad shown in Figure 4. The truck uses two KONI 04A 2032 vertical dampers to control the vertical motion of the railcar suspension. The dampers are needed on the Buffer railcar and not on the Atlas railcar because track geometry deviations have more input on the four-axle railcar than on a twelve-axle railcar so additional damping is required. The Buffer railcar truck configuration is shown in Table 5.

Table 5. Buffer railcar truck configuration

Part	Description	
Secondary suspension	Five D7 outer coils, five D6 inner coils, five D6A inner-inner coils, two 49427-1, two 49427-2	
Primary suspension	Adapter Plus pads, ASF part number 10523A	
Side bearings	Miner TCC-III 60LT	
Friction wedge	Amsted part number 1-9249	
Bearings and adapters	K class 6 1/2 x 9 bearings with 6 1/2 x 9 special adapter ASF Part number 10523A	
Center bowl plate	Metal horizontal liner	
Vertical hydraulic dampers	KONI damper 04a 2032	
Side frames	F9N-10FH-UB	
Bolsters	B9N-714N-FS	
	A-end truck average	B-end truck average
Spring nest height	7.75 inches	7.78 inches
Scale weight	131,200 pounds	131,975 pounds

5.0 SUMMARY RESULTS

The summary testing and modeling results for the Single-Car Test and Post-Test Analysis are presented in Section 5.1 for the Atlas railcar and Section 5.3 for the Buffer railcar. Section 5.2 is a brief discussion of the Atlas derailment that occurred during testing. Section 5.4 is a brief

[1] The AAR-1B wheel profile was subsequently changed to the AAR-2A wheel profile. See Section 5.1.

discussion of the Atlas weld cracks that occurred during testing. Section 5.5 is a brief discussion of a design change necessary to keep the dunnage blocks secured on Atlas.

5.1 Atlas Railcar Summary Results

The Atlas railcar testing and modeling results shown in Table 6 were presented and approved by the AAR's EEC. The letter of approval from EEC is presented in Appendix A.

During the Post-Test Analysis (S-2043, Paragraph 8.0), results from the finite element analysis (FEA) structural simulations and structural test strain measurements listed in Table 6 (S-2043, Paragraph 5.4.2–5.4.6) were evaluated to determine if stresses were less than 75 percent of the allowable stress for all load cases. The results indicate that stresses were less than 75 percent of the allowable stress, thereby eliminating the requirement for "Refining the FEA" (S-2043, Paragraph 8.1).

The Atlas railcar met most AAR S-2043 non-structural static and dynamic criteria. However, the Atlas railcar equipped with CSM 58 primary suspension pads 1) with a minimum test load, 2) with AAR Standard KR wheel profile (i.e., worn) wheelsets, and 3) while operating at a high speed (above 65 mph) did not meet the single-car dynamic test requirement for hunting (S-2043, Paragraph 5.5.7) referenced in Table 1. Additional testing with an alternative pad (CSM 70) was part of the testing regime. The stiffer CSM 70 pad met the hunting performance criteria but did not meet curving performance criteria under the single-car dynamic test (S-2043, Paragraph 5.5.10) parameters. After much testing, modeling, and analysis, the Project decided to go back to using CSM 58 pads in order to meet the curving performance criteria.

With the CSM 58 pads, however, the Project still had a problem with hunting performance. When the test included all three of the other conditions listed above simultaneously, the railcar failed to meet the hunting test requirement. Therefore, DOE had three remaining options for meeting the hunting test requirement:

- Adding ballast weight to the load for shipments with a very light shipping cask
- Replacing the 1B-profiled wheelsets on a regular schedule before they become significantly worn.
- Operating the train strictly in accordance with the OT-55 speed limit of 50 mph.

It should be noted that during Phase 5 testing of the Atlas train, which was underway as this Phase 4 report was being prepared, the Atlas Railcar Project discovered that all the railcars exhibited better curving performance with 2A wheel profiles. In order to achieve acceptable curving performance, the Project, in consultation with the AAR, had to change all the wheels from the 1B profile to the new 2A profile. The 1B wheel profile is being phased out across the freight rail industry. The 2A profile is similar to the KR (i.e., worn) profile and will likely produce hunting performance similar to the KR. Therefore, DOE will not be able to choose the second option above to prevent hunting. Nevertheless, the first and third options above are still operative. The Atlas Railcar will have acceptable hunting performance as long as DOE operates the trains with heavy loads and/or in strict accordance with the 50-mph speed limit.

The testing and vehicle dynamic modeling results of the Atlas railcar equipped with CSM 58 pads were presented to AAR's EEC for approval, with the exception of the criteria for hunting (S-2043, Paragraph 5.5.7). Based on the compromise of hunting performance versus curving performance described in Appendix D, and because OT-55 restricts Atlas railcar operations to speeds well below the hunting speed of 65 mph, the EEC granted approval for single-car testing of the Atlas railcar under S-2043. The summary results for the Atlas railcar are in Table 6.

The preliminary vehicle dynamic simulations were performed according to Standard S-2043, Paragraph 4.3 (Dynamic Analysis) as part of the railcar design phase before the prototype railcar was built. The results of the preliminary simulation were submitted to the AAR as part of the preliminary design review package. Following the vehicle characterization and the dynamic tests, the models of the vehicles were revised to better represent the vehicles. The test results were compared to the preliminary dynamic analysis predictions and revised model predictions to verify that modeling accurately represents the vehicle as required in Standard S-2043, Paragraph 8 (Post-Test Analysis).

As part of the design criteria, static brake testing was conducted at the manufacturer's facility per relevant requirements of AAR Standards S-401 and S-486 (Paragraph 4.0). The Atlas and Buffer railcars Single Car Testing (Paragraph 5.0) was conducted primarily by MxV Rail at the TTC.

Table 6. Atlas railcar summary analysis and test results

Standard S-2043 Paragraph	**Atlas Railcar Met/Not Met**	
	Revised Simulations CSM 58 pads	**Test Result and Details if Not Met**
4.2 Nonstructural Static Analysis/5.2 Nonstructural Static Tests		
4.2.1/5.2.1 Truck Twist Equalization	Not Simulated	Not Met with CSM 58 pads EEC Comment: "Most cases of this very severe requirement were met. EEC understands why the center truck of a tri-span bolster would have difficulty meeting the requirement. Values found were 10-17 percentage points less than allowed by S-2043. A minimum of 24% of the static load was still carried, which is reasonable. This is a stationary test, and the EEC accepts the results based on the more important dynamic aspects of proper equalization were shown to be acceptable by performance in 5.5.15 Curving with single perturbation, 5.5.10 Dynamic curving, and 5.5.14 Limiting spiral"
4.2.2/5.2.2 Carbody Twist Equalization	Not Simulated	Met with CSM 58 pads

Standard S-2043 Paragraph	Atlas Railcar Met/Not Met	
	Revised Simulations CSM 58 pads	**Test Result and Details if Not Met**
4.2.3/5.2.3 Static Curve Stability	Not Simulated	Met with CSM 58 pads
4.2.4/5.2.4 Horizontal Curve Negotiation	Not Simulated	Met with CSM 58 pads
5.4.2 Squeeze (Compressive End) Load	Not Simulated	Met with CSM 58 pads
5.4.3 Coupler Vertical Loads	Not Simulated	Met with CSM 58 pads
5.4.4 Jacking	Not Simulated	Met with CSM 58 pads
5.4.5 Twist	Not Simulated	Met with CSM 58 pads
5.4.6 Impact	Not Simulated	Met with CSM 58 pads
4.3.11.3/5.5.7 Hunting	Not Met	Not Met with CSM 58 pads (At Minimum Test Load: Railcar did not meet the carbody lateral acceleration standard deviation criteria of 0.13 at speeds greater than 65 mph) EEC Comment: “The hunting measured with the CSM 58 adapter pad was mild and does not present safety concerns. Additionally, the conditions that the railcar hunted in test will not be encountered in service (i.e., operating at speeds above 65, use of wide flange worn wheelsets with a conicity prone to hunting). The operating plan must include a maximum speed to avoid the speeds at which hunting was encountered.”
4.3.9.6/5.5.8 Twist and Roll	Met	Not tested with CSM 58 pads – Met with CSM 70 pads
5.5.9 Yaw and Sway	Met	Not tested with CSM 58 pads – Met with CSM 70 pads
5.5.10 Dynamic Curving	Met	Met with CSM 58 pads
4.3.9.7/5.5.11 Pitch and Bounce (Chapter 11)	Met	Not tested with CSM 58 pads – Met with CSM 70 pads
4.3.9.7/5.5.12 Pitch and Bounce (Special)	Met in preliminary simulations	Not tested because the truck center spacing is close to Chapter 11 wavelength (EEC approved)
4.3.10.1/5.5.13 Single Bump Test	Met	Not tested with CSM 58 pads – Met with CSM 70 pads
4.3.11.6/5.5.14 Curve Entry/Exit	Met	Not tested with CSM 58 pads – Met with CSM 70 pads

Standard S-2043 Paragraph	Atlas Railcar Met/Not Met	
	Revised Simulations CSM 58 pads	**Test Result and Details if Not Met**
4.3.10.25.5.15 Curving with Single Rail Perturbation	Not met	Minimum Test Load: Not met with CSM 70 pads: EEC Comment: "Testing did not meet criteria using the CSM 70 and CSM 65 pads. However, modeling with the CSM 58 pad produced successful results for wheel/rail forces. The EEC considers the wheel/rail force requirements to be met. The carbody roll angle that does not meet in modeling with a 3-inch perturbation is simply an effect of local track geometry that cannot be addressed realistically. The EEC accepts the roll angle results as they are."
4.3.11.4/5.5.16 Standard Chapter 11 Constant Curving	Met	Not tested with CSM 58 pads – Not Met with CSM 70 pads: EEC Comment: "Test results were produced using the CSM 70 adapter pads. The CSM 58 pads provide better curving as shown by modeling results. The EEC considers this requirement to be met by use of the CSM 58 pads."
4.3.11.7/5.5.17 Special Trackwork, No. 7 (analysis) No. 10 (test) Crossovers	Met	Not tested on No. 7 with CSM 58 pads – Tests met with CSM 70 pads on a No. 10 crossover
4.3.11.5 Curving with Various Lubrication Conditions	Not Met in following cases Min Test Load with new profiles, case 4 Min Test Load with worn profiles, cases 1, 2 and 4 Max Test Load with worn profiles, cases 1, 2, and 4	Testing not required EEC Comment in response to these results: The EEC agrees with the expert review recommendations that during multiple car testing the Atlas railcar be stopped in the TTC WRM 12 degree curve, the local depot activity 10 degree curve, and the BNSF Alps N.M. horseshoe 10 degree curve (if possible), and the car slowly pulled through the exit spiral of the curve while gage spreading and gage spreading forces are monitored.
4.3.12 Ride Quality	Met in preliminary simulations	Testing not required for non-passenger-carrying railcars
4.3.13 Buff and Draft Curving	Met	Single car testing not required
4.3.14 Braking Effects on Steering	Met in preliminary simulations	Testing not required

Standard S-2043 Paragraph	Atlas Railcar Met/Not Met	
	Revised Simulations CSM 58 pads	**Test Result and Details if Not Met**
4.3.15 Worn Component Simulations	Not Met for: Hunting stability, maximum lateral acceleration standard deviation	Testing not required EEC Comment: "The hunting measured with the CSM 58 adapter pad was mild and does not present safety concerns. Additionally, the conditions that the car hunted in test will not be encountered in service (i.e., operating at speeds above 65, use of wide flange worn wheelsets with a conicity prone to hunting). The operating plan must include a maximum speed to avoid the speeds at which hunting was encountered."

5.2 Derailment Incident and Investigation during Atlas Testing

At 1:00 p.m. (MDT) on July 8, 2020, one axle of the DOE Atlas railcar test train derailed during testing on the Urban Rail Building (URB) north wye track at the TTC. No one was injured. The leading axle of the trailing (B-end) span bolster of Atlas railcar IDOX 010001, climbed the gage face of the outside (high) rail, then traveled about 19 feet with the flange on the top of the rail before dropping to the field side. The derailment occurred when MxV Rail personnel were testing the Atlas railcar in the Curving with Single Rail Perturbation (CWSRP) test zone specified in AAR Standard S-2043.[1]

Figure 8. Derailed Axle 6 in final position outside of the curve

The point of derailment (POD) was in the body of a 12-degree left-hand (LH) curve with no superelevation. The POD was within the 2-inch-high rail dip of the CWSRP, resulting in a reverse cross level of 1.88 inches. At the POD, the gage was 56.72 inches, and the curvature was 12.5 degrees. The alignment deviation of a 62-foot chord from average curvature (155-foot average) was 3.7 inches at the POD. At the time of the derailment, the railcar was being shoved at 6 mph. The subject railcar was at the lead end of the movement with the instrumentation railcar and locomotive trailing.

At the time of the derailment, all six axles of the B-end (trailing) span bolster were instrumented wheelsets (IWS) that had been installed for testing. The railcar was tested with a simulated load (without any hazardous material).

MxV Rail noted damage to 1) two of the IWS, 2) the B-end span bolster, and 3) the left-side frame of the D-truck. The IWS were inspected, tested, and returned to service. The span bolster damage was repaired per the railcar builder's instructions, and the damaged left-side frame was replaced.

A three-dimensional wheel-rail contact analysis was also conducted to estimate how the angle of attack of the wheelset to the rail would affect the contact conditions. The results showed that the angle of attack of the wheelset to the rail changes the contact condition, causing the maximum contact angle to reduce by approximately 1 degree for the likely values of the angle of attack. The reduced contact angle, combined with high friction measured at the derailment point, may have contributed to the derailment occurring at a lower L/V than expected.

While it includes cross level and gage definitions for this test zone, AAR Standard S-2043 is silent on curvature and alignment tolerances. The post-derailment track geometry test zone measurements showed variations in curvature and alignment, resulting in a test zone that was more challenging than intended. Simulations conducted as part of the derailment investigation showed that improvements in the curvature and alignment variation with other test zone parameters held constant resulted in a railcar performance that would meet AAR Standard S-2043 criteria.

MxV Rail proposed revisions to AAR Standard S-2043 that would add tolerances for curvature and alignment and adjust the track to meet the proposed requirements and retest with no modifications to the railcar other than the necessary repairs. The AAR EEC accepted the proposed revisions and agreed that the CWSRP test needed to be repeated. MxV Rail adjusted the test zone and repeated the test on August 26 and August 27, 2020. The results from the retest met AAR Standard S-2043 criteria.

The primary cause of the derailment was a 3.7-inch variation in high rail alignment over a 47-foot test zone that resulted in a test zone that was more challenging than intended. A revision to AAR Standard S-2043 that will include additional requirements for curvature and alignment in the test zone is in progress.

5.3 Buffer Railcar Summary Results

The Buffer railcar results were presented and approved by AAR's EEC based on the testing and modeling results shown in Table 7. The letters of approval from the EEC are presented in Appendix B and Appendix C.

The Buffer railcar met all S-2043 single-car structural and dynamic testing requirements for approval of the next phase of testing. The results in Table 7 also provide the S-2043 criteria not met under specific modeling conditions. The EEC considered the performance sufficient to ensure an adequate margin of safety and granted approval for S-2043 requirements under Phase 4 testing and modeling. With EEC approval of the Buffer railcar for the Design (S-2043, Paragraph 4.0), Single Car-Testing (S-2043, Paragraph 5.0), and Post-Test Analysis (S-2043, Paragraph 8.0) results under Phase 4, the next testing and modeling phase based on S-2043 requirements is Multiple-Car Testing (S-2043, Paragraph 6.0).

The Post-Test Analysis (S-2043, Paragraph 8.0) using FEA simulations and structural test strain measurements showed that stresses were less than 75 percent of the allowable stress for all load cases listed under S-2043, Paragraph 5.4 Structural Tests in Table 7, eliminating the requirement for FEA to be refined per Paragraph 8.1 of Standard S-2043.

The revised Buffer railcar vehicle dynamics model did not meet the criteria for peak-to-peak carbody lateral acceleration for the 39-foot wavelength inputs (1.38g, limit = 1.3g) or the 44.5-foot wavelength inputs (1.31g, limit = 1.3g) in yaw and sway simulations. In contrast, the Buffer railcar met the test requirements for yaw and sway, indicating that the model is conservative. The yaw and sway test was only performed with 39-foot wavelength inputs. The EEC chose to approve the Buffer railcar in this regime based on the test result.

The revised vehicle dynamics modeling predictions did not meet the S-2043 criteria for truck side L/V ratio (0.52, limit = 0.5) in the Curving with Various Lubrication Conditions regime (S-2043, Paragraph 4.3.11.5). This exception occurred for counterclockwise runs with Case 2 lubrication and the worn wheel profile at 12 and 24 mph. The Case 2 lubrication condition was a 0.5 coefficient of friction on the top of both rails and a 0.2 coefficient of friction on the gage face of the high rail. The simulations met S-2043 criteria for curving with various lubrication conditions during clockwise runs for this lubrication and profile case and for all runs with other lubrication and profile combinations. The EEC chose to approve the Buffer railcar in this regime based on the near pass.

Because there were only small changes to the design of the Buffer railcar since the original dynamic predictions were performed, only a small subset of the regimes was run with the revised dynamic model. These regimes were chosen because they allowed comparison with the test data or because the original dynamic predictions for the regime were close to or did not meet the criteria.

As part of the railcar design phase, preliminary simulations were performed according to the Dynamic Analysis (S-2043, Paragraph 4.3) before the prototype railcar was built. The results of the preliminary simulation were submitted to the AAR as part of the preliminary design review package. These test results were used to compare the preliminary dynamic analysis predictions and the revised model predictions to verify that modeling accurately represents the vehicle as required in Post-Test Analysis (S-2043, Paragraph 8.0).

As part of the design criteria (S-2043, Paragraph 4.0), static brake testing was conducted at the manufacturer's facility per the relevant requirements of AAR Standards S-401 and S-486.

Table 7 shows a summary of the test results and the model predictions for the Buffer railcar.

Table 7. Buffer Railcar Summary Test Results

S-2043 Paragraph	Met/Not Met	
	Revised Simulations	**Test Result**
5.2 Nonstructural Static Tests		
4.2.1/5.2.1 Truck Twist Equalization	Simulated with the Original Model Only*	Met
4.2.2/5.2.2 Carbody Twist Equalization	Simulated with the Original Model Only*	Met
4.2.3/5.2.3 Static Curve Stability	Simulated with the Original Model Only*	Met
4.2.4/5.2.4 Horizontal Curve Negotiation	Simulated with the Original Model Only*	Met
5.4 Structural Tests		
5.4.2 Squeeze (Compressive End) Load	Simulated with the Original Model Only**	Met
5.4.3 Coupler Vertical Loads	Simulated with the Original Model Only**	Met
5.4.4 Jacking	Simulated with the Original Model Only**	Met
5.4.5 Twist	Simulated with the Original Model Only**	Met
5.4.6 Impact	Not Required per S-2043	Met
5.5 Dynamic Tests		
4.3.11.3/5.5.7 Hunting	Met	Met
4.3.9.6/5.5.8 Twist and Roll	Met	Met
5.5.9 Yaw and Sway	Not Met P-P Lat Accel 1.38 Limit=1.3 EEC chose to approve due to the test result.	Met
5.5.10 Dynamic Curving	Met	Met
4.3.9.7/5.5.11 Pitch and Bounce (Chapter 11)	Met	Met
4.3.9.7/5.5.12 Pitch and Bounce (Special)	Met	Met
4.3.10.1/5.5.13 Single Bump Test	Simulated with the Original Model Only*	Met
4.3.11.6/5.5.14 Curve Entry/Exit	Simulated with the Original Model Only*	Met
4.3.10.25.5.15 Curving with Single Rail Perturbation	Met	Met
4.3.11.4/5.5.16 Standard Chapter 11 Constant Curving	Simulated with the Original Model Only*	Met

S-2043 Paragraph	Met/Not Met	
4.3.11.7/5.5.17 Special Trackwork	Simulated with the Original Model Only*	Met
4.3.11.5 Curving with Various Lubrication Conditions	Not Met Truck Side L/V 0.52, Limit=0.50 EEC chose to approve due to the near pass.	Testing not required
4.3.12 Ride Quality	Simulated with the Original Model Only*	Testing not required for non passenger-carrying railcars
4.3.13 Buff and Draft Curving	Met	Single car testing not required
4.3.14 Braking Effects on Steering	Simulated with the Original Model Only*	Testing not required
4.3.15 Worn Component Simulations	Simulated with the Original Model Only*	Testing not required
*Because the revised model showed little change compared to the original model, and because the original dynamic analysis showed a margin of safety with respect to the criteria for these regimes, these regimes were not simulated with the revised model. **Revised FEA predictions were not required per standard S-2043 paragraph 8.1 because no measured stress exceeded 75% of the allowable stress.		

5.4 Weld Cracks on the Atlas Railcar

In December 2020, cracked tri-span bolster center plate welds were found during track performance testing. In January 2021, Kasgro sent welders to the TTC to remove the defects and reweld the center plates. After all weld repairs, MxV Rail personnel performed a non-destructive examination (NDE) of the repair welds, which were found to be acceptable with no cracks.

In June 2022, MxV Rail's Rail Vehicle Maintenance (RVM) department inspected the Atlas railcar, the Buffer railcars, and the REV. One crack was found in the B-truck centerplate on left side of the Atlas railcar, parallel to the rail.

The crack was discussed with the DOE and Kasgro and was to be repaired in July while the consist was parked for installation of IWS. Figure 9 and Figure 10 show the crack defect.

Figure 9. Atlas Railcar – Crack is on Left Side of Centerplate, B-Truck

Figure 10. Atlas Railcar – Close-up of Crack on Left Side of Centerplate, B-Truck

During Kasgro repairs to the weld cracks discovered in June, more serious defects were found in the tri-span bolster base material. It was agreed that both tri-span bolsters be shipped back to Kasgro to be repaired and to begin studies to determine whether the cracks were the result of an engineering/design issue, a manufacturing process or repair process problem, or a material/metallurgical issue. The Atlas railcar cracking discovery progression can be outlined as follows:

- Cracking Type 1 (B-end tri-span bolster, B-truck centerplate) – Reported to DOE in June 2022 – cracks parallel to the weld beads in Figure 9 and Figure 10 as shown above.

- Cracking Type 2 (B-end tri-span bolster, C-truck centerplate) – Discovered Monday, July 25, 2022. Figure 11 shows vertical cracks that have the potential to migrate to the base tri-span bolster material. Kasgro determined that these cracks were in the centerplate.

Figure 11. Cracks in B-end tri-span bolster, C-truck centerplate

- Cracking Type 3 (B-span bolster, newly replaced B-truck centerplate). Cracks found after Kasgro's repair of Cracking Type 1, shown in Figure 12 and Figure 13. The cracks were in the tri-span bolster, above and perpendicular to the top weld bead. These cracks were significantly more concerning as they were in the tri-span bolster.

Figure 12. Cracking in tri-span bolster with new B truck centerplate

Figure 13. Magnified image of cracks in tri-span bolster

The DOE, Kasgro, and MxV Rail agreed that both tri-span bolsters be shipped back to Kasgro for repairs or replacement. The tri-span bolsters were shipped by MxV Rail to Kasgro at the end of the first week of August 2022, and replacements were received back at the TTC on August 29, 2022. When received, MxV Rail installed the replacement tri-span bolsters to continue testing.

5.4.1 Design Change as a Result of Cracking Issue

To avoid future cracking issues, Kasgro changed the attachment method for the six centerplates to the two Atlas railcar tri-span bolsters. The former method, from the original build drawings, is to bolt and weld them in place.

The revised method, which will be used for further dynamic tests regarding the Atlas railcar, will use a standard AAR bolting arrangement plus a tack weld to the bolt heads so the bolts cannot back out.

Kasgro has revised the Atlas fabrication drawings and is awaiting documentation and analysis requirements from the EEC. The AAR EEC is developing those requirements as of the writing of this report. In addition, Kasgro has provided information from the tests performed to determine the root cause of the cracking issues. When weld cracks were again found in June 2022 in the tri-span bolster center welds, Kasgro sent a repair welder to MxV Rail to do on-site repairs. The repairs to the B-end of the tri-span bolster center plate consisted of removing the original bolted and welded center plate before installing a new center plate of the same configuration. After rewelding the center plate, MxV Rail personnel performed an NDE on the B-end tri-span center plate repair welds and the adjacent tri-span bolster base metal (Figure 13 and Figure 14). The repair welds did not have any indications or cracks, but it was noted that there were now transverse surface cracks along the center plate weld heat affected zone (HAZ) of the B-end tri-span bolster base metal that had not been previously noted.

The decision to return the tri-span bolsters to Kasgro shop was made so that all required repairs could be handled at the Kasgro facility in a controlled shop environment, allowing Kasgro to correctly repair and return the tri-span bolsters to MxV Rail as soon as possible. The most practical way to repair these defective welds and the cracks in tri-span bolster base metal was discussed by Kasgro Engineering and fabrication personnel. Kasgro decided that making additional weld repairs to tri-span bolster center plate welds and the tri-span bolsters base metal cracks along the HAZ was not the best path forward.

The Atlas tri-span bolsters were delivered to the Kasgro Rail shop for repairs on August 11, 2022. All components and attachments to the original tri-span bolsters were removed, and Kasgro used two new tri-span bolsters to replace the original tri-span bolsters. In addition, the attachment design for center plates to tri-span bolster was changed from a bolt and welded design to a 12-bolt design center plate design (Figure 14).

Figure 14. 12-bolt centerplate mounted to replacement Atlas tri-span bolster

Kasgro had the 12-bolt design center plates in stock. Because Kasgro could not confirm what was causing the weld cracks, the all-bolt design was chosen to avoid any additional weld cracking issues with the Atlas tri-span bolster center plates for the remainder of the S-2043 Atlas railcar testing. All AAR requirements for use of bolted center plates were followed.

All repairs and modifications were completed, and the two (2) tri-span bolster assemblies were shipped back to MxV Rail and delivered at the end of August.

Kasgro sent the original center plate (Figure 15) removed from the B-end, left side of the Atlas railcar to an independent metallurgical test lab to determine if there were any issues with material properties of center plates. The metallurgical test lab concluded the center plate mechanical and chemical properties were in the acceptable range, and it was likely the cracks developed in the welds initially and then propagated into the center plate (see Kasgro Report 1).

Figure 15. Atlas BL-end centerplate after removal

Kasgro also sent a section of the original B-end tri-span bolster back to the steel mill that originally made the steel (Figure 16). The steel mill metallurgical lab investigated the surface indications located in the HAZ (Figure 12 and Figure 13) using a liquid dye penetrant NDE along the welds and determined that the originally noted surface indications were most probably a result of the welding process and not material related. Kasgro's opinion is that the indications were most likely caused by the arc gouging removal of cracked welds and subsequent repair welding. The steel mill test lab did use NDE and ultrasonic testing to find two crack indications, that extended 5 inches and 6 inches in length but did not appear to encroach on the exterior edges of the test sample (see Kasgro Report 2).

Figure 16. Tri-span section sent for NDE testing

The steel mill lab conclusions indicated both the chemical composition and mechanical tests results obtained from the sample received for investigation meet the ASTM A572-15 GR. 60 steel requirements. These results were consistent with MTR (Material Test Reports) of the possible plate serials, and they match the chemistry of the plates sent to Kasgro (see Kasgro Report 3).

Based on the results from the sample received from the investigation, both testing laboratories concluded there was no evidence that points out issues related to the material. The multiple cracks that were observed are probably related to welding practices used during the fabrication of the part.

5.5 Dunnage Blocks – Lateral Movement

Whenever the Atlas railcar is carrying a load that requires end stops, dunnage is required as padding between the load and the end stops. This dunnage is in the form of heavy wooden blocks. Movement of one of the dunnage blocks on the Atlas Cask railcar was exhibited during testing at the TTC (Figure 17). A design modification was required to prevent the heavy wooden blocks from wiggling free and falling off the side of the railcar.

Figure 17. Dunnage problem: block on right side has slipped downward

The solution to this issue is welding pieces of angle iron to the Atlas railcar's end stops. This will prevent lateral movement of the dunnage blocks as the railcar experiences many miles of bumps and turns on the nation's rail lines. Orano, DOE's contractor for the cask securement system design and manufacture, approved MxV Rail's proposal to weld 2- to 4-inch, 72-inch-long angles to the end stops on each side of the dunnage blocks. The angles would be installed 1 to 2 inches outside the dunnage block. The angle flat edge will be on the block side. Slot welds will be used and ground smooth on the block side to eliminate the possibility of restricting block movement. The angle top edge will be welded to hinder water entry from above, while the bottom edge will not be welded to encourage moisture to drain.

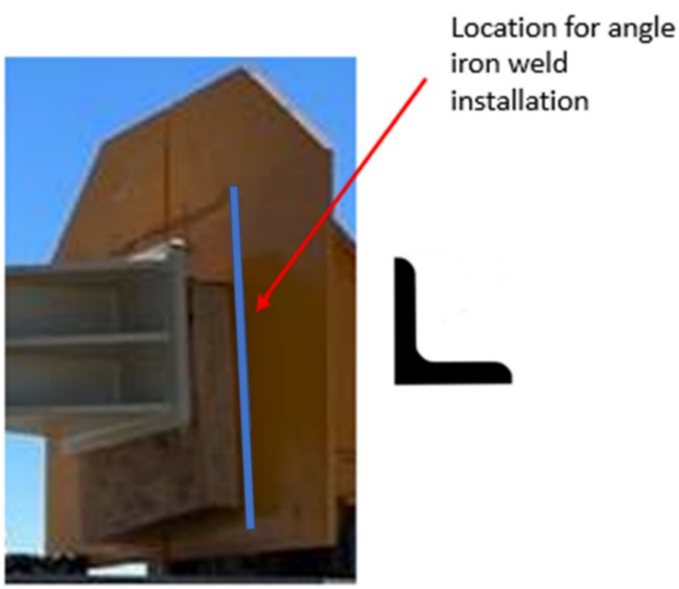

Figure 18. Solution of the dunnage movement problem

6.0 OVERVIEW OF REPORTS FOR ATLAS AND BUFFER RAILCARS

This section provides a general overview and reference tables for the four full reports developed under Phase 4 certification activities for the Atlas and Buffer railcars. Each of these two railcars has a Test Report and a Post-Test Analysis report. The tables are designed to provide a specific reference for testing and modeling report sections with corresponding references to AAR S-2043 paragraph certification requirements. Each of the four full reports is provided as an appendix in this Phase 4 Report (Appendix D through Appendix G).

6.1 Atlas Railcar Reports With S-2043 References

Atlas Single-Car Test and Post-Test Analysis testing and modeling report sections with S-2043 reference paragraphs are provided in Sections 6.1.1 and 6.1.2 of this summary report.

6.1.1 S-2043 Certification Tests of U.S. DOE Atlas Railcar Design Project 12-Axle Cask Car (Single-Car Test Report P-21-037)

Single-car testing is performed to verify that the railcar performs as designed throughout the static and dynamic testing of the railcar. The Single-Car Test report sections with S-2043 paragraphs can be referenced in Table 8. Appendix D provides the full Atlas railcar Single-Car Test report that corresponds with Table 8.

Table 8. Atlas railcar single-car tests report reference table

Atlas Railcar Test Report P-21-037: Reference			S-2043 Reference(s)
Report Section	Description	Page	Paragraph
8	Results	8	5.0
8.1	Vehicle Characterization Tests	9	5.1
8.1.1	Component Characterization Tests	9	5.1.3
8.1.2	Vertical Suspension Stiffness and Damping	16	5.1.4.3
8.1.3	Lateral Suspension Stiffness and Damping	22	5.1.4.4
8.1.4	Truck Rotation Stiffness and Breakaway Moment	28	5.1.4.5
8.1.5	Interaxle Longitudinal Stiffness	32	5.1.4.6
8.1.6	Modal Characterization	35	5.1.4.7
8.2	Nonstructural Static Tests	39	5.2
8.2.1	Truck Twist Equalization	39	5.2.1
8.2.2	Carbody Twist Equalization	42	5.2.2
8.2.3	Static Curve Stability	44	5.2.3
8.2.4	Horizontal Curve Negotiation	45	5.2.4
8.3	Static Brake Tests	45	5.3
8.4	Structural Tests	45	5.4
8.4.1	Preliminary and Post Test Inspection	49	5.4.1.1
8.4.2	Measured Stress from Test Loads	49	5.4.1.2
8.4.3	Squeeze (Compressive End) Load	51	5.4.2
8.4.4	Coupler Vertical Loads	61	5.4.3

Atlas Railcar Test Report P-21-037: Reference			S-2043 Reference(s)
Report Section	Description	Page	Paragraph
8.4.5	Jacking	67	5.4.4
8.4.6	Twist	71	5.4.5
8.4.7	Impact	79	5.4.6
8.4.8	Securement System Analysis	84	5.4.7
8.4.8.1	Dimensional Inspection	84	5.4.7
8.4.8.2	Force Calculations	86	5.4.7
8.4.8.3	Stress Analysis	88	5.4.7
8.4.8.4	Allowable Stresses, Acceptance Criteria, and Margin of Safety	89	5.4.7
8.4.8.5	Component Stress Analysis	90	5.4.7
8.4.8.6	Weld Analysis	103	5.4.7
8.5	Dynamic Tests	105	5.5
8.5.1	Primary Suspension Pad Configuration Changes	108	7.2
8.5.2	Minimum Load Hunting	110	5.5.7
8.5.3	Maximum Load Hunting	112	5.5.7
8.5.4	Minimum Test Load Twist and Roll	114	5.5.8
8.5.5	Maximum Test Load Twist and Roll	115	5.5.8
8.5.6	Yaw and Sway	116	5.5.9
8.5.7	Minimum Load Dynamic Curving	117	5.5.10
8.5.8	Maximum Load Dynamic Curving	118	5.5.10
8.5.9	Pitch and Bounce (Chapter 11)	121	5.5.11
8.5.10	Pitch and Bounce (Special)	122	5.5.12
8.5.11	Minimum Load Single Bump Test	122	5.5.13
8.5.12	Maximum Load Single Bump Test	123	5.5.13
8.5.13	Minimum Test Load Curve Entry/Exit	124	5.5.14
8.5.13.1	Minimum Load Limiting Spiral Negotiation	124	5.5.14.1
8.5.13.2	Minimum Load Normal Spiral Negotiation	126	5.5.14.2
8.5.14	Maximum Load Curve Entry/Exit	127	5.5.14
8.5.14.1	Maximum Load Limiting Spiral Negotiation	128	5.5.14.1
8.5.14.2	Maximum Load Normal Spiral Negotiation	129	5.5.14.2
8.5.15	Minimum Load Curving with Single Rail Perturbation	130	5.5.15
8.5.16	Maximum Load Curving with Single Rail Perturbation	134	5.5.15
8.5.17	Minimum Load Standard Chapter 11 Constant Curving	137	5.5.16
8.5.18	Maximum Load Standard Chapter 11 Constant Curving	139	5.5.16
8.5.19	Minimum Test Load Special Trackwork	141	5.5.17
8.5.20	Maximum Test Load Special Trackwork	145	5.5.17
8.6	Ride Quality	148	5.5.18

6.1.2 Atlas Car Post-Test Analysis (Report P-21-049 [formerly Report P-21-042])

The Post-Test Analysis report shows comparisons of pre-test FEA structural simulations and the vehicle dynamic modeling predictions with test data for the Atlas railcar from the Single-Car Test. If necessary, models are revised to represent the vehicle more accurately, and revised predictions are also presented in the post test analysis report. The Post-Test Analysis testing and modeling report sections with S-2043 paragraphs can be referenced in Table 9. Appendix E provides the full Atlas Post-Test Analysis report that corresponds with Table 9.

Table 9. Atlas railcar post-test analysis report reference table

Atlas Railcar Post-Test Analysis Report P-21-049 (formerly P-21-042)			AAR S-2043 Report Reference: Paragraph(s)		
Report Section	Description	Page	4.0 DESIGN	5.0 SINGLE-CAR TEST	8.0 POST-TEST ANALYSIS
4	Refining the FEA	5			8.1
4.1	Loading Conditions for Structural Tests	6	4.1.5.2		
4.1.1	Test Loads	6	4.1.5.2		
4.1.2	Measured Stresses from Test Loads	6	4.1.5.2		
4.2	Squeeze (Compressive End) Load	9	4.1.5.7	5.4.2	
4.3	Coupler Vertical Loads	12	4.1.5.3	5.4.3	
4.4	Jacking	14	4.1.5.4	5.4.4	
4.5	Twist	16	4.1.5.5	5.4.5	
4.5.1	Suspension Twist	16	4.1.5.5	5.4.5.1	
4.5.2	Carbody Twist	19		5.4.5.2	
4.6	Impact	21	4.1.5.8	5.4.6	
5.0	New FEA Predictions	23			8.2
6.0	Refining the Dynamic Model	23			8.3
7.0	New Dynamic Predictions	27			8.4
7.1	Twist and Roll	29	4.3.9.6	5.5.8	
7.2	Pitch and Bounce (Chapter 11)	32	4.3.9.7	5.5.11	
7.3	Yaw and Sway	35	4.3.9.8	5.5.9	
7.4	Dynamic Curving	37	4.3.9.9	5.5.10	
7.5	Single Bump Test	43	4.3.10.1	5.5.13	
7.6	Curving with Single Rail Perturbation	47	4.3.10.2	5.5.15	
7.7	Hunting	53	4.3.11.3	5.5.7	
7.8	Constant Curving	57	4.3.11.4	5.5.16	
7.9	Curving with Various Lubrication Conditions	61	4.3.11.5		
7.10	Limiting Spiral Negotiation	71	4.3.11.6	5.5.14.1	
7.11	Special Trackwork: Turnouts and Crossovers (S-2043, Paragraph 4.3.11.7)	74	4.3.11.7	5.5.17	

Atlas Railcar Post-Test Analysis Report P-21-049 (formerly P-21-042)			AAR S-2043 Report Reference: Paragraph(s)		
Report Section	Description	Page	4.0 DESIGN	5.0 SINGLE-CAR TEST	8.0 POST-TEST ANALYSIS
7.12	Buff and Draft Curving	77	4.3.13		
7.13	Worn Component Simulations	79	4.3.15		
7.13.1	Worn Constant Contact Side Bearings	80	4.3.15		
7.13.2	Centerplate	82	4.3.15		
7.13.3	Primary Pad	84	4.3.15		
7.13.4	Friction Wedges	86	4.3.15		
7.13.5	Broken Spring	88	4.3.15		

6.2 Buffer Railcar Reports

Buffer Single-Car Test and Post-Test Analysis testing and modeling report sections with S-2043 reference paragraphs are provided in Section 6.2.1 and 6.2.2.

6.2.1 AAR Standard S-2043 Single-Car Certification Tests of U.S. DOE Atlas Railcar Design Project Buffer Railcar (Report P-20-032)

The single-car test is performed to verify that the Buffer railcar performs as designed through static and dynamic testing of the railcar. The Single-Car Test report sections with S-2043 paragraphs can be referenced in Table 10. Appendix G provides the full Buffer railcar Single-Car Test report that corresponds with Table 10.

Table 10. Buffer railcar single-car tests report reference table

Buffer Railcar Test Report P-20-032: Reference			S-2043 Reference(s)
Section	Description	Page	Paragraph (s)
5	Results	4	5.0
5.1	Vehicle Characterization	4	5.1
5.1.1	Component Characterization Tests	4	5.1.3
5.1.2	Vertical Suspension Stiffness and Damping	10	5.1.4.3
5.1.3	Lateral Suspension Stiffness and Damping	16	5.1.4.4
5.1.4	Truck Rotation Stiffness and Breakaway Moment	21	5.1.4.5
5.1.5	Interaxle Longitudinal Stiffness	23	5.1.4.6
5.1.6	Modal Characterization	25	5.1.4.7
5.2	Nonstructural Static Tests	28	5.2
5.2.1	Truck Twist Equalization	28	5.2.1
5.2.2	Carbody Twist Equalization	29	5.2.2
5.2.3	Static Curve Stability	31	5.2.3
5.2.4	Horizontal Curve Negotiation	31	5.2.4

Buffer Railcar Test Report P-20-032: Reference			S-2043 Reference(s)
5.3	Static Brake Tests	32	5.3
5.4	Structural Tests	32	5.4
5.4.1	Preliminary and Post Test Inspection	35	5.4.1.1
5.4.2	Squeeze (Compressive End) Load	35	5.4.2
5.4.3	Coupler Vertical Loads	36	5.4.3
5.4.4	Jacking	37	5.4.4
5.4.5	Twist	38	5.4.5
5.4.6	Impact	41	5.4.6
5.4.7	Securement System	41	5.4.7
5.5	Dynamic Tests	42	5.5
5.5.1	Hunting	44	5.5.7
5.5.2	Twist and Roll	46	5.5.8
5.5.3	Yaw and Sway	46	5.5.9
5.5.4	Dynamic Curving	47	5.5.10
5.5.5	Pitch and Bounce (Chapter 11)	48	5.5.11
5.5.6	Special Pitch and Bounce	49	5.5.12
5.5.7	Single Bump Test	50	5.5.13
5.5.8	Limiting Spiral Negotiation	51	5.5.14.1
5.5.9	Normal Spiral Negotiation	52	5.5.14.2
5.5.10	Curving with Single Rail Perturbation	54	5.5.15
5.5.11	Standard Chapter 11 Constant Curving	56	5.5.16
5.5.12	Special Trackwork	57	5.5.17
5.6	Ride Quality	61	6.5.18

6.2.2 Buffer Car Post-Test Analysis (Report P-21-013)

The post-test analysis report shows comparisons of pre-test FEA structural simulations and the vehicle dynamic modeling predictions with test data for the Buffer railcar from the single-car test results. MxV Rail revised the model to reflect the vehicle more accurately and performed simulations to 1) demonstrate the model performance compared to test data and 2) check the performance in regimes where the original dynamic analysis was close to or did not meet the criteria. Section 7 of the Post-Test Analysis report describes the regimes that were not included in new dynamic predictions. The Post-Test Analysis, testing, and modeling report sections with S-2043 paragraphs can be referenced in Table 11. Appendix F provides the full Buffer railcar Post-Test Analysis report that corresponds with Table 11.

Table 11. Buffer railcar post-test analysis report reference table

Buffer Car Post-Test Analysis Report P-21-013			S-2043 Report Reference(s): Paragraph(s)		
Section	Description	Page	4.0 DESIGN	5.0 SINGLE-CAR TEST	8.0 POST-TEST ANALYSIS
4	Refining the Finite Element Analysis (FEA)	4			8.1
4.1	Squeeze (Compressive End) Load	4	4.1.5.7	5.4.2	
4.2	Coupler Vertical Loads	5	4.1.5.3	5.4.3	
4.3	Jacking	6	4.1.5.4	5.4.4	
4.4	Twist	7	4.1.5.5	5.4.5	
4.4.1	Suspension Twist	7	4.1.5.5	5.4.5.1	
4.4.2	Carbody Twist	8		5.4.5.2	
4.5	Impact Test	9	4.1.5.8	5.4.6	
5	New Finite Element Analysis Predictions	10			8.2
6	Refining the Dynamic Model	10			8.3
7	New Dynamic Predictions	14			8.4
7.1	Twist and Roll	15	4.3.9.6	5.5.8	
7.2	Pitch and Bounce	17	4.3.9.7	5.5.11	
7.3	Special Pitch and Bounce (44.5-foot wavelength)	18	4.3.9.7	5.5.12	
7.4	Yaw and Sway	20	4.3.9.8	5.5.9	
7.5	Dynamic Curving	22	4.3.9.9	5.5.10	
7.6	Curving with a Single-rail Perturbation	24	4.3.10.2	5.5.15	
7.7	Hunting	26	4.3.11.3	5.5.7	
7.8	Curving with Various Lubrication Conditions	27	4.3.11.5		
7.9	Turnouts and Crossovers	29	4.3.11.7	5.5.17	
7.10	Buff and Draft Curving	30	4.3.13		

7.0 CONCLUSIONS

Both the Atlas and Buffer railcars received EEC approval of Single-Car Testing in accordance with AAR S-2043. Both of these railcars have since moved into the Multicar Testing (Paragraph 6.0) phase of AAR S-2043 certification.

On behalf of the DOE, MxV Rail requested exceptions from the AAR EEC to approve the Atlas railcar because the post-test simulations with the production CSM 58 pads did not meet some of the criteria for hunting, curving with single rail perturbation, and curving with various lubrication conditions. The onset of the hunting regime occurred at speeds above 65 mph—beyond the 50-mph limit recommended in OT-55 for cars in HLRM service. Although the performance simulated for curving with a single rail perturbation and curving with various lubrication conditions did not meet Standard S-2043 criteria, it did meet Chapter 11 criteria.

The results from the Single Car-Test (Paragraph 5.0) for the Atlas railcar, specifically the FEA simulations and structural test strain measurements, both showed that stresses were less than 75 percent of the allowable stress, thereby eliminating the requirement in Standard S-2043, Paragraph 8.1 for the FEA to be refined.

The Buffer railcar met all S-2043 single-car structural and dynamic test requirements. The FEA simulations and structural test strain measurements both showed that stresses were less than 75 percent of the allowable stress, thereby eliminating the requirement for the FEA to be refined (S-2043, Paragraph 8.1).

The revised vehicle dynamics model simulation predicted the Buffer railcar would not meet the criterion for peak-to-peak carbody lateral acceleration for the 39-foot wavelength inputs (1.38g, limit=1.3g) or the 44.5-foot wavelength inputs (1.31g, limit=1.3g) in yaw and sway tests. In contrast, the Buffer railcar met test requirements for yaw and sway tests. The yaw and sway test is only performed with 39-foot wavelength inputs.

The revised vehicle dynamic modeling predictions for the Atlas railcar did not meet criteria for truck side L/V ratio (0.52, limit=0.5) in the curving with various lubrication conditions regime. This exception occurred for counterclockwise runs with Case 2 lubrication and the worn wheel profile at 12 and 24 mph. The Case 2 lubrication condition is a 0.5 coefficient of friction on the top of both rails and a 0.2 coefficient of friction on the gage face of the high rail. Simulations meet S-2043 criteria for curving with various lubrication conditions during clockwise runs for this lubrication and profile case and for all runs with other lubrication and profile combinations.

References

1. AAR *Manual of Standards and Recommended Practices*, Car Construction Fundamentals and Details, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043, Effective: 2003; Last Revised: 2017, Association of American Railroads, Washington, D.C.

2. Electronic Code of Federal Regulations, Title 49, Subtitle B, Chapter II, Part 213—Track Safety Standards. Downloaded from https://www.ecfr.gov/cgibin/retrieveECFR?gp=&SID=5dd8cd0b6dd88207ddc99c4bbc9527e0&mc=true&r=PART&n=pt49.4.214.

3. Wu, H., and Elkins, J. "Investigation of Wheel Flange Climb Derailment Criteria." Research Report R-931. Association of American Railroads, Pueblo, CO. 1999.

4. Elkins, J., and Wu, H. "New Criteria for Flange Climb Derailment." IEEE/ASME Joint Railroad Conference paper. Newark, New Jersey. April 4-6, 2000.

5. 2020 Field Manual of The AAR Interchange Rules, adopted by The Association of American Railroads, Safety and Operations, Rules and Standards, Effective January 1, 2020, Association of American Railroads, Washington, D.C.

6. AAR Manual of Standards and Recommended Practices Section C – Part II, "Design, Fabrication and Construction of Freight Cars." Appendix C Specification for Instrumented Wheelsets, Association of American Railroads, Washington D.C., 2003; implemented November 2015.

7. EEC Docket 209.240. "Kasgro DOE HLRM Cask and Buffer Car." TTCI Document Number CR-20-002. TTCI local area network < Q:\Business Services\Tech Docs\DOE Controlled Document Folder\CR-Correspondence>, January 2016, revised August 20, 2020.